Proceedings of the Bangkok symposium on acid sulphate soils

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Second International Symposium on
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H. Dost and N. van Breemen

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INTRODUCTION

This collection of papers covers the main body of written information presented at *the Second International Symposium on Acid Sulphate Soils,* held in Bangkok, Thailand, from 18-24 January 1981.

The Symposium was convened under the auspices of the Government of the Kingdom of Thailand and the International Society of Soil Science. Its excellent organization was in the capable hands of

Mr. Samarn Panichapong, on behalf of the Department of Land Development of the Ministry of Agriculture and Cooperatives of Thailand.

The Symposium was attended by 127 participants: from Thailand (65), Malaysia (16), The Netherlands (8), Indonesia (7), USA (5), The Philippines (5), Vietnam (4), United Kingdom (4), Germany (2), Denmark (2), Senegal (1), France (1) and Canada (1). In twelve sessions covering four days in Bangkok and a two-day intermission for field trips in the Central Plain and coastal zone of Thailand, participants presented and discussed relevant information. The Symposium ended with the formulation of resolutions, official speeches, and a farewell party.

Some forty participants joined a post-symposium field trip along the west coast of Malaysia, which was organized by the Malaysian Agricultural Research Institute and Harrisons and Crossfields Oil Palm Research Station.

The emphasis of the Symposium was on the management of soil/water/plant systems under acid sulphate soil conditions in tropical agro-ecological zones in Southeast Asia and West Africa. As such, the second symposium at Bangkok was a complementary sequel to the first symposium at Wageningen in 1972, where most of the presentations pertained to the genesis, geographical distribution, morphology, dynamics, and classification of acid sulphate soils.

Many of the contributions to the Bangkok Symposium reflect the awareness of the acid sulphate soil problems in the tropical countries concerned, and that the development and implementation of effective problem-solving programs are being stimulated by cooperation among centres of advanced technology in Europe, Japan, and North America, among international organizations and institutes, and among the local universities, development agencies, experimental stations, and extension services. The Symposium itself was instrumental in reinforcing or establishing such cooperation and contacts.

The Symposium, and especially the field trips in Thailand and Malaysia, strikingly demonstrated the diversity of agro-ecological zones with acid sulphate soil problems and the magnitude of the rural communities and areas affected by them. Problem solving under such conditions requires years of specialized team work for inventories, applied research, and the development of feasible reclamation methods, followed by extension programs involving a multitude of trained field workers. Obviously such programs demand an enormous informative input - an input that has to be canalized mainly by the local educational and executive agencies, which to that end rely heavily on international contacts, such as those provided by this Symposium, for up-to-date technological information.

The need for up-to-date information is probably felt even more by professionals and agencies that have only incidental international contacts and have to work in relative isolation and with fledgling organizations. They are, moreover, rarely represented at international symposia. It therefore seems right and proper that especially the written information presented at the Bangkok Symposium should become available and accessible to a much larger forum than represented at the Symposium itself.

The present publication aims at reaching this larger forum. It concentrates on the essential technical information presented at the Symposium, leaving out documents, speeches, discussions, etc., which, had they been included, would have made the volume unwieldy and unnecessarily expensive.

As a courtesy to colleagues in *'francophone'* West Africa, where the next symposium is to be held, a French-language chapter of summaries has been added.

This publication has been made possible by the cooperation of the Organizing Committee of the Symposium, the Directorate General for International Cooperation of The Netherlands, and the International Institute for Land Reclamation and Improvement (ILRI) at Wageningen.
The editors offer their thanks to the directorate and staff of ILRI for the interesting commission and for an excellent collaboration and to Mrs. Nadia Pons-Ghitulescu and M. Claude Marius for preparing the French-language chapter.

The editors

GENERAL RESOLUTIONS

1. The participants (of the 2nd International Symposium on Acid Sulphate Soils, 18-24 January 1981) warmly thank the Minister of Agriculture and Cooperatives and the Director General of the Land Development Department of the Kingdom of Thailand for their consent to organize the Symposium in Thailand and their support for the activities of the International Society of Soil Science; Mr. Panichapong and his staff, whose untiring efforts have been responsible for the success of this symposium at both the professional and personal level; and the Directors and staff of the regional centers for their hospitality and cooperation.

   We also wish to take this opportunity to thank our Malaysian colleagues, in particular the Director and staff of the Malaysian Agricultural Research and Development Institute, for organizing the post-conference tour in Malaysia.

2. We recognize:
   - the increased awareness of the problems of acid sulphate soils;
   - the upsurge of research effort and its practical applications to agricultural development on these soils, notably in southeast Asia and West Africa;
   - the progress that has been made in the amelioration of acid sulphate soils, by liming, flooding and control of the watertable;
   - the progress in developing alternative uses of the land;
   - the contribution to our understanding of the problems that have been made by theoretical models and experimentation, and also the

importance of moving out from the laboratory and into the farmers fields, both to back-up basic research and to demonstrate the practical application of new management practices;

- the importance of studying these soils, not in isolation but as components of a living, integrated system of land, water, crops and people. Land development has an impact on many related facets of the environment and we must develop a range of alternative management strategies that can take account of the social, economic and environment implications of land development;
- that different social and physical settings will require different approaches to the problem.

3. Problems remain. The discussions in this symposium have demonstrated that acid sulphate soils remain problem soils.
   - Some old criteria for recognizing acid sulphate soils, and for managing them, have been questioned, new methods have been proposed.
   - We need a common language for communication among soil scientists to assist the transfer of experience and technology between countries and regions, and we endorse the efforts of the International Society of Soil Science to develop an International Reference Base for Soil Classification.
   - We need a common basis for field experimentation, a code of appropriate methods and characterization of sites so that experience and results of research can be transferred to similar areas.
   - We need long-term monitoring of alternative management practices in representative environments.
   - There is still a big gap between the development of appropriate technology and its application.
   - We know little of the physiology of plants, particularly of root behaviour under severely acid conditions, and we need both basic research and innovative screening or selection of crop varieties for tolerance to iron and aluminum toxicity and, in the case of rice, for fast growth.

4. The continued pressure on land resources will demand continued exploitation, or reclamation, of acid sulphate soils and other marginal

or difficult land. So concerted research effort is still required. To coordinate this effort *we recommend* that an international working group be set up, with the following tasks:

- to pool and evaluate information about both innovative and traditional management systems, some of which are not capital intensive and do not require massive engineering, soil amendments and fertilizer;
- to formulate alternative management strategies for acid sulphate soils;
- to scrutinize technical proposals in the fields of soil characterization and classification;
- to formulate criteria for recognition of acid sulphate problems;
- to prepare guidelines for experimental methods and for characterization of experimental sites, *in the context of their physical and social environment.*

A further function of the group will be:

- to disseminate their findings, not just as bulletins, but to explore contacts with development agencies and land users at various levels.

5. *We recommend* that a third symposium be convened, in four years time, in West Africa. The working group to suggest the venue; assist the host country and organizations in the preparation of the symposium; and to raise financial support for research and participation from a broader spectrum of the developing countries - where the problems and potential mainly lie.

6. Finally, we urge governments, international and national development agencies and private institutions to support this programme to stimulate and coordinate research and development, so that we may overcome the remaining problems posed by acid sulphate soils and their environment, and harness their productive potential, which is so often under-rated.

SPECIFIC TECHNICAL CONCLUSIONS AND RECOMMENDATIONS

Prepared by ad hoc commissions at the Second International
Symposium on Acid Sulphate Soils
Bangkok, Thailand
18-24 January 1981

Recommendations for basic research

1. The physiological mechanisms of tolerance to high Fe^{2+} levels in the soil solution need to be classified.

2. Varietal screening and selection methods for tolerance to Fe and Al need to be developed that are large-scale, simple and rapid.

3. The physicochemical and biological aspects of pyrite oxidation and of the transport processes of acid within the soil and from the soil to drainage or supernatant water are reasonably well understood, but need to be published in a brief, easily understandable and readily available form.

4. The main factors determining the rate of reduction following flooding, and the rate of pH-rise to levels beyond those at which aluminum or iron toxicity occurs, should be studied.

5. Models are needed to predict the rate of progress and consequences of reclamation procedures for acid sulphate soils. These models would have to be built up from manageable sub-models fitted together. Examples of such sub-models include the description of voids in acid sulphate soils and their development from season to season and year to year, and the relationship between water movement in, through and over the soil, and transport and removal of rate of reduction.

6. A better understanding is required of the variation in the properties of acid sulphate soils from one region to another, e.g. contents of pyrite, iron, manganese, calcium, potassium or clay mineralogy, each of which may determine which reclamation or management system will be most effective.

Recommendations for applied research on acid sulphate soils

1. The emphasis of applied research should be directed to improvement in low cost management, where the constraints are availability of water and fertilizers. Accordingly the research recommendations given here pertain mainly to rice-based cropping systems. However, also the needs for research on aquaculture and tree crop production should be recognized. In these latter fields remarkable results have been obtained with aquaculture in mangrove swamp areas, and with production of tree crops such as casuarina, eucalyptus, citrus, mango, and banana in the monsoon areas, and oil palm and cocoa in the permanently wet regions, and coconut in both regions. Further research along this line should be stimulated. Research groups with common aims and interests in different countries should be identified and means for cooperations and exchange of experiences should be provided by international agricultural development agencies.

2. Soil and water management for rice-based cropping systems
   - Both in large-scale schemes, e.g. for tidal lands, and in small-scale schemes, e.g. for individual farmers, the emphasis should be on minimizing pyrite oxidation and maximizing the removal of acidic substances by leaching. Research should be carried out within a framework of a baseline survey followed by monitoring crop performance, soil and water composition and hydrology over at least 3 consecutive years. In order to facilitate comparison of research results, standard methods for site characterization, evaluating plant performance, and analyzing soil and water have to be agreed upon.

     Special attention should be given to the problem of safely discarding the acid surface water.

- Liming in relatively low doses (several tons/ha) has given promising results in Thailand, but is not always effective elsewhere. The reasons for this difference should be investigated.

  Studies on fertilizer application should aim at optimizing the use of phosphate. While nitrogen is limiting in most acid sulphate soils, its application usually does not present specific problems. The common use of raw salts by farmers as amendments on acid sulphate soils indicates that it may be useful to study its effect.
- As promising areas of applied research are indicated: dry land versus wet land tillage for its effect on leaching acid sulphate soils, and soil management and cropping systems combining wet land rice and short duration dry land crops as soybeans, water melon, maize, sorghum and sesame seed.

3. Varietal screening.

There is an urgent need for development of short duration, acid tolerant, and salt tolerant cultivars. Efforts to compare traditional rice variants that are well adapted to acid sulphate soil conditions from different countries should be encouraged.

DIRECTIONS OF FURTHER RESEARCH ON ACID SULFATE SOILS

R. Brinkman
The International Rice Research Institute
Los Baños, Philippines

Before addressing the question what kinds of research should be done on acid sulfate soils, we should define the problem, or problems, that should be solved by this research.

The acid sulfate problem comprises two main aspects:

- the rapid formation, once or repeatedly, of acid in excess of the rapid buffering capacity of the soil to the extent that toxic conditions develop for crop plants or fish;
- the slow rate or high cost of the removal or the temporary or permanent neutralization of the acid.

Lesser, but more persistent, problems are the potential acidity that may still be present in the subsoil and the strong phosphate fixation in the surface and subsoil of many reclaimed acid sulfate soils, which may necessitate adaptation of management practices.

There is one major point of caution. As research improves the chances of success in changing the vegetation and the drainage status of large acid sulfate areas, the impact which these changes will have locally and elsewhere should be known and considered. These changes may affect the land itself, land and water downstream (including coastal waters and sea), plant and animal life locally and downstream, and the people who were living near or within the area to be developed.

Both basic, supporting as well as practical, applied kinds of research are needed for the efficient use of acid sulfate soils. They will be dealt with in that order.

1 Nature and properties of sediments

Some fundamental work is still needed to ascertain the dimensions of the acid sulfate problem. Although there is a general geogenetic model of pyrite formation in sediments (Pons and van Breemen, this symposium), it still needs to be tested.

Practical field methods of characterizing pyrite-containing sediments are not yet generally applicable. The total amounts of potential acid in excess of the soil's neutralizing capacity may not be as important as thought previously. However, soils without and with such excess potential acid may occur in close association, and need to be systematically distinguished and mapped. This could be done most efficiently once the nature of the sediments and the sedimentation processes are well understood, and clearly described for each estuary area, and once the relationship between the sedimentation conditions, vegetation and pyrite-accumulation have been sorted out. However, identification and mapping should continue with present or improved criteria and methods, even while this basic knowledge may still be inadequate.

1.1 Stable characteristics, constant within regions

Some properties of sediments which influence the nature and direction of the oxidation and neutralization processes, such as the iron and manganese contents, the clay mineralogy and cation exchange capacity of the clay, tend to differ between estuaries but to vary within a narrow range for a given estuary. A description of such characteristics could form a basis for comparing the results of reclamation experiments in different regions. For example, a kaolinitic sediment with a low CEC and a very low exchangeable calcium content would react to liming in a different way from a smectitic sediment with a low percentage, but adequate absolute content of exchangeable Ca after oxidation.

1.2 Characteristics varying with time, depth and location

Contents of pyrite and organic matter vary with depth in a given soil as well as over short distances in a landscape, especially where a pattern of creek or spillway levees is present. They also change rapidly with time upon drainage, but at strongly decreasing rates with depth.

The distribution of sulfidic horizons or layers at different depths in the landscape probably is the most important item of information that detailed mapping should provide. This can be supported by co-varying characteristics such as the content and nature of organic matter, clay content, soil consistence and details of soil color and mottling.

It seems to me that we are close to the definition of practical field mapping criteria for actual and for potential acid sulfate soils. It would be useful if several field soil scientists would get together to note and compare the mapping criteria applicable to their respective areas of experience. I believe, in spite of the great variation in characteristics reported in the literature, that the mapping problem could be simplified with the knowledge available now in scattered form.

2 Oxidation, reduction and transport processes

2.1 Oxidation

The physicochemical and biological oxidation process of pyrite as well as the qualitative aspects of transport processes of the acid products, within the soil and from the soil to drainage or supernatant water, are reasonably well understood by a few scientists. However, no brief and easily understandable description has been published so far in a readily available form.

2.2 Reduction

What factors influence the rates of progress of the reduction processes upon flooding, for example the production rate of iron or sulfide? A quantitative or semiquantitative model is needed to predict or explain the very different rates at which different soils attain safe pH levels and at which the Al concentration decreases below toxicity limits. It should also explain the occurrence of transient Fe or S toxicity, or the absence of either, during reduction. Parameters in the model may have to be estimated in a pragmatic manner, because information on the biological reaction rates is limited, but the model itself should be firmly rooted in the known physicochemical basis.

2.3 An integral model

This information on oxidation and reduction will need to be fitted into a larger model that relates water movement within and on soils (by irrigation or natural flooding) to transport and removal of acids as well as to the rates of reduction. Such an integral model would help in predicting the progress rate of reclamation, but also in estimating the rate of acid outflow: one of the consequences of acid sulfate reclamation. The chemistry of the irrigation or floodwater will need to be taken into account if it contains more than traces of bicarbonates, acids or salts.

2.4 Voids and water movement

A submodel of the integral model involves the relation of observable voids in the soil (both permanent and variable ones) with the water movement over and within the soil. This would require a simple descriptive system for voids in specific soils, involving three aspects: their distribution at a given time, the progressive changes in void patterns with the years after reclamation and the seasonal fluctuations especially of cracks. Only the first aspect is adequately covered at present. For such a descriptive system to be coherent and of predictive value, a study of the factors influencing the physical stability of voids in acid clayey soils may be needed.

3 Tolerance studies

Acid sulfate soils support plants - but some plants do better than others. There are great differences in tolerance to acidity, high aluminum or iron and low available phosphate contents between species and between cultivars, for example of rice. These can be exploited through screening and selection, supported by continued work on the physiology of tolerance.

3.1 Rapid screening and selection methods

Rapid, reliable and low-cost screening and selection methods are needed to identify lines or plants in a population with the highest tolerance levels, so that reclamation inputs can be minimized.

A possible method, suggested by Gunawardena in IRRI for salinity tolerance selection, would combine two existing techniques. One is sequential testing, i.e. use of a toposequence or other naturally occurring gradient with an increasingly severe stress: in the present case, for example, increasingly shallow occurrence of acid sulfate material. The other is use of a male-sterile, continuously segregating population. This is sown or transplanted in a broad strip extending from one end of the sequence to the other. Fewer and fewer plants are expected to survive toward the most severe acid sulfate conditions. The plants successfully producing seed at the severe end of the sequence are harvested for continued selection next season: a small proportion of the total population. Thus materials are continually selected near the limit for survival and production. Presumably, this would strongly favor individuals with the highest tolerance levels.

If consistent relations could be found between morphological plant characteristics, for example speed of initial root growth, and tolerance levels to these stresses, that would make selection more rapid and simple.

3.2 Fish

Screening of fish species for tolerance to acidity and toxicities would similarly widen production possibilities and decrease reclamation costs for fishponds in acid sulfate soils.

4 Agronomic experiments

4.1 Wetland rice; small lime applications

Experiments with wetland rice on acid sulfate soils should test shallow drainage followed by preflooding, with a series of lime treatments ranging from very small applications (for example, 100 or 200 kg/ha) to the amounts usually considered necessary, against more elaborate reclamation methods. The experimental design should also include a wide range of phosphate applications, both of water-soluble phosphate, broadcast and incorporated compared with placement, as well as of any available low-cost phosphates, finely ground, broadcast and incorporated.

I expect that response of wetland rice on acid sulfate soils to lime could be of three very different kinds. In soils with a low CEC and very low absolute contents of exchangeable Ca and other bases, a nutrient effect would be likely, at very low lime application rates.

In soils with a high CEC, a very large total concentration of acid and an extremely acid reaction, amounts of several tons per ha may be needed to depress toxic levels of aluminum in the early stages of rice growth, especially where organic matter or free iron contents are low.

In any acid sulfate wetland soil with at least moderate contents of free iron and organic matter, small applications of finely ground lime to the soil surface, without incorporation, could serve to trigger soil reduction by a localized improvement in the conditions for microbial activity. From such microsites, reduction could proceed throughout the soil mass as far as easily reducible organic matter is present. No residual effects of lime should be expected if this third process is the main result of lime application. However, such applications could have rates so low, that annual application at the start of every wet season is economically feasible.

4.2 Dryland crops; minimal vs. maximal drainage

In the case of dryland crops, a reduction-triggering effect does not come into play. For these crops, free acids would need to be removed or neutralized. Two main approaches are possible: the minimal-drainage and the maximal-drainage methods. The latter would be most effective in areas with a strong dry season and adequate rainfall or suppletory irrigation in the wet season. It would be expected to result in a safe soil for a range of crops, if the potential acid sulfate soil has a stable tubular macropore system to begin with. In other cases, oxidation may not progress rapidly enough below the surface horizon for effective removal of acids by leaching over the desired 0.5 to 1 m depth.

In the minimal-drainage method, there is a persistent hazard that acids formed by oxidation will rise into the root zone by capillary movement during a dry season or an irrigation water shortage. The resulting damage may be considerable, especially for perennial crops. An analysis of past yield records to estimate the severity of this effect may lead to efforts at reclamation to greater depth.

Such reclamation should be done before replanting. Lowering the effective drainage level under a standing perennial crop may seriously damage its root system and productivity by the resulting acid and aluminum ions.

4.3 Reclamation of saline acid sulfate soils for crops

Wherever saline acid sulfate soils are to be reclaimed for agriculture, it would be useful to compare the conventional fresh-water leaching with another method: initial drying and oxidation of the saline soil to as great a depth as possible (0.5 to 1 m), followed by leaching, followed by adjustment of drainage level by stopgates or stoplogs to the appropriate depth.

In this way, maximum use is made of the salt present in the soil to eliminate acid; the remainder of the acid, mainly in lower horizons, is immobilized. Where saline or brackish water is available, this can be used for the first leaching after oxidation to further increase the efficiency of acid removal.

Experiments such as these would precede use for wetland rice or dryland crops and could lead to similar or possibly more favourable conditions for crop growth than the experiments described above for non-saline acid sulfate soils, provided that adequate fresh water is available throughout the year.

4.4 Fishponds

In the case of fishponds on acid sulfate soils, experiments are needed on optimum size of fish to be stocked, rates and application frequencies of especially phosphate fertilizers, and the most economic crops that could be grown on the dikes.

4.5 Which land characteristics should be recorded for each experiment?

Wherever experiments on acid sulfate soils are done, a number of questions on the soil itself, the climate or weather and the water management will need to be answered and reported together with the results of the experiment. The nature of such questions is indicated by some examples below.

How thick are the non-acid sulfate surface horizons? What are the pH, CEC, cation composition, organic matter and free iron content of these horizons and the horizons below? What is the saturated hydraulic conductivity of the deeper horizons, and what is the geometry of the macropore system? What is the depth and annual fluctuation of the oxidation boundary? What are the estimated rates and directions of water movement during the growing season at the soil surface and just below the rooting zone?

What is the drainage depth and interval, how is the irrigation water managed? How are rainfall and evapotranspiration distributed before and during the growing season that is studied?

4.6 Priority: wetland rice experiments

It may be difficult to answer every one of these questions for the site of each experiment. However, if I would have to indicate one priority in the long list of desirable research on acid sulfate soils, it would be: field experiments on wetland rice with different kinds of water management and very low to moderate liming rates, over a range of locations in widely different areas, both fresh and saline, and with extensive description of the soil, the hydrologic conditions and the management details at each site. The results could then be published in a coherent manner. By systematic comparison we could then arrive at near-optimum reclamation and management methods for a wide range of conditions.

SOCIAL AND ECONOMIC ASPECTS OF THE RECLAMATION OF ACID SULFATE SOIL AREAS

R. Brinkman
The International Rice Research Institute
Los Baños, Philippines

Many participants in this symposium are intensively engaged in technical, scientific or managerial aspects of land use or land development in acid sulfate areas. It seems wise, therefore, to start with a discussion of the social and economic reasons for our work and the implications of our possible recommendations for the people and for the physical environment, before we concentrate on detailed scientific, technical and developmental aspects.

Changing an ecosystem needs to be approached with the greatest caution, to prevent social or economic damage to the families directly involved and to others nearby or elsewhere; and to prevent irreversible impoverishment of the natural diversity, which contains known and unknown resources.

After touching on the distribution and extent of the acid sulfate soils, I will discuss separately those in the salt-water and in the fresh-water zones. For the saline acid sulfate soils, the main problem is the question whether or not to protect and preserve them in their natural state. For the fresh-water acid sulfate soil areas, the main social and economic problem is to create an effective kind of development plan, that makes maximum use of the variability in the soils and the capabilities of the settlers, and that is designed for progressive change and improvement to correct for past mistakes.

1 Where people live

The world is a well-populated place. People are living in a great variety of places, but not in all places. Where people can move freely, for example within a given country, they tend to distribute in such a way that productivity of labor becomes similar in different places. The great differences in population density from place to place then reflect, at least in part, income opportunities at the level of available technology and resources. Large empty areas may thus be useless at present technology. For each area empty or almost empty of people, there is a reason: for example, no water in the Empty Quarter of Saudi Arabia. Many such reasons can be summarized under a few major terms. Non-use occurs because there is no available technology or because there are better opportunities elsewhere for the people. In the short run, there are other reasons as well: these can be found in history, politics and physical infrastructure. But the longer-term reasons lie in the unavailability of technology appropriate to the land and in the presence of alternative opportunities of economic activity for the people by whom the area could be reached. Attempts at colonization without recognition of these facts have caused great hardship and loss of development capital in several cases.

2 Occurrence and extent of acid sulfate soils

The world-wide extent of acid sulfate soils is about 13 million hectares: about one percent of the world's cultivated land. When the extent of the acid sulfate soils is compared with the extent of some of the world's other problem soils (Table 1), it is clear that peat soils or saline and sodic soils, for example, are far more extensive - and, incidentally, more persistent. Acid sulfate conditions constitute a problem that persists for a limited number of years, and that bedevils a small part of the earth's crust; a small part even of the total area of problem soils that the population of the world is faced with. Several of the other kinds of problem soils, however, mainly lie in areas that have other major problems as well and that are far away from great concentrations of people. The acid sulfate soils tend to occur under favourable climates for food production (Table 2), often near densely populated coastal areas or river plains (Figure 1), and their development would thus be of immediate interest.

Table 1. World distribution of some problem soils[1] (million ha)

Region	Type of soils			
	Acid sulfate soils	Peat soils	Planosols	Saline and sodic soils
Asia and Far East	6.7	23.5	2.7	19.5
Africa	3.7	12.2	15.9	69.5
Latin America	2.1	7.4	67.2	59.4
North America	0.1	117.8	12.3	16.0
Near and Middle East	0.0	0.0	0.0	53.1
Australia	0.0	4.1	49.3	84.7
Europe	0.0	75.0	4.0	20.7
World total	12.6	240.0	151.4	322.9

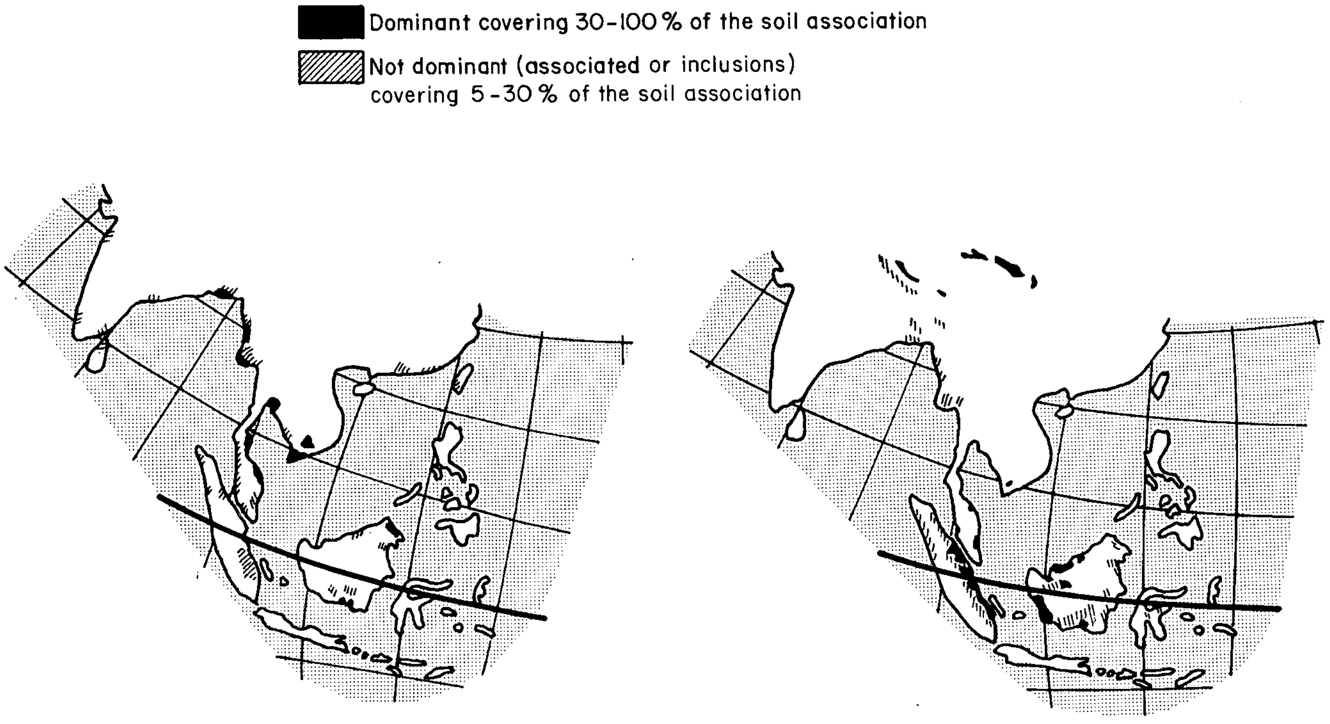
[1] Adapted from Beek et al. (1980), based on data from FAO/Unesco Soil map of the World

Table 2. World distribution of acid sulfate soils[1] (million ha)

	Length of growing periods (days)				
Region	< 90	90-180	180-300	> 300	Total
Asia and Far East	0.0	0.2	5.1	1.4	6.7
Africa	0.4	0.7	1.5	1.1	3.7
Latin America	0.0	0.1	0.8	1.2	2.1
North America	0.0	0.0	0.0	0.0	0.1
Other regions	-	-	-	-	0.0
World total	0.4	1.0	7.4	3.7	12.6

[1] Adapted from Beek et al. (1980), based on data from FAO/Unesco Soil map of the World. Growing period data according to FAO Agro-ecological Zones Project, Rome

In comparison with acid sulfate soils the extent of peat soils is larger (Figure 1). Some of the extensive, unused peat areas are enclosed by



Acid sulfate soils

Peat soils

Figure 1. Distribution of acid sulfate soils and peat soils in South and Southeast Asia. Simplified from Beek et al. (1980). Data from FAO/Unesco Soil Map of the World.

acid sulfate margins. These, in turn, generally adjoin more intensively used, better land. In this geographic sense, acid sulfate soils are marginal. There are not yet any economically or even technically valid recipes for the reclamation of certain central, large peat areas. Practical possibilities exist for the development of some acid sulfate soils, and not yet for others. In this sense, too, we are working on the margin of the technically and economically possible. This implies the chance of failure, partial or total, in specific land development efforts.

3 Reasons for development

Decisions on whether or not to develop given areas of acid sulfate soils, and on the direction which development should take, regrettably are often not based on their physical and chemical qualities. However, such decisions may be prompted by population pressure - in adjacent areas or further away - or by the need for employment possibilities or commodities which hopefully could be produced by the land.

The large acid sulfate areas along the northeastern coast of South America (Figure 2) generally lie between a strip of better land in the young coastal plain, toward the coast, and higher land further south. In Guyana, they have largely been developed into reservoirs: low-level seasonal lakes supplying irrigation water for sugar-cane and rice on the better land toward the coast. This extensive use, without any need for soil reclamation, was possible because there is a relative abundance of land compared with the small population. A similar situation occurs in some other parts of South America. The West African acid sulfate areas (Figure 2) are under a somewhat greater pressure for development.

The ratio of population to available, usable land is much higher in South and Southeast Asia. Thus, large areas of acid sulfate soils have been reclaimed by the people, partly without the benefit of scientific advice, particularly in the Central Plain of Thailand. In Indonesia and Vietnam, too, there are heavy pressures on land and urgent needs for land development. These pressures and needs constitute an important reason why the Second International Symposium on Acid Sulfate Soils was convened in 1981.

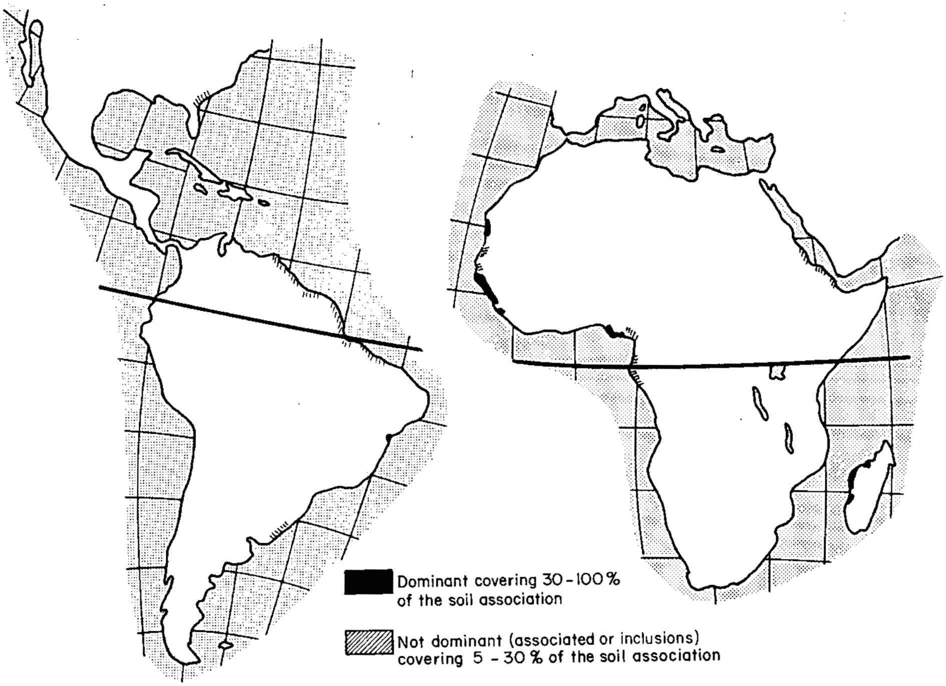


Figure 2. Distribution of acid sulfate soils in Africa and the Americas. Simplified from Beek et al. (1980). Data from FAO/Unesco Soil Map of the World.

4 Possible uses and their socio-economic implications

There is a variety of possible uses of acid sulfate soils:

- for all types of acid sulfate soils, and including some adjacent peat areas: nature reserve, or low-level irrigation water storage and flood protection;
- for inland, fresh-water areas: wetland rice, rubber, oil palm or pineapple;
- for areas closer to the sea, mainly with mangrove and some with a palm vegetation: biomass production for energy, or wood and bark production;
- for the saline areas adjacent to the coast: brackish-water fishponds, or salt pans in climates with a dependable dry season;
- for the salt-water edges: nurseries for fish, shellfish and other marine life. This brings us back to the first use mentioned: protection of the natural ecosystem.

Two main kinds of acid sulfate soil areas can thus be distinguished, each having distinct development alternatives with very different socio-economic implications: the fresh-water and the salt-water zones.

4.1 The salt-water zone

The main socio-economic problems in the salt-water zone are those of choice. There are various development possibilities, each feasible when viewed by itself within a limited area. Each has a different impact on the local ecology and on the adjacent sea area, particularly in its fisheries aspect. These consequences need to be clearly considered and weighed before development decisions are taken.

The natural mangrove ecosystem, part of which occurs on potential acid sulfate soils, is ecologically and economically very important.

In The Philippines (Gonzales 1978), fish of more than 40 zoological families have been recorded from the mangrove area, as well as many species of prawn, crab and oyster. Milkfish and prawn fry are collected for rearing in ponds. The mangrove area is both a nursery and the start of a food chain for much marine life; the disappearance of a mangrove fringe from a coast-line could have serious or disastrous consequences for fishing activities off-shore. The mangrove and nipa palm forest by itself also yields several products, for example in the Philippines: viscose rayon for textile fibers, tannin for leather manufacture, firewood and charcoal for fuel, thatch and shingles for roofing and walls, palm sap for vinegar and wine, timber for construction and furniture. The main alternatives to keeping the area as a mangrove ecosystem are salt pans, brackish-water fishponds, and wetland rice fields. All three uses require land reclamation measures, involving changes made by engineering, water management and chemical inputs. All three produce large amounts of acids during the reclamation period, part of which will reach the sea. Where extensive areas are to be reclaimed, the impact of this on adjacent coastal fringes will need to be estimated in order to determine a safe rate of reclamation.

At this point I would like to quote some words of Jose Janolo, secretary of the Department of Natural Resources in Manila, on the occasion of the international workshop on mangrove and estuarine area development, in 1977.

> 'We must .. respect our environment and treat it with consideration and care .. There is a very real danger that, in our eagerness to produce and develop .., we may be overlooking the limits of the ecosystem. Have we paused to consider that no technology can ever recreate an extinct species or reconstitute fundamental chemical-biological cycles? .. Our approach to the development of mangrove and estuarine areas .. must be based on an awe and respect for the complex multifaceted and interconnected, but finite environment of which we are all inhabitants.' (Janolo 1978)

Salt pans, rice fields or fishponds. If areas with saline acid sulfate soils are to be reclaimed, there are generally no great infrastructural problems. The main requirement is roads: for inputs and produce, as well as to get the people to services, and services to the people.

In Bangladesh, for example, there is a small potential acid sulfate area called the Chakaria Sunderbans. This was covered by mangrove and was saline, tidal and not yet acid. It was developed (reclaimed) by local people for rainfed wetland rice and rapidly became extremely acid as soon as the tidewater was excluded by dikes. The rice gave very low yields and failed in some fields. Then the people, who mainly lived on the higher land nearby, changed their poor and failing rice fields into salt pans. In local spots, extremely acid water welled up through the soil into the salt pans. Such spots were isolated and made harmless by separate small dikes. Even though the salt pans are only productive for about 4 months per year, in the dry season, annual incomes per ha were higher than even from good rainfed rice land.

In the Philippines, where much of the acid sulfate area is of the saline type, many of the individual patches are also small, and occur within a few km from schools and markets. Even in this relatively favorable situation, where there is a good infrastructure and where effective procedures for land reclamation and management are known at least to some technical experts, as well as to the land users in some parts of the country, there may still be major socio-economic problems. On coastal acid sulfate soils in Sorsogon, for example, on the southern tip of Luzon Island, wetland paddy yields of about 250 kg/ha are reported. Some farmers keep operating at this level because they have no other opportunities and because they have relatively large holdings.

Rice farming on such land generally appears to be losing ground in two ways: by farmers abandoning the land and migrating to towns, and by conversion of the land into brackish-water fishponds. The latter is a major engineering operating that requires considerable financial resources, but can result in an economically viable production system.

Although the conversion to fishponds appears to be economically sound, there is a major social danger. The conversion requires capital and unrestricted access to saline tidewater for every pond operator. Both these aspects carry the seeds for increasing social disparity, the rich getting richer and the poor being pushed out from the land. Such developments could be prevented by public canals open to tidewater, and by access to sources of medium-term credit for the poor farmer with little land.

4.2 The fresh-water zone

The potential acid sulfate soils in a fresh-water environment seem to constitute a less varied and less valuable natural ecosystem than the saline ones. The reclamation and use of fresh-water acid sulfate soils generally raise greater technical and infrastructural problems, as well as economic and social ones, than the acid sulfate soils in the saline coastal fringe. The individual areas are generally more extensive. In many, there is little or no tidal range to assist drainage and irrigation. There is no salt water to help speed up the removal of acids. Acid drainage water will need to be removed without damage to land downstream. Provision of access and services is generally more difficult and expensive. Known, technically sound procedures of reclamation for wetland or selected dryland crops are not necessarily economic even at low labor costs.

Because of the extent of the 'empty' areas, their large-scale colonization requires infrastructure locally, in the new land, since established services on the old land may be too far away. Similarly, a new network of social connections, support and organization needs to grow or to be developed in large, contiguous colonization areas.

Acid sulfate soil areas are not necessarily homogeneous throughout: they may vary in severity over short distances, and especially along rivers there generally are strips of land without acid sulfate problems. For the most severe acid sulfate soils there do not yet seem to be effective and economically feasible reclamation methods. For the less severe kinds there are practical development possibilities. Some of these have been found by scientists, but several have been developed by the people living and farming on the edges of the acid sulfate areas or within them.

Farmers in the Mekong Delta, for example, developed a system of shallow, broad drains at close intervals throughout the extent of the rainfed wetland rice fields on acid sulfate land. The first rains of the wet season wash much of the acid out of the surface soil into the drains. There it is immobilized by reduction or it is removed toward the rivers. By the time sufficient rain has fallen to raise the water level to the land surface, most of the acid has been removed from the upper few cm and the rest has been immobilized by reduction locally. Reported paddy yields under this system are about 2.5 t/ha, compared with a previous average of about 0.5 t/ha.

5 Failures and successes

5.1 Holland in the last three centuries

In the year 1641, a famous Dutch engineer who became known by the name of Leeghwater (Empty-the-water) devised a plan to drain the largest lake in the Netherlands, 4 meters deep and with a clayey bottom. The task was too great for the windmills existing at that time; two centuries later, in 1848, the Dutch state undertook the work with English steam engines. The drainage was a success - the colonization by farmers was a disaster. Acid sulfate soils covered part of the empoldered lake bottom, and two generations of farmers abandoned the land or went destitute trying to wrest a living from their farms.

Seen in a perspective of centuries, acid sulfate soils are a temporary phenomenon. In the natural, permanently wet state, the acid in them is hidden in the form of pyrite and the soils can exist essentially unchanged for long periods. After drainage, extreme acidity develops, precluding most of the relatively easy development possibilities of swamp areas with better soils. After several decades of leaching by rainfall or irrigation, if drainage has been maintained, much of the acid has been removed and the soil may have become moderately suited for some uses. After a century, it may even become good agricultural land: the former Dutch lake now is a prosperous area.

5.2 Settlement scheme

A more recent example is a polder developed shortly before 1960 in Guyana, South America, to the west of Georgetown. There, the colonists were rice farmers. After a few years, 90 percent of them had abandoned the land again: an enormous economic loss and a social disaster.

At present, there are colonization schemes planned and under execution in acid sulfate areas. People in the planning-and-development investment sector now think of 'socio-economic' aspects of such schemes. We technicians, and planners as well, firmly believe that we will never make mistakes as bad as our predecessors made. But can we bear the responsibility for the chance that they will become similar failures, with consequent social disruption? We should realize that the term 'social' or, worse, 'socio' is not a mere appendix to embellish 'economic'. Its basic meaning is linked with 'together' - not with provision of things from above. Let us examine a kind of organization and planning that may increase the chances of social and economic success.

5.3 Spontaneous colonization

There is a gradual, organic process of land development and homesteading going on in some areas with spontaneous colonization, for example, on Palawan Island in the Philippines (James 1978) and in the tidal swamp land of Kalimantan and Sumatera in Indonesia (Collier 1979).
In the latter, a few Buginese settlers first dig a short section of main canal from a river, then a smaller cross canal serving land on both sides. As clearing proceeds and an economic base becomes established, family members or friends arrive, first stay with the original settlers and work on their land, then start clearing a section of land for themselves under the leadership of the original settler on the canal. Progressively, the main canal is extended and further cross canals are dug. Where problems arise, certain sections can be left unused: meanwhile, they are being drained by the presence of the canals and may in due course become usable. Such local, temporary failures can be absorbed by the social structure that has developed, and do not destroy the local economy. The new people arriving learn the methods of development and farming appropriate to the area from the earlier arrivals. They tend to stay even if there are partial failures because of their investment in money, working time and effort. As the cultivated area expands, there is time for concurrent development and improvement of local services and for the emergence of an effective social organization.

5.4 A Comparison

When we observe developments in large, one-shot reclamation and settlement projects by governments, a very different picture emerges. Total costs per hectare may be similar (or higher), but the rate of abandonment or other failures is higher than in the spontaneous settlements. Settlers in government projects tend to come from very different places. Those who become neighbors generally do not know each other, and all are new in the area, with no local support or experience to draw on. There is no social network or structure; the services provided by government are supposed to keep the people together and active until an economic basis and a social structure have evolved that will stabilize the new community.

This comparison does not intend to show that spontaneous migration would constitute an adequate answer to the economic and social ills of government-organized settlement. Often, the pioneer settlers are social leaders, independent souls, and belong to the relatively rich. The people resettled in government projects mainly belong to the poor, and had very few resources to draw on in their original location. Nevertheless, they should never be uprooted and transplanted, with government credit and fertilizer, into a social vacuum.

6 Development centered on farmers' capabilities

We need to use and adapt the strengths and valuable aspects out of the spontaneous migration experience to improve the government-stimulated programs. The people can protect themselves by their own active participation against some of the mistakes that politicians, planners and we scientists may make.

There is some recent experience with broad overall plans that have wide meshes, gaps, to be filled in later. Only a few of these meshes are filled in detail at the start. This kind of plan-structure allowing small-scale mistakes and progressive improvements would need physical space to correct such mistakes: a frontier situation would be desirable.

In a frontier situation, when there is enough land ready for development between presently used and undeveloped areas, small-scale experiments can be made on different kinds of acid sulfate soils at limited cost, both by the farmers and by scientists on farmers' fields. Successes can be immediately applied on similar land, while failures hold up the advance of part of the reclamation frontier: a gradual and organic process, rather like the tide coming in on a flat beach, successive waves claiming more of the area: then here, then there, and with occasional long delays in certain places.

The settlers for a given project should not be appointed all at once. The first wave of settlers will need to be chosen very carefully. These pioneers should be selected primarily on their capabilities of management, innovation and farming. If possible, they should be chosen with the participation of the villages in which they live. The settlers for a given stretch of frontier should preferably come from villages near to each other and they should be prepared to work together. As more settlers gradually arrive, they find older as well as more recently established settlers in the new area, with a range of practical experience on how to reclaim and use the land.

The willingness to settle in the new land at first may have to be stimulated by considerable direct assistance, but will tend to increase with time, as information about the progress of reclamation filters back from the settlers to the villages of origin. This will increase the chances of success and decrease the amounts of public money that will need to be used for direct assistance. Thus, more resources are available for adequate development of the general infrastructure such as roads, main drains or main irrigation structures.

The crucial aspect in the reclamation of acid sulfate soils is mobilizing the strength of the community of people, creating the possibility for a broad base of experience. If the people moving into areas of new development are strengthened, not weakened, in their technical abilities, their social organization and their mutual support; if they have a stake in the development of the land rather than just being planted there with government credit and fertilizers, they will not sell their borrowed ploughs and roof-sheets and go, but they will jointly make a success of the development even of acid sulfate soils. Our present task is to help in shaping the technical tools for reclamation, making maximum use of the varied experience of the practical farmers.

Acknowledgements

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FACTORS INFLUENCING THE FORMATION OF POTENTIAL ACIDITY IN TIDAL SWAMPS

L.J. Pons and N. van Breemen
Department of Soil Science and Geology,
Agricultural University
Wageningen, The Netherlands

1 Summary

An explanation is offered for the geographic distribution of potentially acid sulfate soil materials in relation to climatic zones and the physiography of coastal plains. For this purpose potential acidity is defined as an excess of pyrite over acid neutralizing components. The essential ingredients and environmental conditions for the formation, accumulation or sedimentation of pyrite and acid neutralizing components are listed and interpreted in terms of actual and past physiographic settings, illustrated by well-known situations. Potential acidity is built up predominantly in kaolinite-rich, non-calcareous sediments in tidal flats below mean high water level, with a dense mangrove vegetation, amply flushed by saline or brackish tides at a sedimentation rate allowing for the mangroves to persist well below mean high water level for at least several decades.

These conditions are favoured by a subsidence of the land relative to the sea level or by low sedimentation rates and by a tropical humid climate. A relative rise of the land or an increase in sedimentation rate lead to rapid siltation of tidal creeks and quick lateral accretion of closed shorelines at levels well above mean sea level minimizes the influence of tidal flushing and mangrove vegetation, and thereby will depress the rate of pyrite accumulation and of decarbonisation and consequently of the potential acidity in tidal deposits.

Of the estimated 500 million hectares fine textured soils developed in marine and fluviatile sediments (FAO/UNESCO, Soil Map of the World 1971-1979: Fluvisols and Gleysols), about 12.5 million hectares are highly pyritic and will acidify upon aeration, or have already done so (Table 1). Still larger areas of pyritic sediments are continuously water-saturated and covered by peat or non-pyritic sediments. Moreover pre-Holocene pyritic coastal sediments, often in combination with peat, commonly give rise to serious acidity problems, especially as a result of open-cast mines in tertiary lignite deposits and coal of carboniferous age.

Table 1. Regional distribution of acid sulphate soils (based on data from FAO/UNESCO Soil Map of the World; length of growing periods according to FAO Agro-Ecological Zones Project, Rome)

Region	Area (10^6 ha)	Area (million ha) per length of growing period			
		< 90 days	90-180	180-300	> 300 days
Africa	3.7	0.4	0.7	1.5	1.1
Near and Middle East	-	-	-	-	-
Asia and Far East	6.7	-	0.2	5.1	1.4
Latin America	2.1	-	0.1	0.8	1.2
Australia	-	-	-	-	-
N. America	0.1	-	-	-	-
Europe	-	-	-	-	-
World total	12.6				

Potential soil acidity due to excess pyrite over neutralizing substances is formed mainly in tidal swamps and marshes, but sometimes also in sea bottom sediments. Up to now little is known about the reasons why pyritic contents are dangerously high in some areas and much lower in apparently similar adjacent areas. The aim of this article is to explain, sometimes rather speculatively, the distribution of potentially acid sulfate soils in relation to climatic zones and the physiography of the coastal plains. Such knowledge should help to solve problems in identification, cartography and reclamation of these soils. This article is similar in scope as the paper by Pons, Van Breemen and Driessen (in press).

3 Formation of potential soil sulfate acidity

Acid sulfate soils are formed by oxidation of sulfidic muds when the quantity of sulfuric acid, formed by oxidation of reduced S-compounds exceeds the acid-neutralizing capacity of adsorbed bases and easily weatherable minerals to the extent that the pH drops below 4.
Pyrite (cubic FeS_2) is quantitatively the most important sulfur mineral in such sediments. Accumulation of sedimentary pyrite requires (a) reduction of sulfate to sulfide, (b) partial oxidation of sulfide to polysulfides or to elementary S and (c) either formation of FeS (from Fe-oxides or Fe-silicates) followed by combination of FeS and S to FeS_2, or direct precipitation of FeS_2 from Fe^{++} and polysulfides.
Regardless of the actual pathway, the following overall reaction describes complete pyritization of ferric oxide:

$$Fe_2O_{3(s)} + 4SO^{2-}_{4(aq)} + 8CH_2O + \tfrac{1}{2}O_{2(g)} \rightarrow 2FeS_{2(s)} + 8HCO^{-}_{3(aq)} + 4H_2O \tag{1}$$

The essential ingredients for the accumulation of pyrite are:
1) sulfate, continuously supplied over an appreciable period (e.g. with sea water);
2) iron-containing minerals present in the sediments;
3) metabolizable organic matter (CH_2O);
4) sulfate-reducing bacteria, which are practically always present;
5) an anaerobic environment;
6) limited aeration for oxidation of all sulfide to disulfide.

Potential acidity can develop only if at least a part of the alkalinity in the form of bicarbonate (HCO_3^-), formed during sulfate reduction, is removed from the system. This requires leaching of the interstitial solution. Leaching is favoured strongly by tidal action and may further accelerate pyrite formation by breaking up diffusion-controlled rate-limiting processes and by supplying dissolved oxygen as well as sulfate from sea water. Removal of HCO_3^- also tends to depress the pH, giving slightly acid conditions which favour pyrite formation kinetically.
The pyrite content is a measure for the potential acidity, according to the reaction

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+ \qquad (2)$$

If any bases present are represented by their oxide components, the neutralizing capacity follows from the equation

$$M_xO_{x.z/2} + x.zH^+ \rightarrow xM^{z+} + (x.z/2)H_2O \qquad (3)$$

The acid neutralizing capacity of soil material depends on the amount of exchangeable bases and the contents of easily weatherable silicates and of carbonates. If fine-textured marine clays contain appreciable amounts of smectitic clay and are saturated with bases, their exchange complex may inactivate acidity released by up to 0.5% pyrite-S and prevent a drop in pH below 4.0. An example of neutralization by silicates is the replacement of Mg from smectites by Fe(III) from oxidizing pyrite, sometimes up to the equivalent of 1% pyrite-S (Van Breemen 1980). Three per cent $CaCO_3$ balances the acidity produced by 1% pyrite.

4 Distribution of potential acidity

Potential acidity can be formed most readily in:

- poorly drained inland valleys, subject to influx of sulfate-rich water;
- bottoms of saline and brackish lagoons, seas and lakes; and
- saline and brackish tidal flats and tidal swamps.

Inland valleys, with potential acidity are relatively rare with the supply of sulfates as the limiting factor. Examples include the pyritic papyrus peats of Oeganda (Chenery 1954), pyritic sandy gley soils in valleys in the Eastern Netherlands (Poelman 1973) and the sulfidic peat soils of Minnesota.

Bottoms of saline and brackish lagoons, seas and lakes, may be high in sulfides. Contents of primary (synsedimentary) organic matter usually limit sulfate reduction and the quantities of sulfides formed under these conditions (Berner 1971). Subaquatic sediments with potential acidity are generally limited to boreal and temperate climatic zones because there, contrary to tropical zones, decay of organic matter is slow and contents of primary organic matter in sediments are relatively high (Pons 1965). Subaquatic sediments often contain relatively high amounts of iron monosulfides next to pyrite, resulting in black colours. This may be due to insufficient aeration of the bottom sediments for complete pyritization of sulfide. Examples are the bottom sediments of the Black Sea (Berner 1971) and of the former Littorina Sea (now the Baltic Sea) which contain more than 2% reduced sulfur and little or no carbonates (Wiklander et al. 1950). Isostatic rise of the land after the last glaciation resulted into drainage of considerable areas of Littorina sediments and caused the formation of acid sulfate soils along the Baltic coasts of Sweden and Finland. In the Netherlands, the bottom sediments of the former Zuyder Sea also contain more than 1% reduced sulfur (Ente 1964) but their relatively high carbonate contents prevent acidification upon reclamation.

Pyrite formation in tidal flats and marshes. Saline and brackish tidal flats and tidal swamps are quantitatively most important as a source of potential acid sulfate soils. The bare tidal flats and the lower parts of the swamps are regularly inundated with sulfate-rich water and permanently reduced. The highest parts near and above mean high tide, however, show predominantly aeration and little or no sulfate reduction.

In sediments of bare tidal flats and creek bottoms the content of primary organic matter may limit pyrite formation. They are generally low in organic matter (0.5-2%) in the tropics, but may be organic-rich in temperate regions, especially at high clay content. This explains the relatively high primary pyrite contents in temperate areas relative to those in the tropics (Pons 1965). On tidal marshes and swamps, however, a telmatophytic vegetation may add large quantities of organic matter to the primary organic matter. Telmatophytes which develop roots in reduced muds, include mangroves (Rhizophoraceae) in the tropics and reeds (Phragmites) and rushes (Scirpus) in temperate tidal marshes. Water temperature, salinity and duration of the inundations influence type and distribution of the vegetation, and thus control the supply of secondary organic matter to the mud. Figure 1 shows how the vegetation is adapted to the range of conditions in tidal marshes in different climates.

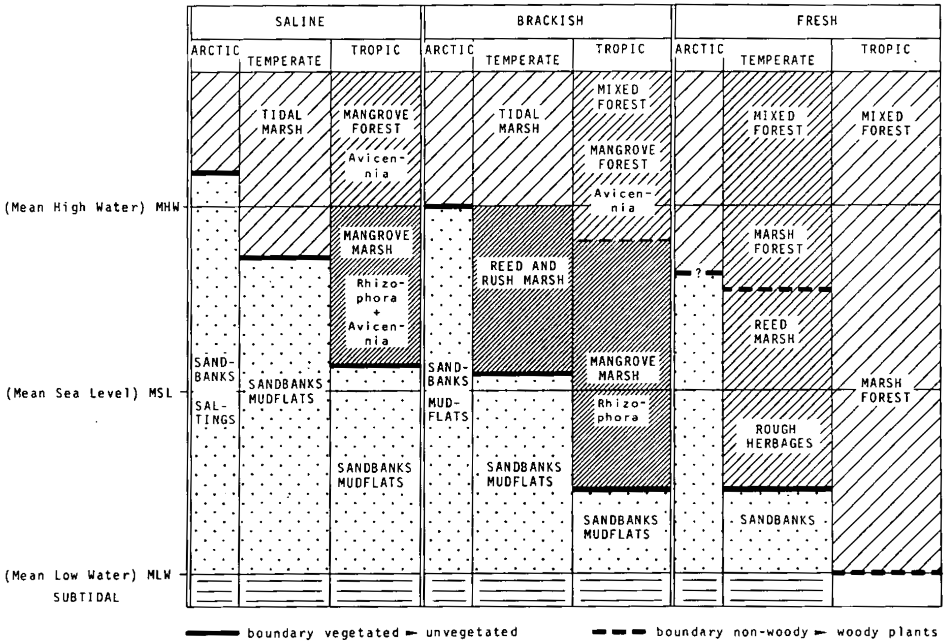

Figure 1. Vegetations of tidal marshes of arctic, temperate and tropic zones in relation to salinity and levels of tides

Adaption of the vegetation to lower topographic levels with longer inundations (and thus more reduced conditions) is greater in the tropics than in temperate and arctic zones and also greater in brackish than in saline conditions. In arid and semi-arid tropical coastal areas the growth of mangrove vegetations is hampered completely, perhaps due to very high salinities (Marius 1972).
Figure 1 illustrates that abundant supply of organic matter, favorable for pyrite accumulation can be expected in the 'low' brackish zone between mean sea level (MSL) and mean high water (MHW) in temperate areas with reeds (Phragmites) and rushes (Scirpus) and in the 'low' saline and brackish zone between mean low water (MLW) and mean high water (MHW) in tropical areas with Rhizophora and other mangrove trees.

5 Neutralizing compounds in tidal environments

Broadly speaking, the contents of neutralizing compounds of tidal sediments at the time of deposition, viz. exchangeable bases, easily weatherable silicate minerals and carbonates, vary with climates.

In the humid tropics, and especially in the smaller estuaries, kaolinite is often the dominant clay mineral in tidal sediments. These sediments are not only low in exchangeable bases but are also ineffective in neutralizing acid by weathering (Vieillefon 1973). Rivers from arid and semi-arid catchment areas supply mainly smectites to their estuaries, and, even though clay contents are often lower than in the humid tropics (Allen 1964), may neutralize an important fraction of the acidity formed upon oxidation. Those of the temperate areas have a mixed clay mineralogy with an appreciable exchangeable base content. Clayey sediments of large rivers of the humid tropics, including the Amazone and the Mekong, have moderate amounts of adsorbed bases and have a fair neutralizing capacity upon weathering.

Most volcanic catchment areas provide sediments rich in weatherable minerals. E.g. in tidal flats of the volcanic island of Java, in contrast to those of Sumatra and Kalimantan, the presence of such minerals lowers or prevents potential acidity (Driessen 1974).

Carbonates are practically absent in most coastal sediments in the humid tropics. Most rivers transport acidic water and non-calcareous sediments because their catchment areas include old, strongly weathered soils. Moreover coastal sea water in the tropics is often deluted with acid river water so any carbonate present runs the risk to be dissolved (Brinkman and Pons 1968). By contrast marine sediments in arid and semi-arid and in temperate zones frequently contain much more primary carbonates.

Summarizing (see also Table 2): the very fine textured clays of the large humid tropical estuaries show a moderately high neutralizing capacity. Sediments of arid, semi-arid and temperate areas and of volcanic regions have generally lower clay contents, but both because of a richer mineralogy and higher carbonate content, these sediments are highest in acid neutralizing capacity. Only the small estuaries in the humid tropics are generally very low in neutralizing materials and hence are often strongly acid or potentially acid.

Table 2. Occurrence of neutralizing ingredients in tidal deposits in environments favourable for pyrite accumulation (xxx abundant, xx fair, x rare, - none)

	Humid tropics			Humid temperate zone		Arid and semi-arid zone	
	Regions with recent volcanism	Small estuaries	Large estuaries	Clayey deposits	Sandy deposits	Clayey deposits	Sandy deposits
Exchangeable bases	xxx	x	xx	xxx	x/xx	xxx	xx
Weatherable silicate minerals	xxx	x	x	xx	xx	xxx	xxx
Primary carbonates	-	-	x/-	x/-	xxx/-	xxx/-	xxx/-

6 Dynamics of tidal environments and the formation of potential acidity

The time required for the formation of appreciable amounts of potential acidity (i.e. of pyrite) is probably in the order of decades to centuries. So, the tidal marsh vegetation has to persist at a given location for at least such a period of time in order to build up sufficient quantities of pyrite. This implies that sedimentation must be slow (Moormann and Pons 1974). Tidal environments with low sedimentation rates often have many well-developed creeks. Estuarine areas generally show numerous creeks in contrast to rapidly accreting coastal systems as in Malaysia (Diemont and Van Wijngaarden 1974) and along the Guyana coast (Brinkman and Pons 1968).

According to Diemont and Van Wijngaarden (1974) reduced substrata of large coastal swamps behind a closed accreting shore line in Malaysia have less than 0.5% pyrite-sulfur, are low in organic matter and show a field pH between 8 and 8.4, reflecting high concentrations of HCO_3^- (10-26 mol/m^3) in the soil solution. Those of the estuarine swamps, dissected by tidal creeks, have 1-2.5% pyrite sulfur, are high in undecomposed organic matter and show field pH's between 6.2 and 6.8 in the upper meter, with interstitial water low in dissolved HCO_3^-

(2-10 mol/m^3). Black FeS was locally found in sediments of the accreting coast, but not in estuarine sediments. During spring tides the concentrations of dissolved sulfide in the estuarine sediments dropped to undetectable levels whereas they remained almost constant along the accreting coast. These observations can be explained by much more effective tidal flushing in tidal marshes with a well-developed creek system. Tidal flushing would favour temporary limited aeration, necessary for the complete pyritization of ferric iron and leaching of interstitial water and evacuation of HCO_3^- so that a relatively low pH (6.5-7) is maintained.

In tidal environments, dissolution of $CaCO_3$ (secondary decalcification) may be much stronger than under terrestrial conditions (Van der Sluys 1970, Salomons 1974). This accelerated dissolution is also a result of tidal flushing combined with dissolution of $CaCO_3$ by CO_2 produced during the decomposition of plant remains. Oxidation of some pyrite during low tides would also remove $CaCO_3$ (Kooistra 1978).

Summarizing one may conclude that in saline and brackish marshes, dissected by creeks, leaching by tidal action may contribute to potential acidity, both by favouring pyrite formation and by removal of carbonates.

If sedimentation is outweighed by accumulation of organic debris, pyritic peats may develop. Pyritic mangrove peats are known from the Niger delta (ILACO), from Senegal (Vieillefon 1973), in Kenya (unpublished observations by Van Wijngaarden and Pons), and in Malaysia and Indonesia (Driessen 1974). Thin layers of pyritic reed and rush peats are very common e.g. in The Netherlands. In these peats, iron may become the limiting factor for pyrite formation. The same may be true for mangrove marshes composed dominantly of quartz sands (Vieillefon 1973).

During the last 3000 years many deltas, estuaries and coasts in Europe have witnessed a strongly accelerated sedimentation due to deforestation and land reclamation, especially since Roman times.

Elsewhere, including in the humid tropics, this process is now becoming increasingly important. For this reason recent sediments often have a lower potential acidity than sub recent sediments. Moormann and Pons (1974) described the Mekong delta as an example.

Summarizing one may say, that from the point of dynamic development of tidal environments many factors cooperate to result in high potential acidity in the humid tropics: dense vegetation, low sedimentation rates, and low primary and secondary carbonate contents in recent times increased soil erosion and concomitant accelerated sedimentation in tidal flats has somewhat decreased the rate of formation of potential acidity in many tropical areas.

7 The influence of relative sea level changes on tidal environments in relation with potential acidity

Both the formation of coastal land forms and the development of potential acidity in their sediments is strongly influenced by relative sea level changes. After the last glaciation the sea level rose by about 3-4 m per 1000 years (Blackwelder et al. 1979) and levelled off until a maximum was reached some 5,500 years BP and, apart from a slight drop some 5000 years ago (Fairbridge 1961) probably remained stable ever since. Slight differences in local tectonisms, however, resulted in different patterns of changes in the relative sea level as illustrated by Figure 2.

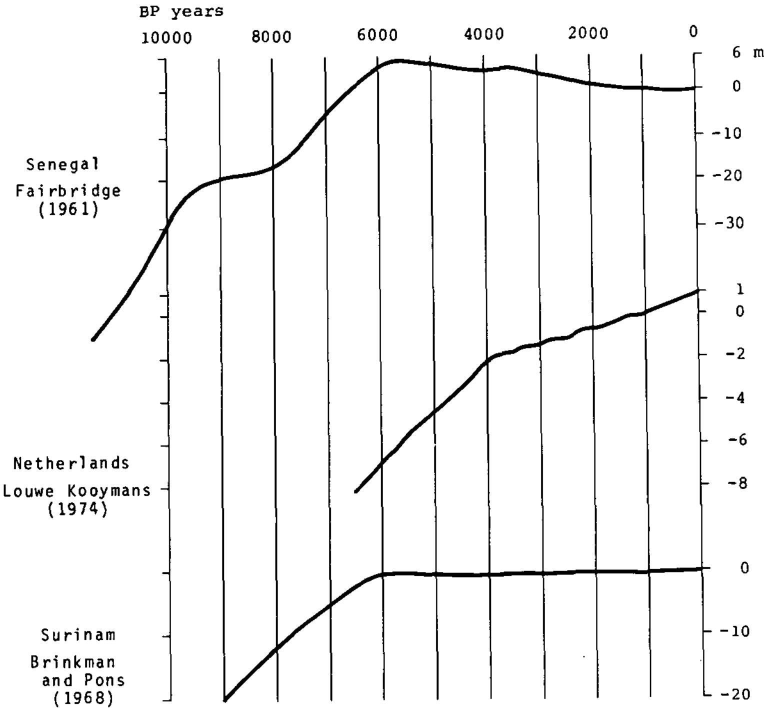

Figure 2. Changes in relative sea levels for the coastal plains of a stable coast, of The Netherlands and of Surinam

Fairbridge's curve applies to stable coasts, e.g. Senegal, Kenya, Australia, etc. The curve of Louwe Kooymans (1974) is not only characteristic for The Netherlands, where land subsidence caused continued rise in sea level after 5,500 years BP, but also for many other subsiding areas as the Orinoco delta, the Mississippi delta, etc. Along the Surinam coast the sea level remained constant during the last 5,500 years (Brinkman and Pons 1968). This pattern is also characteristic for many deltas e.g. the Bangkok plain and the Mekong delta.
Figure 3 illustrates how sea level changes and sediment supply may affect the formation of potential acidity in coastal areas. When the rise of sea level is high relative to the supply of sediment, transgression will take place.

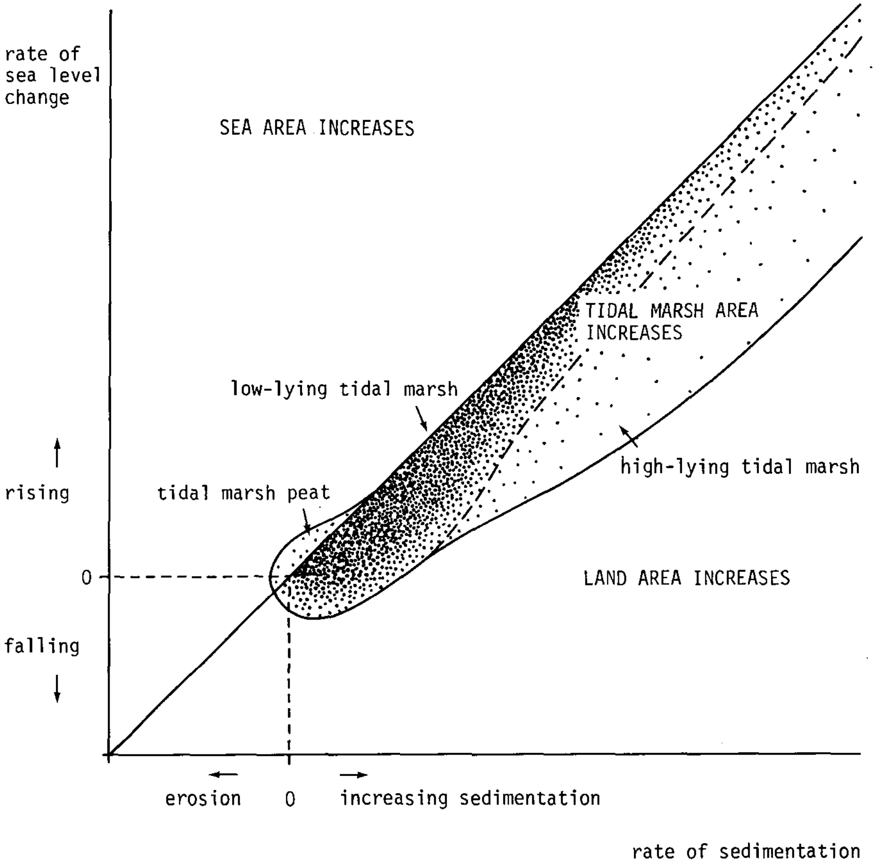

Figure 3. Effect of changes in sea level and sediment supply on the accumulation of potential acidity in tidal swamps. Level of potential acidity is represented by relative density of dot distribution

When sediment supply and relative sea level rise are more or less balanced a broad zone of stationary relatively low lying mangroves will occur (Brinkman and Pons 1968). Under these conditions vertical sedimentation predominates and potential acidity will be built up over considerable depths. If the sediment supply is relatively high the land area will grow by lateral accretion of the coast. Broad areas of relatively high-elevated tidal marshes are formed. The belt with mangroves and other salt and brackish marsh vegetations will shift rapidly seaward with the growing coast and only little potential acidity is formed (Moormann and Pons 1974).

After the last glaciation, in many areas with considerable supply of sediments the rise in sea level during the early Holocene was approximately balanced by the sediment supply. This resulted in a vertical build-up of sediments under stationary tidal marsh conditions. The silting-up of creeks was also retarded and tidal flushing of the relative low mangrove and salt marshes was maintained during long periods giving rise to thick sediments with high potential acidity.

After the stabilisation of the sea level during the late Holocene the still considerable supply of sediments caused lateral coastal accretion in these areas. A zone with high-lying mangroves rapidly shifted seaward with the growing coast. Only limited time was available for the formation of potential acidity. In addition, less favourable chemical conditions in these relatively high lying sediments for both pyrite formation as well as for decarbonation, contributed to their generally low level of potential acidity.

Erosion caused by deforestation in watersheds during the last parts of the Late Holocene has further accelerated the already high rates of coastal accretion in many of these regions.

In areas of low sediment supply, where transgressions took place in early Holocene times, sea level stabilisation in late Holocene times brought about stationary coasts with low lying mangroves. In such areas potential acidity is formed at present. Examples are the estuary of the Siné-Saloum (Marius 1972), the estuary of the Casamance river where recent sedimentation is so slow that locally pyrite peats are formed (Vieillefon 1973), and the estuary of the Saigon river (Moormann and Pons 1974).

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SOIL SURVEY OF TIDAL SULPHIDIC SOILS IN THE TROPICS: A CASE STUDY

P. Thomas and J.A. Varley
Land Resources Development Centre,
Overseas Development Administration
United Kingdom

1 Summary

The need to identify and survey tidal sulphidic soils in the tropics is discussed. Various identification techniques in common use are reviewed. An account of a systematic soil survey of a tidal region in the tropics is given, and the various techniques employed are evaluated. Particularly valued techniques include remote sensing, methodical field work with pH monitoring, a soil sample bagging procedure to minimize oxidation and a shuttle system between field and laboratory ensuring the rapid transportation, of soil samples, analysis and the transfer of results to the field. The conclusion drawn is that the survey of sulphidic soils under the rigorous conditions of the tropical tidal regions holds no serious problems when a systematic approach, designed to meet the need to minimize field and laboratory work, is adopted.

2 Introduction

The tidal regions of the tropics are among the most inhospitable environments known to man. Shortage of fresh water, regular tidal flooding along a maze of channels and creeks, deep soft muds covered by dense swamp vegetation, high temperatures and humidity together with diseases such as malaria, have all combined to make living and working conditions extremely difficult. As a result, these regions have remained relatively undeveloped, human settlement has been sparse and largely restricted to fishing and the collection of forest products.

This situation is rapidly changing. Technically it is becoming increasingly easy to overcome the inhospitable conditions, while the pressures exerted by expanding populations establish the need for ever more land for settlement. The bunding, clearing and draining of virgin tidal lands have partly satisfied this need, with the unfortunate result of unexpectedly producing from time to time acid sulphate conditions and the attendant land management problems. Such problems may be avoided or at least minimized by the identification, survey and delineation of sulphidic soils before reclamation: potential acid sulphate soils may then be avoided or appropriate management plans formulated to overcome the adverse soil conditions when they arise.

Even though a number of field tests have been used to identify sulphidic soil material, soil surveys in the tropics have tended to stop where tidal regions start. Thus, experience in the use of such tests and soil survey techniques appropriate to such rigorous conditions is limited. This paper is presented with these limitations in mind: it reviews the characteristics of sulphidic soil material and methods used to identify such material in the field. A case study is presented of a recent soil survey of a tidal area in The Gambia during which a number of these methods were employed and soil survey techniques were established to map sulphidic soils.

3 Identification

The presence of oxidisable sulphur, mostly in the form of pyrite (FeS_2), is the essential property of sulphidic soil material. The suggested minimum amounts of total sulphur varies from 0.75% (US Department of Agriculture and Soil Survey Staff 1975) to 0.4% (Allbrook 1973) and as low as 0.1% (Bloomfield 1973).

The changes in soil reaction on oxidizing the sulphur is also a common property used in the identification of sulphidic soil material. Soil reaction is normally near neutral, but on draining becomes extremely acid, commonly dropping below pH 3.0 and sometimes as low as pH 2.0. (US Department of Agriculture Soil Survey Staff 1975): The effect of free carbonates in reducing the degree of acidity is recognized in the USDA definition of sulphidic soil material (ibid), in that the calcium carbonate equivalent should be less than 3 times the total sulphur content. The hydrochloric acid field test for carbonates has been used for this purpose (Brinkman and Pons 1973).

In the field, colour has also been used particularly when yellow (jarosite) mottling occurs on air-dried clods (Beers 1962). Reduced grey colours have been associated with sulphidic material (Allbrook 1973, Kevie 1973) particularly when mixed with black mottles or dark discolorations (Brinkman and Pons 1973, Westerveld and Holst 1973, Kawasaki and Mekaru 1978); while both the presence (Vieillefon 1973) and absence (Kevie 1973) of greenish colours have been found indicative. Other physical properties which have been used as identification criteria include consistence, particularly in unripe muds (Brinkman and Pons 1973); organic matter especially fibrous material (Tomlinson 1957, Hesse 1961a, Kevie 1973) or mineral layers associated with such material (Coulter 1966, Thomas 1967); odour of hydrogen sulphide (Brinkman and Pons 1973, Kawasaki and Mekaru 1978).

The formation of ochre in field drains has been found indicative of sulphidic material in adjoining land (Bloomfield 1972, 1973, Trafford et al. 1973), together with black drainage water associated with monosulphides (Kevie 1969). Fish mortality and a bitter taste has been attributed to river water draining sulphidic soils (Dunn 1965).

Other sulphide identification tests used, and not dependent on elaborate laboratory facilities, include the measurement of the fall in pH after oxidation by hydrogen peroxide (Beers 1962), air-drying (Beers 1962, Thomas 1967, Andriesse 1973, Breemen et al. 1973, Food and Agriculture Organization 1975); and the use of poles painted with red-lead (Wiedemann 1973, Powlson 1976).

Vegetation and physiography have also been used for predicting sulphidic soils, commonly associated with mangrove swamps and also nipa swamps in parts of S.E. Asia (Bloomfield and Coulter 1973). Certain mangrove species have been used as indicators (MacLuskie 1952, Tomlinson 1957, Hesse 1961a, Hesse and Jeffrey 1963, Beye 1973) together with localized differences in elevation (Breemen 1973, Grant 1973, Dent 1980).

4 Case study

The soil survey selected for study presents many of the features including difficulties encountered in mounting and undertaking a systematic survey of tidal sulphidic soils in the tropics within a strict time limit. The survey provided opportunities to test many of the methods used to identify sulphidic soils.

The area concerned covers about 44,000 ha along a 92 km stretch of the estuary of the Gambia River starting some 127 km from the river mouth, and was identified solely on the basis of the possible occurrence of sulphidic soils. An earlier feasibility study (Coode and Partners 1979) proposed the construction of a 7 km long river barrage. This barrage would provide a barrier to salt water tides, provide an extensive fresh water reservoir for irrigation and a road crossing. This feasibility study suggested that should the level of the reservoir fall below present river levels, the resultant drainage of the sulphidic soils would give rise to serious problems, particularly relating to the formation of acid sulphate soils and its effects on farming and forestry and water pollution concerning irrigation and fisheries.

A team from the Land Resources Development Centre (LRDC) of the UK Overseas Development Administration (ODA) was deployed to undertake a survey of the sulphidic soils. Plans for the barrage were so poised and the likely advent of the rainy season meant that the time available to complete the field work was barely four months.

4.1 Pre-field work

This phase was devoted to collecting, reviewing, and assessing information relevant to the area; remote sensing using both convential air photographs and satellite imagery; establishing an operational plan; and the administrative task of mounting a survey in a remote area of a distant country. The main activities and their inter-relationships are shown in Figure 1.

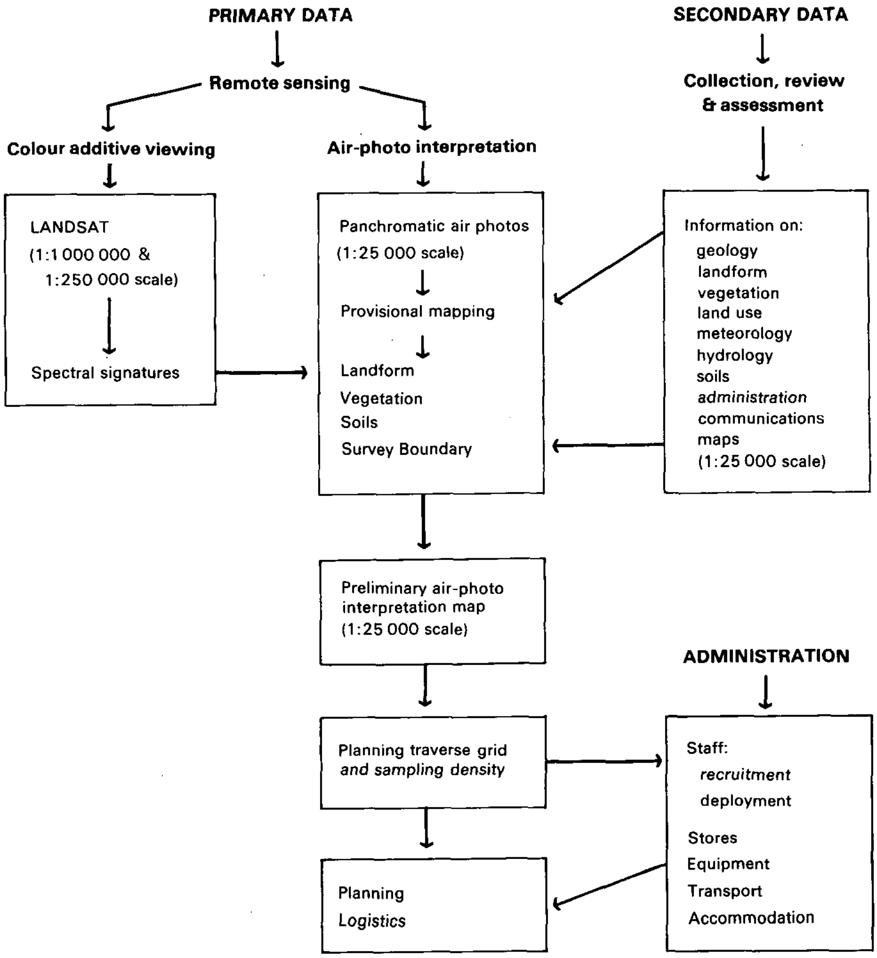


FIGURE 1 The main activities and their inter-relationships during the pre-field work phase

The air-photo interpretation (API) and use of information derived from previous work (Dunsmore et al. 1976, Johnson 1978, Coode and Partners 1979) revealed that much of the area was *Rhizophora* and *Avicennia* mangrove swamp which changed upstream to flooded grassland. It also confirmed that access was generally difficult. Colour additive techniques employed on the LANDSAT imagery produced distinctive spectral signatures over parts of the area, which were thought at the time to be related to the possible distribution of sulphidic soils.

A 1:25,000 scale map, with tentative thematic boundaries delineated by API, provided a base map on which to plan field operations. Because of the poor access and anticipated problems in locating observation points in the field, a fixed grid system of survey was adopted. The recommendations made by the Food and Agriculture Organization (1975) for soil surveys undertaken for reclamation of tidal lands were used, with some modification, as a basis for planning the survey. 1,000 m national grid lines shown on the base map were used to delineate traverse lines aligned roughly at right angles to the river. Soil observation points at 250 m intervals were marked on the traverse lines, and cards were designed to record bore-hole observation of critical soil data at 25 cm depth intervals: location, date, vegetation, watertable, depth, colour, mottles, texture, ripeness, roots, organic matter and other inclusions.

4.2 Field work

Three field teams were deployed full time. Each team comprised one soil survey assistant and three or four labourers and had the use of a Land Rover. A large launch, together with inflatable dinghy, was available for work on the river and creeks.

Work in the mangroves was based on traverses cut on compass bearings with the 250 m spaced observation points measured by tape. Elsewhere, from the mangrove, observation points were located by reference to the aerial photographs. For ease of location during the survey, brightly coloured flags were placed on the river banks to mark the origin of each traverse.

A total of 1,261 routine auger bore observations were made along some 320 km of traverse and in certain selected sites to confirm soil conditions. The observations were made initially over much of the area on the 1,000 m grid but, with the increasing experience of soil conditions together with the onset of the rains, they were restricted to alternate traverses i.e., at 2,000 m intervals. Work on 34 pit profiles supplemented the auger bore observations making the overall soil observation density 1 per 34 ha over the 44,000 ha. All soils were described in the field according to the FAO guidelines for soil profile descriptions (Food and Agriculture Organization 1965).

Conventional augers were found to be unsuited for the unripe and some half-ripe soils. Considerable difficulty was experienced in withdrawing samples from bore holes. A special auger was designed and made at an early stage of the survey. This consisted of 110 cm length of mild steel tubing tapered from a diameter of 10 cm at its upper end to 7 cm at its lower end. This tool removed a relatively undisturbed cylindrical soil core. A slit along the length of the tube allowed for observations and sampling of the core.

Some 5,000 auger bore samples, each about 1 kg in weight, were collected and taken to the base camp in 500-gauge polythene bags. Each bag was tightly secured using plastic wire and clearly labelled with details of traverse, bore number and depth of sampling. One in 10 samples was selected, according to the auger descriptions, for sulphur and pyrite analysis. Since pyrite oxidizes very rapidly, even in polythene bags (Begheijn et al. 1978), the samples were dispatched immediately after sampling to the LRDC laboratory in the UK.

In order that the pyrite values should be accurate and meaningful, it was considered essential that oxidation of the sample should be prevented or at least minimized. Where few samples are involved, the complete filling *in situ* of a sample container or air removal with nitrogen gas are recognized techniques. However, with the needs of the survey calling for the collection of hundreds of samples for total sulphur and pyrite analyses, then other more rapid methods of sampling and sealing to prevent oxidation had to be sought. It was recognized that the methods used would not be the most desirable and that some losses of pyrite by oxidation would probably occur. About 200 g freshly collected reduced soil were placed in a 10 cm × 7.5 cm, 500-gauge plastic bag. As much air as possible was removed by pressing on the bag which was then closed by heat-sealing. This sealed bag containing the soil was placed inside a further 500-gauge plastic bag. Again as much air as possible was removed and this second bag heat-sealed. With so much water and soft mud around, labelling was a problem. The occasional small leakage of the inner bag precluded the usual practice of placing a cardboard label between the bags. In the end, a water-proof spirit pen was found to be by far the most suitable method of marking. A marked plastic lable was placed in the soil and the outer bag was also marked. All labels were clearly readable when removed from the mud and washed. No samples were lost through unreadable labels.

A shuttle system was devised by which a weekly batch of soils was dispatched by air usually arriving in the LRDC laboratory within 6 days of sampling, and the results were received in the field within 2 to 3 weeks.

A pH monitoring programme was devised whereby changes in soil reaction on air-drying were recorded in a simple field laboratory established for the purpose at the base camp. pH measurements were made on the 5,000 soil samples brought in from the field. The use of a Kane-May 'Accuchem' digital pH meter with a combination electrode provided a reliable method of obtaining a great number of accurate and rapid pH determinations to establish normal field pH values. The determinations were made on 1:5 soil to water ratio samples as soon as possible after sampling. In order to measure the effects of aeration and oxidation on the sulphidic soils, the samples were exposed to air by loosening the necks of the polythene storage bags. Measurements were made at intervals to monitor changes. It was found that, with the samples kept in the shade and with the mean diurnal temperature range of 20 to 30°C and relative humidities of 40-80%, about 30 days were necessary for significant changes in pH.

The presence of free carbonates was frequently tested with 10% hydrochloric acid (US Department of Agriculture Soil Survey Staff 1951). The test was invariably negative.

A number of red-lead pole tests were made during the preliminary stages of the field work following the methods of Wiedemann (1973), Powlson (1976) and Coode and Partners (1979). Wooden poles 100 × 3 × 3 cm in size were coated with red-lead in a medium of linseed oil. The poles were hammered into the soil, labelled with traverse and bore numbers and left for between 2 to 3 weeks. After the prescribed time had elapsed the poles were collected and washed, after which the degree of reduction (blackening) of the red-lead along the length of the pole was noted.

4.3 Post-field work

Parts of this phase ran concurrent to the actual field work: soil analysis started within a week, while soil classification and mapping slowly evolved by the synthesis of field and laboratory data. The major part of report compilation and final map production was undertaken on the completion of the field work.

The soil samples were unpacked immediately on arrival at the LRDC laboratory, and dried as rapidly as possible. Some unripe soil samples contained up to 80% water which necessitated a longer than average drying period. The samples were heated at 105°C in a forced-draught oven. Samples having lower moisture contents were sliced into roughly 0.5 cm cubes to ensure rapid drying. Unripe samples with the higher moisture contents were first dried for one hour, then sliced into cubes for further drying. All samples were dry in 2 to 4 hours. They were then finely ground and placed in sealed glass bottles.

A 'Leco' induction furnace with automatic titrator was used for the determination of total sulphur. An amount (usually 0.05 g) of finely ground soil was mixed with iron and tin and placed in a muffle furnace at 450°C for 30 minutes to destroy organic matter. When cool a 0.05 g copper ring was placed on top of the sintered mixture. The pre-treated soil sample was heated rapidly in an induction furnace to about 1,650°C in a stream of oxygen. The sulphur in the sample was converted to sulphur dioxide which was absorbed in hydrochloric acid containing sodium azide, potassium iodide and starch. Halide interferences were removed by passing the evolved gases through crushed antimony. The starch iodide blue complex was destroyed by the action of sulphur dioxide, and iodate from the automatic titrator was added as the combustion proceeded in order to restore the original blue colour. The volume of potassium iodate added was proportional to the sulphur content of the sample. 559 samples were analysed in duplicate for total sulphur.

Pyrite sulphur was measured as the difference in sulphate before and after oxidation with hydrochloric peroxide. Archer's (1956) method was used, where the sulphate was reduced to hydrogen sulphide by the use of a reduction mixture based on hypophosphorus acid. The hydrogen sulphide produced was absorbed in alkali and titrated against mercuric acetate using dithizone as an indicator. The pyrite content of 90 samples was determined.

The increasing availability of field and laboratory data during the course of the survey enabled a number of soil classification approximations, cumulating in the recognition of 7 soil series based on differences in parent material, morphology and sulphur content particularly relating to soil use. The main characteristics of the soil series are given in Table 1. The recognition of sulphidic material in the Bamba and Yelitenda Series being of critical importance, the relationship between the sulphur and pyrite contents and the data obtained from the pH monitoring programme was the prime concern at this phase of the survey. It was established at a relatively early stage that total sulphur contents in excess of about 0.75% and correspondingly high pyrite contents were closely related to a large change in pH on air-drying. The effect of drying on the acidity of six of the soil series, in relation to their sulphur contents, is shown in Figure 2. After the relationship of pH with sulphur and pyrite contents had been established, the identification of sulphidic material depended largely on pH data. Since the read-lead pole test is only a measure of water soluble sulphides, as expected, there was poor correlation between the tests and the laboratory values of sulphur and pyrite. The red-lead pole tests were therefore discontinued.

As it was not found possible to map out each series individually, nine soil mapping units were recognized, each comprising 2 or more defined series combinations. The details are given in Table 2.

The report of the survey, together with a 1:70,000 scale soil map, was completed within a few months. The main conclusion was that although sulphidic soils and the related potential acid sulphate soil problem did exist, it occurred over a much smaller area (12,900 ha) than previously estimated.

Table 1. Main characteristics of the soil series (Thomas et al. 1979)

Soil series	Parent material	Sulphidic material	pH[1]	Texture	Salinity[2]	Gleying[3]	Drainage[4] class	Ripeness[5] 0-50 cm	Ripeness[5] 50-100 cm	Reddish mottles	Concre-tions	Potential[6] acidity	Correlation[7]
Bamba	tidal mud	present	6-2	clay	slight	gleyed	vpd	unripe	unripe	absent	absent	+	Typic Sulfaquent
Yelitenda	tidal mud	present	6-2	clay	moderate	gleyed	vpd	half ripe	half ripe	absent	absent	+	Typic Sulfaquent
Pakuba	floodplain alluvium	absent	6-4	clay	non-moderate	gleyed	vpd-pd	half ripe	half ripe	absent	absent	-	Haplic Hydraquent
Jassong	floodplain alluvium	absent	6-4	clay	non-moderate	gleyed	vpd-pd	ripe	half ripe	absent	absent	-	Tropic Fluvaquent
Salikene	floodplain alluvium	absent	6-4	clay	non-moderate	gleyed	vpd-pd	ripe	ripe	absent	absent	-	Tropic Fluvaquent
Mandori	terrace alluvium	absent	6-4	clay	non-strong	gleyed	id	ripe	ripe	present	absent	-	Aquic Camborthid
Kauur	terrace alluvium	absent	6-4	clay	non-strong	gleyed	id	ripe	ripe	present	present	-	Aquic Camborthid

Notes

[1] pH air dried soil

[2] for at least part of the year

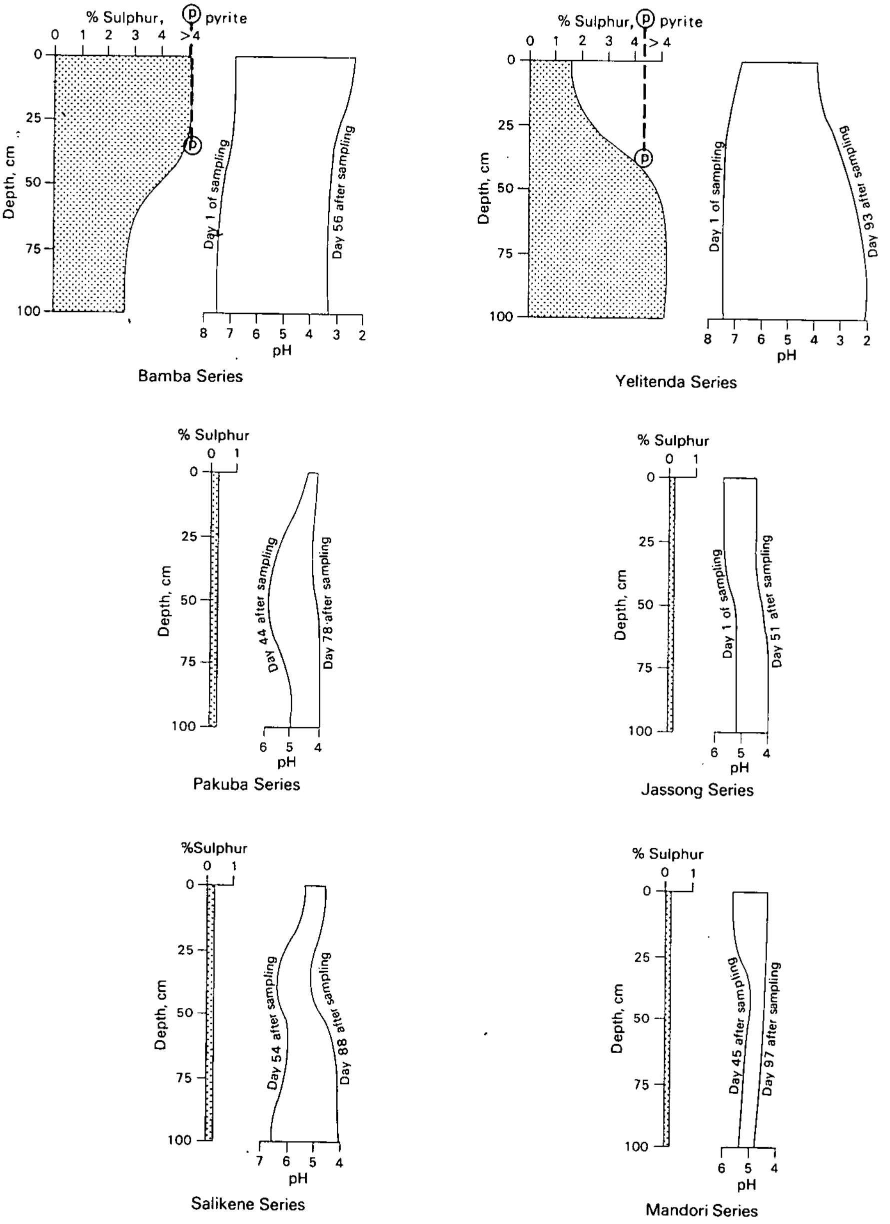
[3] within 1 m

[4] vpd - very poorly drained
pd - poorly drained
id - imperfectly drained

[5] depth below surface

[6] + - potential acid sulphate soil
- - not potential acid sulphate soil

[7] with 'Soil Taxonomy' (USDA Soil Survey Staff 1975)



Bamba Series

Yelitenda Series

Pakuba Series

Jassong Series

Salikene Series

Mandori Series

Figure 2. Effect of drying on the acidity of soil series varying in sulphur content. Changes in pH with depth, days after sampling % sulphur. Note marked increase in acidity in the more sulphidic Bamba and Yelitenda Series, and also their pyrite contents (Thomas et al. 1979)

Table 2. The soil mapping units, their areas, soil series combinations, main characteristics, topographical location, landform and acid sulphate potential (Thomas et al. 1980)

Soil mapping unit	Area		Soil series		Main characteristics of the major soil series	Topographic location and landform	Acid sulphate potential
	ha	ac	Major	Typical Inclusions			
Bamba Series	2 400	6 000	Bamba	Yelitenda	Unripe, sulphidic, slightly saline muds	Lower tidal zone of the tidal flats	Present
Yelitenda Series	10 500	25 000	Yelitenda	Bamba	Half ripe, sulphidic, moderately saline muds	Upper tidal zone of the tidal flats	Present
Pakuba Series	7 500	18 600	Pakuba	Jassong Salikene	Half ripe, very poorly and poorly drained, non to moderately saline clays, derived from floodplain alluvium	Mainly the lower and middle reaches of the floodplain	Absent
Jassong Series	5 800	14 300	Jassong	Pakuba Salikene	Ripe over half ripe very poorly and poorly drained, non to moderately saline clays, derived from floodplain alluvium	Sporadically along the floodplain, except for the extensive area at the mouth of Sofaniama Bolon	Absent
Salikene Series	6 000	14 900	Salikene	Pakuba Jassong	Ripe, very poorly and poorly drained, non to moderately saline clays, derived from floodplain alluvium	Common to the upper reaches of the floodplain	Absent
Salikene-Pakuba Association	2 600	6 600	Salikene Pakuba	Jassong	Ripe and half ripe, very poorly and poorly drained, non to moderately saline clays, derived from floodplain alluvium Half ripe, very poorly drained and poorly drained, non to moderately saline clays, derived from flood plain alluvium	Common to the middle reaches of the floodplain	Absent
Mandori Series	5 900	14 500	Mandori	Kauur	Deep, imperfectly drained, mottled, non to strongly saline clays, derived from terrace alluvium	Terrace surface throughout area	Absent
Mandori-Jassong Association	1 100	2 600	Mandori Jassong	Kauur Salikene	Deep, imperfectly drained, mottled, non to strongly saline clays, derived from terrace alluvium Ripe over half ripe, very poorly and poorly drained, non to moderately saline clays, derived from floodplain alluvium	Terrace surface locally dissected by drainage depressions; sporadic throughout area	Absent
Mandori-Salikene Association	2 200	5 300	Mandori Salikene	Kauur Jassong	Deep, imperfectly drained, mottled, non to strongly saline clays, derived from terrace alluvium Ripe, very poorly and poorly drained, non to moderately saline clays, derived from floodplain alluvium	Terrace surface locally dissected by drainage depressions, typically of the middle reaches	Absent

5 Evaluation

The experience gained during a systematic soil survey of this kind provides an opportunity to evaluate many of the techniques used in the past to identify and map sulphidic soils. The experience points to the overall need to develop the most efficient combination of techniques to fulfill survey objectives.

Conventional API provided an invaluable tool for vegetation analysis, distinguishing in particular between mangrove forest and other forms of vegetation, although these were not found to be exclusively indicative of sulphidic soils. This relationship between mangrove vegetation and the distribution of sulphidic soils was marred where mangrove forest had been cleared and was under secondary forms of vegetation. This distribution of mangrove was also clearly related to the distinct spectral signatures visible on colour composites of LANDSAT imagery, but field work on similarly coloured areas found not to be under mangrove lead to the conclusion that the usefulness of the technique as applied was limited to distinguishing between flooded and non-flooded land. A similar observation has been made by Darche (1979).

The choice of a regular survey grid and fixed soil observation points and sampling depths proved successful, particularly with a number of teams being deployed simultaneously in the field. The selection of a limited number of well chosen critical soil properties minimized field work and helped to standardize data recording, and proved invaluable at a later stage when rationalizing soil classification and soil mapping criteria.

Field properties which proved in this instance to be unmistakenly linked with sulphidic soils were the presence of mangrove, unripe consistence and yellow jarosite mottling on nearby exposed earthwork. Other properties shown to be of more limited assistance for identification included the presence of reduced grey or greenish grey colours - with or without black mottles, quantities of organic matter - particularly fibrous roots - or associated mineral layers, half-ripe consistence and hydrogen sulphide odour from disturbed soil. The use of the latter group of properties was unreliable because they could also be related to some reduced but non-sulphidic soils.

Of the field tests tried, that of monitoring changes in soil reaction on

air-drying to provide a pH spectrum was outstandingly useful and simple - requiring only a pH metre and electrode and about 30 days for oxidation.
While the pH monitoring programme proved invaluable as a simple field test, it needed to be correlated with and substantiated by the far more time consuming and costly laboratory analysis of total sulphur and pyrite. In order to satisfy the need to combine the field test and laboratory data so as to decrease the effort spent on the laboratory work the following ratios between determinations were established: pyrite: total sulphur - 1:6; total sulphur: pH spectrum - 1:10. With the knowledge and confidence gained during the course of the survey, the need for laboratory data for surveys under similar conditions would be less likely, and more reliance placed on pH spectra and other field criteria.

An evaluation of the packing and transportation of the reduced soil samples from field to laboratory indicated that some pyrite oxidation had taken place. This is an error which is difficult to avoid short of drying the samples in the field. Rapid and complete drying in the field necessitates there being a forced-draught oven and electricity available on the site for use at all times, and this was impractical.
The establishment of a routine soil bagging procedure and shuttle system between field and laboratory ensuring minimal oxidation of the samples and rapid receipt of analytical data, proved to be of critical importance to the success of the survey. In addition to overcoming the problems related to packing, dispatch and freightage it depended on a laboratory service programmed to receive, and analyse without delay, regular consignment of soils.

6 Conclusion

It is possible to undertake methodical soil surveys of tidal sulphidic soils under the rigorous conditions of the tropics by:

- the interpretation of remote sensing imagery combined with field work, so as to decrease the effort spent on field work;
- the use of a systematic approach to field work based on grid survey, fixed observation points and sampling depths, a limited number of

critical soil parameters, and simple but reliable field tests particularly the monitoring of pH, to minimize the need for laboratory data;
- the support of a laboratory service capable of coping with regular batches of soil samples, undertaking rapid analyses, and able to promptly convey the data to the field.

It is hoped that this paper has led to a clearer understanding of the methods related to the identification and survey of sulphidic soils, and will stimulate attention to the increasing need for soil surveys in the tidal swamps of the tropics.

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QUANTITATIVE MODELS TO PREDICT THE RATE AND SEVERITY OF ACID SULPHATE DEVELOPMENT:
A CASE STUDY IN THE GAMBIA

D.L. Dent and R.W. Raiswell
School of Environmental Sciences,
University of East Anglia
Norwich, UK

1 Summary

Using a static model, the amount of acid produced following drainage of sulphidic material can be calculated from the quantity of pyrite sulphur in excess of the soil's neutralizing capacity.

A dynamic model is developed in which the rate of sulphide oxidation is assumed to be controlled by the rate of diffusion of oxygen through water-filled pore space. The rate of acid production is then determined by (1) the excess pyrite S content of the material and (2) its surface to volume ratio - in effect soil structure. Following drainage, unripe soils fissure into coarse prisms of radius less than length. This structure can be modelled approximately by solving equations for the diffusion of oxygen into cylinders.

Both pyrite S and soil structure development occur naturally over a range of values that significantly affects the rate of acid generation. Tables are presented showing the influence of S content and ped size on acid production.

The model is applied to the potential acid sulphate soils of the Gambia. Severe acidity is predicted to develop rapidly if the watertable is lowered. The actual pH values of the soil and river water will depend on the drainage regime and the effectiveness of flushing of acid from the soil to the drainage water.

2 Introduction

Farmers, engineers, planners and investors confront the soil scientist with practical problems of land reclamation. Specific, quantitative answers are required to the following questions:

nature of the problem: 'What problems can be expected?'
extent: 'Where and when will those problems occur?'
magnitude: 'How severe will these problems be; what effects will there be on crop yields, water quality, fisheries and engineering structures?'
alleviation: 'What should be done about it?'

Although the questions and answers are necessarily related to specific development schemes, we must have a theoretical basis for making quantitative predictions. In this paper a physical model of sulphide oxidation is developed to predict the rate of generation of acidity following the drainage of sulphidic material. This model is used to answer some practical questions involved in a major land development project in The Gambia. We accept that the model involves major simplifying assumptions but stating the assumptions serves a useful purpose in identifying those areas where further work is needed and where accurate data are essential.

3 The Gambia Barrage Project

The river Gambia (Figure 1) flows through a region of strongly seasonal climate with an average rainfall of about 1000 mm during a five month wet season and no rain during the seven month dry season. The river is tidal for a distance of more than 200 km upstream and in the dry season, when fresh water flow is much diminished, a tongue of salt water moves upstream almost to the tidal limit. During the wet season fresh water flushes downstream, enabling rice to be grown in the inter-tidal zone when the salt has been washed out from the surface soil.

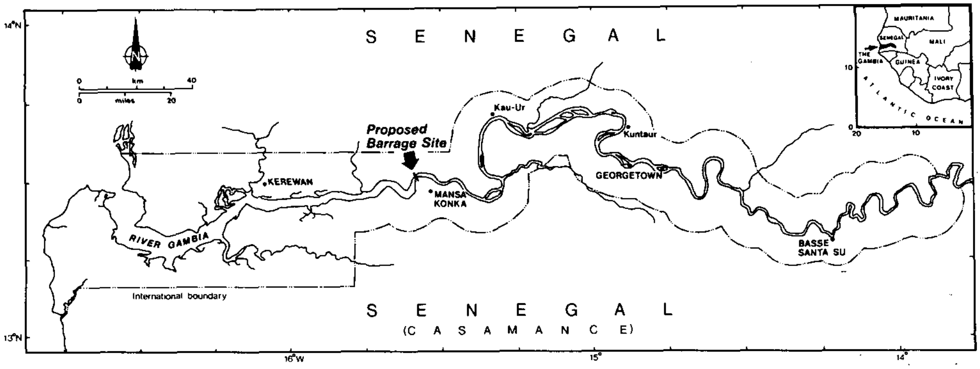


Figure 1. The Gambia: proposed location of barrage

Lower than average fresh water flows, or any increase in the present low level of abstraction of water from the river for irrigation in the dry season, will increase the upstream migration of salt water in the dry season and attenuate the downstream flush of fresh water in the wet season. This will jeopardize some of the existing areas of tidal rice cultivation, estimated to be about 13-19 thousand hectares. A feasibility study has been carried out for a scheme to build a barrage across the tidal river to create, upstream of the barrage, a reservoir of fresh water which would be available for irrigation of a second rice crop in the dry season.

Figure 2 shows the predicted water level of the reservoir assuming average river flow (measured over the period 1970/1971 to 1975/1976) and different levels of water abstraction for irrigation. In the driest of the five years measured, the shortfall of river compared with the average was equivalent to the water use of about 7000 ha irrigated rice.

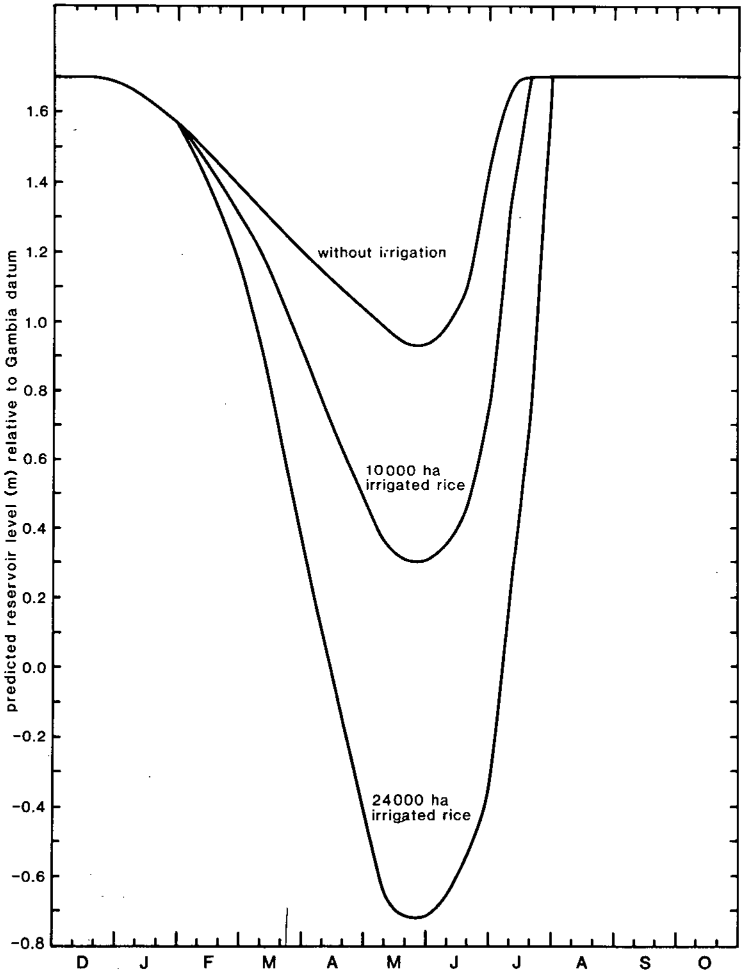


Figure 2. Gambia barrage scheme: predicted water levels in reservoir with water abstraction for different areas of irrigated rice, assuming mean river flow

A reconnaissance soil survey of the area upstream of the proposed barrage (Coode and Partners 1979) indicated extensive areas of unripe, sulphidic soils which would be exposed to the air at low reservoir levels. Subsequent detailed survey (Thomas and Varley, this symposium) demonstrated the presence of 12,900 ha of sulphidic soils upstream of the proposed barrage site.

The elevation of the sulphide datum - the level below which the soil is sulphidic - was established by levelling transects across the intertidal zone, along which stakes coated with red-lead paint were implanted (Figure 3). Hydrogen sulphide generated in the horizon of active sulphate reduction turned the paint black within a week, leaving on the stakes a permanent record of the upper limit of present sulphide accumulation.

The upper limit corresponded closely with the upper boundary of the practically unripe Gr horizon (Dent 1980) identified in the field, and was confirmed by analyses of total S contents (Table 1). Below this level the soils were strongly sulphidic.

Table 1. *Gambia barrage project. Reconnaissance soil survey: soil salinity, sulphur and pH values*

Soil association[1]	Profile Nr.	Horizon[2]	Depth cm	EC_s mS/cm	Total S[3] %	Field pH	pH on exposure[4] 3 (months)	24	Observations on oxidized *samples*
As	03	Gr wγ	1-5	3.0	2.5	7.0	2.8	2.8	
practically			30-50	7.1	5.6	>7.0	2.8/3.0	1.6	heavy jarosite crystalli-
unripe and			80-85	6.1	2.6	7.0	1.5	1.6	sation + some $Al_2(SO_4)_3$
half ripe									
saline gleys	04	Go2 p	0-10	0.6	0.2	5.7/6.5	5.7	6.9	
		Go1 wβ	15-20	1.9	0.3	7.0	5.3	4.2	
		Gr wγ	50-60	9.4	2.4	7.0	1.9	1.2	heavy jarosite
			90-100	7.8	2.0	7.0	1.6	1.6	deposition
	11	Gr p	5-10	2.6	1.3	5.0/5.9	5.3	3.8	
		Gr wγ	40-45	5.4	3.2	5.5/5.9	1.5	1.5	
			90-100	5.2	1.6	6.5	2.0	1.5	
	12	Go1 p	0-10	2.8	0.2	5.3/5.9	5.3	4.6	
		Gr wγ	40-50	9.6	0.9	4.5	3.1	2.7	
			90-100	9.6	3.4	5.9	1.6	1.5	
	16	Gr wγ	10-15	4.2	8.2	5.7/5.9	1.4	1.1	heavy jarosite + gypsum
			40-45	n.d.	3.4	6.5	1.7	1.4	heavy jarosite
			70-80	6.7	6.0	6.9	2.3	1.2	deposition
			100-110	8.4	2.6	6.9	2.5	1.6	
	23	Gr p	10-20	2.2	0.4	6.2	5.0	3.4	gypsum deposition
		Gr wγ	30-40	2.2	2.5	5.9	2.0	1.7	
			90-100	2.2	1.4	5.9	2.1	1.9	
Bs	01b	Go2 wα	30-35	8.6	0.2	5.0/5.7	5.0	4.1	
nearly ripe		Go1 wα	65-70	10.4	0.15	4.7/5.7	4.7	4.2	
saline		J2 wγ	100-110	20.6	n.d.	3.5/4.5	4.5	3.7	
gleys									
	05	Go2 p	0-5	0.7	0.4	5.7/5.7	5.7	5.5	
		Go1 wβ	20-25	0.7	1.2	6.9	3.1	2.6	
		Gr wβ	70-75	12.3	3.6	7.0	2.2	1.1	
	10	Go2 p	0-10	1.7	0.5	6.2	5.7	6.4	
		Go2 wα	15-20	2.0	0.1	4.7/5.0	5.0	4.6	
		Go1 wβ	40-50	2.3	0.6	5.0/5.7	5.1	5.2	heavy iron oxide deposition
		J2 wγ	50-60	4.3	0.6	4.5	4.3	4.3	
		Gr wγ	90-100	4.7	0.6	4.5/6.2	4.3	4.2	
	18a	Go2 p	10-20	0.8	0.2	5.5/5.7	5.5	4.4	
	18c	J2 wβ	30-35	0.7	0.1	4.7/5.7	4.0	3.8	heavy iron oxide deposition
	19	Go2 p	10-15	1.0	0.25	5.3	5.3	3.8	
		Go2 wα	30-35	0.7	0.2	5.3	5.0	3.8	
		Go1 wβ	45-50	1.0	0.1	4.7	4.9	3.7	

Notes are explained on next page.

Table 1 (continued)

Soil	Profile		Depth	EC_s	Total S[3]	Field	pH on exposure[4]		Observations on oxidized
association[1]	Nr.	Horizon[2]	cm	mS/cm	%	pH	3 (months)	24	samples
Cs	08	Ah	1-6	0.3	0.6	5.4	5.3	4.9	
ripe saline		Bg cs	20-25	0.7	0.03	5.7	5.7	6.3	
gleys		Bg	40-50	1.7	0.2	6.0	5.7	7.7	shell present
		Go2 wα	60-80	1.1	0.3	6.5/7.0	6.2	7.0	shell present
	09	Ahg	10-20	1.3	0.2	5.4	5.5	4.4	
		Bg	50-60	2.3	0.1	5.3	5.5	5.0	
		Go2	90-100	8.1	0.6	5.0	5.0	4.7	
	20	Bg	15-20	0.4	n.d.	5.3	5.2	4.4	
		Bg2	45-50	5.2	0.1	4.7/5.0	5.0	4.7	
B	25	Go2 wα	10-20	n.d.	0.6	5.7	5.0	4.0	
nearly ripe		Go1 wβ	50-55	2.4	0.1	4.7/5.0	5.0	4.0	
gley		Gr wγ	90-100	0.5	0.3	5.5/5.7	4.8	3.9	
C	24	Apg	0-10	2.2	0.05	5.9/6.0	5.5	4.2	
ripe gley		Bg	30-40	1.3	0.12	4.7/5.5	5.0	4.2	
		Bg2	55-60	1.3	0.02	5.0/5.5	5.3	4.8	
D		Ah	0-5	0.2	0.03	5.9	5.0	n.d.	
imperfectly		Ag	20-25	0.6	0.05	5.0/5.7	4.9	n.d.	
drained, ripe		2Bg cs	65-70	0.2	0.01	6.5	4.3	n.d.	
alluvial gley		3Bg cs	100-110	0.3	0.25	6.0	4.6	n.d.	

[1] Soil associations and profiles from 1:100,000 reconnaissance survey, Coode & Partners 1978

[2] Horizon nomenclature follows Dent 1980:

Gr	not ripe, permanently reduced, sulphidic
Go1	not ripe, partly oxidising, usually sulphidic
Go2	not ripe, mottled, not sulphidic
J2	not ripe, jarosite pore fillings and cutans, severely acid
A	ripe topsoil
B	ripe, mottled and structure development

Additional subscripts:

p	cultivated topsoil
h	uncultivated topsoil rich in organic matter
g	gley morphology in ripe soils
cs	gypsum deposition
wα	nearly ripe
wβ	half ripe
wγ	practically unripe

[3] Total S determined by X-ray fluorescence

[4] pH on exposure: 500 g samples were stored at field moisture content at 25°C in thin-walled polythene bags and pH measured using a glass electrode pH meter after 3 and 24 months

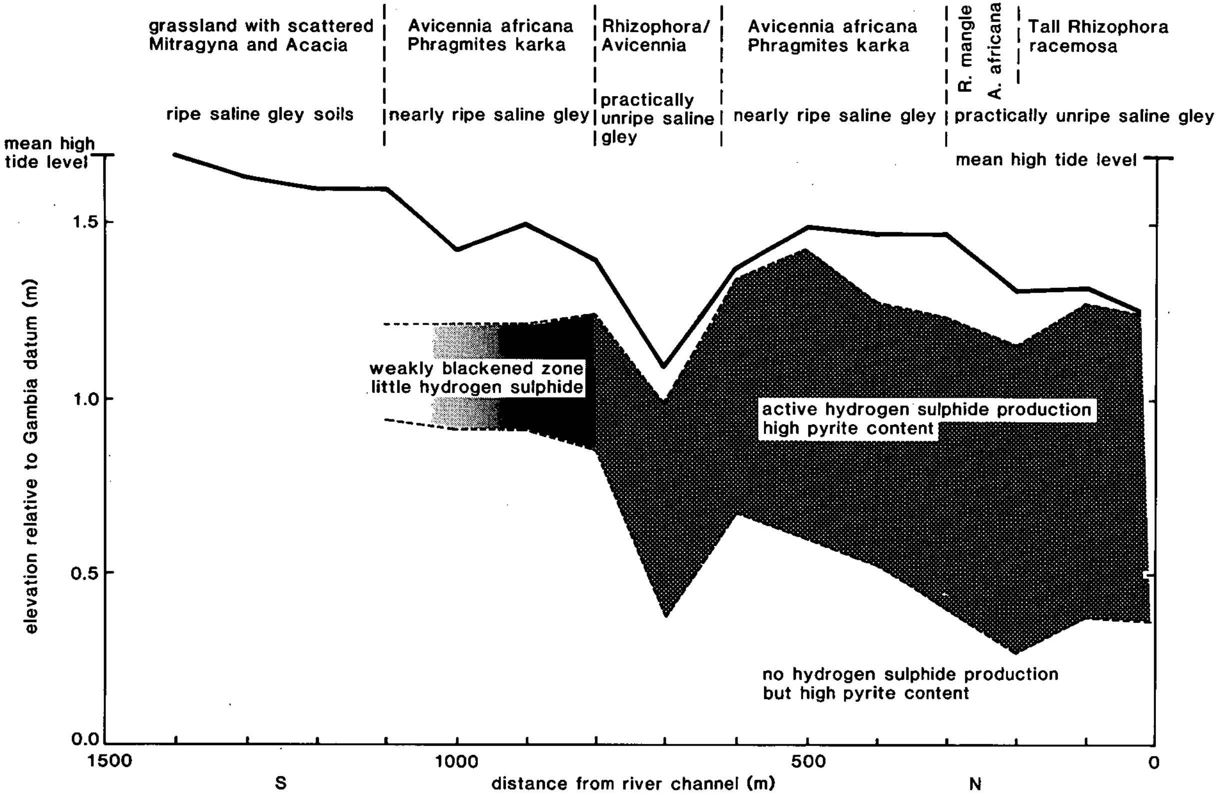


Figure 3. Levelled transect at Sankwia 5 km northeast of Mansa Konko, The Gambia: vegetation, soils and level of sulphide datum

The mean elevation of the sulphide datum in the proposed reservoir area (Figure 3) is +1.3 m above Gambia datum and mean high tide level is +1.7 m. Under a conventional barrage operation, abstraction of water for irrigation of 24,000 ha irrigated rice would lower the water level in the reservoir more than two meters below the sulphide datum in a year of average river flow. Under these conditions acidification of the sulphidic material is inevitable. Figure 4 shows the ultimate pH value, plotted against total sulphur content, of samples collected during the reconnaissance survey which were allowed to oxidise slowly at their field moisture content in thin-walled polythene bags.

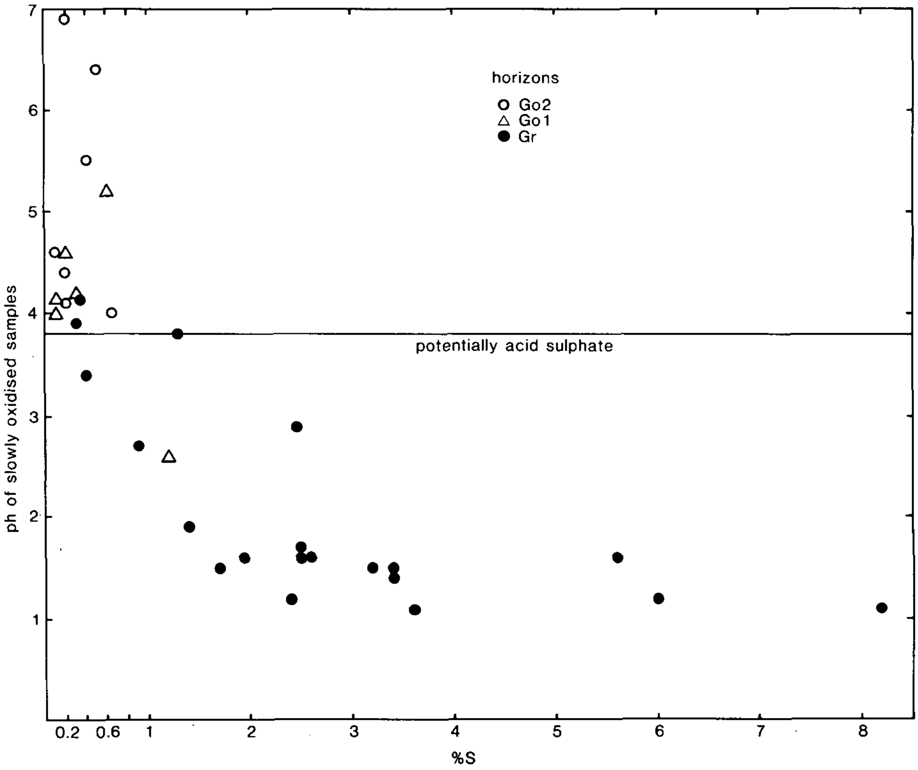


Figure 4. Total sulphur content, and pH values of samples after 2 years oxidation under moist conditions

4 Prediction of the rate and severity of acid sulphate development

Oxidation of wet mud in polythene bags serves to identify the acid sulphate problem, but is inadequate to forecast the rate of acid generation and the fate of the acid under a range of possible drainage conditions in the field. We have tried to estimate the rate of acid production using a simplified model of oxidation by diffusion of oxygen into the sulphidic material.

4.1 A static model

The amount of acid generated depends on the initial concentrations and the fate of the iron sulphides. Four possible cases have been identified:

1) All iron oxidized and remaining in solution as Fe^{3+}

$$FeS_2 + \frac{15}{4} O_2 + \frac{1}{2} H_2O \rightarrow Fe^{3+} + 2SO_4^{2-} + H^+ \qquad (1)$$

2) Iron released as Fe^{2+}

$$FeS_2 + \frac{7}{2} O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \qquad (2)$$

3) All iron oxidized and hydrolyzed to iron III hydroxide

$$FeS_2 + \frac{15}{4} O_2 + \frac{7}{2} H_2O \rightarrow \underset{\substack{\text{iron III}\\ \text{hydroxide}}}{Fe(OH)_3} + 2SO_4^{2-} + 4H^+ \qquad (3)$$

4) Formation of jarosite

$$FeS_2 + \frac{15}{4} O_2 + \frac{5}{2} H_2O + \frac{1}{3} K^+ \rightarrow \frac{1}{3} \underset{\text{jarosite}}{KFe_3\,(SO_4)_2\,(OH)_6} +$$
$$\frac{4}{3} SO_4^{2} + 3H^+ \qquad (4)$$

The conspicuous deposition of hydrated iron oxide and jarosite in young acid sulphate soils suggests that the net result of pyrite oxidation in sulphidic materials is represented by equations (3) and (4).

Van Breemen (1976) argues that in acid ($pH < 4.4$) oxidized environments ($Eh > 400$ mV) jarosite is more stable than amorphous ferric oxide; and field observations confirm that the more severe the acidity, the more dominant is jarosite deposition over iron oxide deposition. Acid generation according to equation (4) is pursued below. In terms of acid production per mole of pyrite this equation predicts three moles of H^+. Although jarosite is ultimately hydrolized to goethite, releasing a further mole of H^+, this reaction goes to completion over many years rather than months under field conditions.

The Gambian sulphidic Gr horizons analyzed have a mean sulphur content of 3.5 per cent, equivalent to 6.54 per cent by mass of pyrite. Assuming an apparent density of 0.63 g cm^3 (Dent 1980 and a small number of determinations in samples from The Gambia), the amount of pyrite per cubic meter of sulphidic material is 3.44×10^2 moles. By equation (4) oxidation of this pyrite will liberate 10.31×10^2 moles H^+.

To estimate the net production of acid, a measure of the neutralizing capacity of the soil is required. Calcium carbonate in the form of shell was rarely observed in the field. In the absence of carbonates the only acid-consuming reactions at low pH values are ion exchange and the incongruent dissolution of silicates.

All sulphidic soils examined were of clay texture, clay content ranging from 56-80 per cent, but there are no data on clay mineralogy or cation exchange properties. The principal sources of sediment are likely to be highly weathered detrital sediments of Tertiary age dominated by quartz and kaolinite (Dunsmore et al. 1976). Determinations of cation exchange capacity of comparable ripe, non-sulphidic soils (Jackhally and Kudang Series) range from 8-20 m.e. per 100 g for samples low in organic matter up to 30-35 m.e. per 100 g for samples with 5-6 per cent carbon, that is 15 and 30 m.e. per 100 g clay (Land Resources Division, unpublished). This suggests a clay fraction of mixed composition, predominantly kaolinite but with some illite or smectite.

Cation exchange is a source of instant neutralization. If we adopt a medium value of 20 m.e. per 100 g cation exchange capacity, excess acid production will be 9.05×10^2 moles H^+ per cubic meter. This free acid released by oxidation of pyrite may remain in situ to react slowly with the residual silicates or may be leached from the system.

Under artificial oxidizing conditions where all the acid remains in situ, buffering reactions maintain the pH values above 1.0 (Table 1) but the extent of neutralization in the field will depend on the rate of acid generation and the effectiveness of leaching.

4.2 A dynamic model

4.2.1 The rate of oxidation of pyrite

The sulphidic material is initially close to neutrality but it acidifies rapidly on exposure to oxidizing conditions.
The lower pH brings Fe^{3+} into solution and promotes a rapid catalytic oxidation of pyrite

$$FeS_2 + 14\ Fe^{3+} + 8H_2O \rightarrow 15\ Fe^{2+} + 2SO_4{}^{2-} + 16H^+ \qquad (5)$$

Fe^{3+} is returned to the system by bacterial oxidation of Fe^{2+} by *Thiobacillus ferrooxidans*

$$Fe^{2+} + \tfrac{1}{4}\ O_2 + H^+ \rightarrow Fe^{3+} + \tfrac{1}{2}\ H_2O \qquad (6)$$

The rate of reaction will be controlled by the surface area of the pyrite and the rate of transfer of oxidants (O_2 and Fe^{3+}) into the system. In the case of recently deposited sulphidic materials such as the Gambian alluvium in which the particle size of the pyrite is small, the rate limiting factor is likely to be the diffusion of oxygen into the system.

4.2.2 Simplifying assumptions

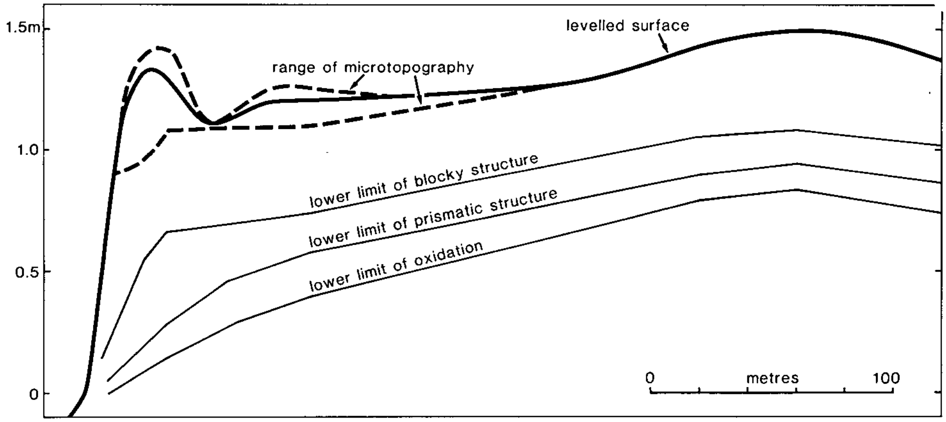
1) *The rate of oxidation of pyrite is controlled by the rate of O_2 transport through water filled pores,* i.e. rate of reaction is faster than the rate of diffusion.
2) *Oxidation of organic matter consumes negligible oxygen compared with oxidation of pyrite.*
3) *No blockage of pores by precipitates.*

4) *No hindrance of O_2 diffusion* by collision and interaction with soil particles (i.e. sediment tortuosity factor = 1, tortuosity is likely to be small for non-charged, molecular species).

If we assume that the rate-limiting process is diffusion of oxygen through water-filled pores, then the rate of oxidation at any point will be related to the distance from the air-water interface. Practically unripe soils under mangrove vegetation are typically very permeable, because of a large proportion of coarse bio-pores, and auger holes bored to 1 m fill with water within a few minutes. However, unless ripening and consequent deep fissuring of the soil mass takes place, lateral drainage over longer distances may be very restricted. The sulphuric horizons of young acid sulphate soils of clay texture commonly fissure into prismatic peds of the order of 20-30 cm cross section. As ripening proceeds these peds fissure into smaller cubic blocks. However, in the absence of artificial drainage the depth of fissuring is reduced at increasing distances from natural creeks (Figure 5).

We are making the further assumption that:

5) *The soil fissures into prismatic peds*, of radius << length, and further that the diffusion of oxygen into these peds can be approximately equated to the rate of diffusion of oxygen into cylinders of equivalent radius.



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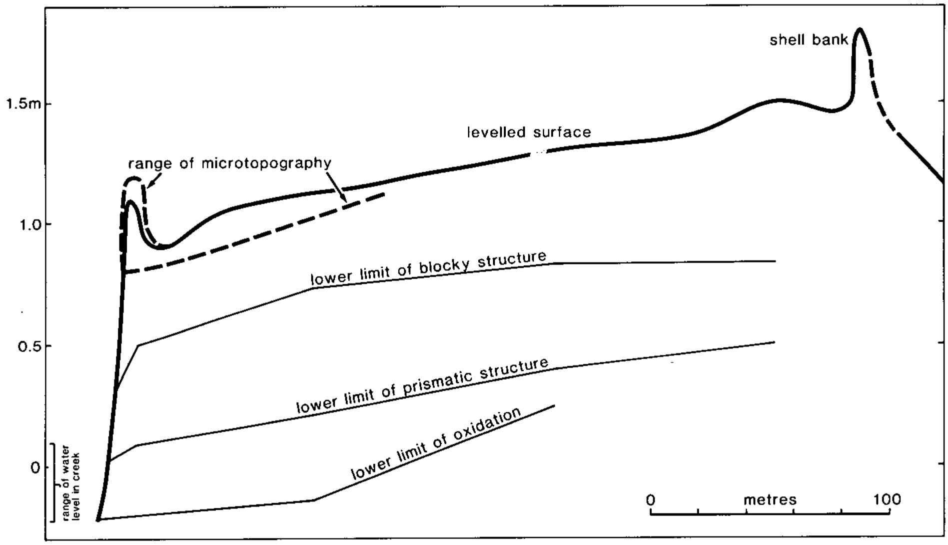

5b

Figure 5. Levelled traverses of polders in Northland, New Zealand showing the lower limits of structure formation and oxidation relative to the water level in draining creeks

a) Waireia Creek after 7 years drainage

b) Omanaia River after 15 years drainage

4.2.3 *Calculation of rate of oxidation*

At time t = 0 the water in pores opening to the surface of the ped becomes saturated with oxygen and the soil is oxidized from the surface inwards. The model assumes instantaneous reaction, so the effect of diffusion plus reaction is analogous to diffusion alone, but with a correspondingly reduced diffusion coefficient - in effect slower diffusion (Crank 1975). If the true diffusion coefficient of dissolved oxygen is D, then the appropriate reduced value for the case of diffusion plus reaction is given by $\frac{D}{R+1}$, where R is defined as below.

Concentration of oxidizable material, expressed as the number of moles of O_2 required for its oxidation	= R ×	Concentration of O_2 in water, expressed in moles

Under reaction conditions of 30°C and $5^{o}/oo$ salinity, the solubility of oxygen is 4.58×10^{-4} moles per litre.

Volume of a cylinder with radius 10 cm and length 200 cm = 6.28×10^4 cm^3
= 62.8 litres.

Mass of this cylinder = $6.28 \times 10^4 \times 0.63$ (apparent density).

Mass of pyrite = $6.28 \times 10^4 \times 0.63 \times \frac{6.54}{100}$
= 2.59×10^3 g
= *21.6 moles pyrite*

This pyrite consumes $21.6 \times \frac{15}{4}$ moles O_2 = *80.9 moles* O_2.

The cylinder has 77 per cent water filled pore space, so there are 48.4 litres of water. Thus the pyrite consumes $\frac{80.9}{48.4} = 1.67$ moles O_2 per litre of water.

We can now evaluate R:

$$1.67 = R \times 4.58 \times 10^{-4}$$
$$R = 3.64 \times 10^3$$

At 30°C the diffusion coefficient D, for O_2 in water = 2.62×10^{-5} cm^2 s^{-1} (Lerman 1979, p. 76), thus D corrected from diffusion plus reaction

$$= \frac{2.62 \times 10^{-5}}{3.64 \times 10^{3}}$$

$$= 7.2 \times 10^{-9}\ cm^{2}\ s^{-1}$$

Crank (1975) gives the solution for diffusion (non-steady state) into a cylinder as:

$$\frac{Mt}{M_\infty} = 1 - \Sigma_{n=1}^{\infty} \frac{4}{a^2\ \alpha_n^2} \exp\ (-D\alpha_n^2 t)$$

where

Mt = quantity of diffusing substance which has entered the cylinder in time t

M_∞ = corresponding quantity after infinite time, i.e. complete oxidation

a = radius of cylinder

D = diffusion coefficient

t = time

α_n = the root of Jo $(a\alpha_n) = 0$

Jo is the Bessel Function of order zero. Values of α_n are given in tables (Aramowitz and Steyum 1965). The diffusion equation must first be transformed so that each α_n is accompanied by a, i.e. $(a\alpha_n)$ because the tables give values of Jo for $(a\alpha_n)$.

$$\frac{Mt}{M_\infty} = 1 - \Sigma_{n=1}^{\infty} \frac{4}{(a^2\alpha_n^2)} \exp\ \{ -D \frac{(a^2\alpha_n^2)t}{a^2} \}$$

n	1	2	3	4	5	6
$a\alpha_n$	2.4048	5.5201	8.6537	11.7915	14.9309	18.071
$a^2\alpha^2_n$	5.783	30.47	74.87	139.0	222.9	326.6

We are going to sum a series of diminishing terms to infinity. Except for very large values of a, this series converges rapidly. t is in seconds so replace by T in years

$t = T \times 3.15 \times 10^7$

Note that $\frac{Mt}{M_\infty}$ corresponds to the fraction of the cylinder oxidized.

Rates of oxidation for different sizes of cylinder

For a cylinder 30 cm diameter, a = 15 cm.

$$\frac{Mt}{M} = 1 - (0.692.e^{-0.0058T} + 0.131.e^{-0.031T} + 0.053.e^{-0.074T} +$$

$$0.029.e^{-0.14T} + \ldots)$$

For T = 1 year $\frac{Mt}{M_\infty} = 1 - \sim 0.912 = 0.08$

For T = 5 years $\frac{Mt}{M_\infty} = 0.146$

For T = 50 years $\frac{Mt}{M_\infty} = 0.46$

For decrease in a, the rate of oxidation increases significantly. A summary of calculated values of degrees of oxidation as a function of time and diameter of cylinder is presented in Table 2 and Figure 6.

Table 2. Rate of oxidation for different cylinder sizes, 3.5% S

Time (years)	5	10	20	30	50
Fraction oxidized					
30 cm diameter	0.15	0.22	0.30	0.36	0.46
20 cm	0.23	0.32	0.42	0.52	0.64
15 cm	0.30	0.41	0.55	0.65	0.78
10 cm	0.43	0.58	0.76	0.86	0.95

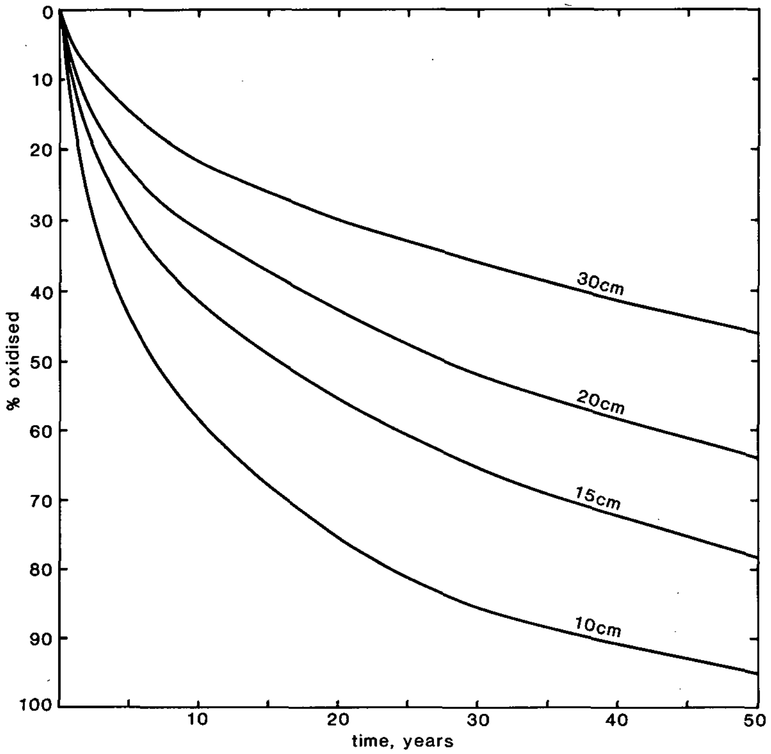

Figure 6. Rates of oxidation of pyrite for cylinders of different diameters, at a sulphur content of 3.5%

Rates of oxidation for different pyrite contents

The above calculations refer to sulphidic material of 3.5 per cent total S = 6.54% pyrite.

Similar calculations have been performed for 2% S (3.75% pyrite) and 5% S (9.38% pyrite), for cylinders of diameter 15 cm and 30 cm. New values for R must be evaluated for different pyrite contents.

Data for the fraction of material oxidized as a function of time for different pyrite contents are presented in Table 3, and plotted in Figure 7.

Table 3. Rate of oxidation (fraction oxidized) for different S contents and cylinder diameters

Time (years)	5	10	20	30	50
Cylinder diameter 15 cm					
2.0% S	0.39	0.52	0.69	0.79	0.91
3.5% S	0.30	0.41	0.55	0.65	0.78
5% S	0.25	0.35	0.47	0.56	0.69
Cylinder diameter 30 cm					
2% S	0.20	0.28	0.39	0.46	0.57
3.5% S	0.15	0.22	0.30	0.36	0.46
5% S	0.13	0.18	0.25	0.31	0.39

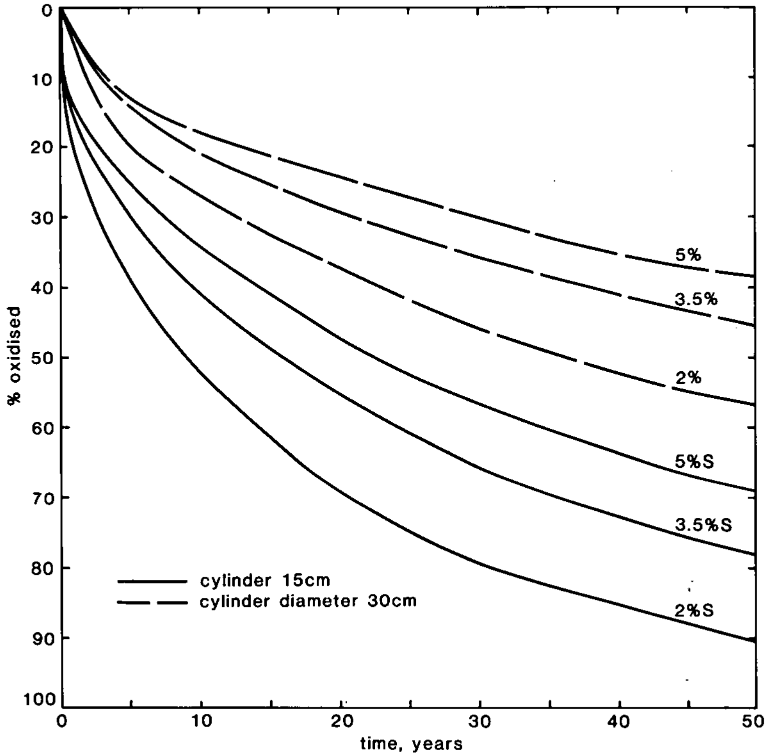

Figure 7. Rates of oxidation of pyrite for materials of different sulphur contents, in cylinders diameter 15 cm and 30 cm

5 Application of the dynamic model to The Gambia

5.1 Rate of acid generation

From the predicted water levels of the reservoir behind the proposed barrage (Figure 2) it can be seen that even without abstraction of water for irrigation the watertable will fall below the sulphide datum for three months of the year. Severe acidity will develop in the upper layer of the whole area of sulphidic soils during the first year of barrage operation. The greater the abstraction of water, the greater the depth of drainage and hence the greater the acidification.

If we assume fissuring of the sulphidic material into peds of 20 cm diameter, a total S content of 3.5% and a horizontal watertable, the net acid generation will be 35.4 moles H^+ per square meter at the T = 1 year rate. This will decrease to 6.6 moles $H^+ m^{-2}$ where T = 10 years, i.e. after about 40 years of drainage to this depth. These values refer to a year of average river flow. Drawdown of the watertable and hence acid generation will be substantially greater in years of low river flow. These are probably low estimates of the rate of acid generation because no allowance has been made for entry of oxygen into the system through coarse pores, or for continued fissuring as the soil mass slowly ripens.

5.2 Fate of the acid

In the Gambian situation a large proportion of the annual increment of acid will be flushed from the soil into the reservoir at the beginning of the wet season. We have no information about the effectiveness of leaching or the buffering effect of dissolution of the silicate clays, but if the whole increment is leached there will be an annual input to the reservoir of 29×10^7 (area of sulphidic soils) $\times 35.4 = 10^{10}$ moles H^+ at the T = 1 year rate, decreasing to 2×10^9 moles H^+ at the T = 10 years rate.

Figure 8 depicts the pH values of the reservoir in mid July, assuming abstraction of water for 24,000 ha rice, oxidation at the T + 10 years rate, total washout of acid, and homogeneous mixing with the reservoir water along 1 km sections. For washout of only 10 per cent of the acid the pH values will be one unit higher. Once the reservoir has been replenished the acidity will be progressively diluted as more fresh water floods downstream and carries the acid beyond the reservoir.

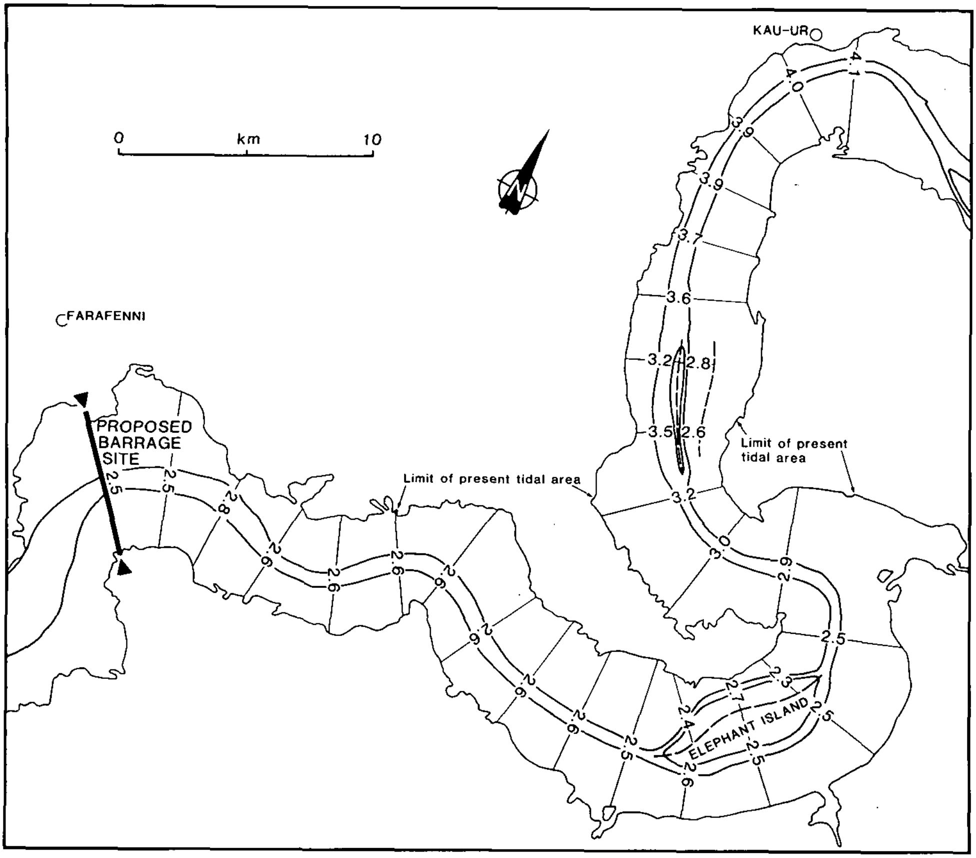

Figure 8. Predicted pH values of the River Gambia upstream of the proposed barrage in mid-July, assuming abstraction of water for 24,000 ha irrigated rice, oxidation at rate T = 10 years for 20 cm peds, and complete washout of acid into the reservoir

More sophisticated calculations could be performed but are hardly justified in view of the many untested assumptions already used. The above is sufficient to indicate the order of magnitude of the problem.

- In the area of sulphide soils upstream of the barrage the development of acidity and changed hydrology will combine to kill the present vegetation and aquatic life.

- Loss of vegetation cover is likely to lead to bank erosion and siltation of the reservoir.
- There are engineering considerations involving the effects of the acidity and high dissolved sulphate content of the reservoir water on steel and concrete structures.
- The ecological effects of the annual flush of acid will extend far downstream of the reservoir and will recur annually for many years.

If the model is correct within an order of magnitude, two alternative design options for the barrage must be considered.

1) Locate the barrage upstream of the most extensive areas of sulphidic soils.
2) A more sophisticated system of water management involving the maintenance of the water level in the reservoir above the sulphide datum. This may be done by the controlled introduction of dense saline water through the barrage into the bottom of the river channel to compensate for the loss of fresh water by abstraction and irrigation (Coode and Partners 1978).

Acknowledgements

We wish to thank Professor C.N. Williams for invaluable assistance and discussion of the problem in the field and Dr. T.M. Wigley for assistance with calculations.

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PROBLEMS OF CLASSIFYING SOILS WITH SULFIDIC HORIZONS IN PENINSULAR MALAYSIA

S. Paramananthan
Department of Agriculture
Peninsular Malaysia, and
B. Gopinathan
Malaysian Agricultural Research and Development Institute
Serdang, Selangor, Malaysia

1 Summary

An acid sulfate soil sequence developed on coastal clay soils in Peninsular Malaysia is described. Soil ripening after the construction of bunds and drains has resulted in the development of sulfuric and cambic horizons. The underlying material is commonly sulfidic. Two similar sequences are recognized, one on marine alluvium, and the other on brackish water deposits. The latter is characterized by higher organic matter content. The problems associated with mapping and classification are noted, and changes in the Soil Taxonomy to cater for the anomalies are proposed.

2 Introduction

Peninsular Malaysia is situated between latitudes 1° 13'N and 7°N and longitudes 99°E and 104° 20'E. The physical relief is dominated by the Central Mountain Range which runs nearly through the middle of the Peninsula. The west coast is dominated by clayey deposits of marine and brackish water origin, while the east coast is dominated by sandy beach ridges. This difference in geomorphology is attributed to the calm seas of the Straits of Malacca off the west coast and the relatively turbulent South China Sea off the east coast.

The coastal clays extend as an almost continuous block along the west coast and is only broken by occasional islands of sedimentary and igneous rocks. The coastal plain varies in width from about 10 km to 50 km. The eastern boundary often grades into peat swamps. The coastal plain which averages in height from 0-15 m above mean sea level is extensively used for agriculture. The agricultural development which began in the early part of this century has been made possible by the construction of a coastal bund to keep out inundation by sea water and the reclamation of these areas by drainage. Rice, rubber, oil palm, coconut, cocoa and coffee are the main crops cultivated on these reclaimed areas. This paper deals mainly with the soils which were developed when large parts of this coastal plain were bunded and drained for the cultivation of perennial crops.

3 Literature Review

Prior to the reconnaissance soil survey of Peninsular Malaysia, very little was known about the coastal clay soils. Dennet (1933) recognized that soils with high concentrations of acid were associated with the nipah palm, and Wilshaw (1940) reports the occurrence of acid conditions on draining coastal soils. Coulter (1952) referred to soils containing considerable amounts of pyrite as gelam (*Melaleuca leucodendron*) soils.

A mixture of circumstantial and intrinsic soil properties was originally used to distinguish potential and actual acid sulfate soils from soils not showing or not expected to develop extreme acidity on drainage and cultivation. Systematic development of morphometric criteria started around 1967 on the basis of experience in comparable tropical countries when the term 'cat clay' or acid sulfate layer as a diagnostic horizon defined tentatively as one with a pH of about 3.3 or less on the air dry-soil and a soluble sulfate content in the air dried soil exceeding 0.1 percent was introduced. The morphometric criteria proposed by Soil Taxonomy (USDA 1974) for sulfidic materials and sulfuric horizons were tested for Malaysian conditions since 1973 using the earlier drafts of Soil Taxonomy when systematic detailed mapping of the coastal plain was initiated by the Soil Survey Section of the Department of Agriculture in West Johore. These studies (Gopinathan 1973, Joseph and Maarof 1975, Paramananthan 1976) made it possible to recognize sequences of development of acid sulfate soils in marine and in brackish water deposits, through a process of ripening. An idealized cross-section across the coastal plain showing this sequential profile development, is presented in Figure 1.

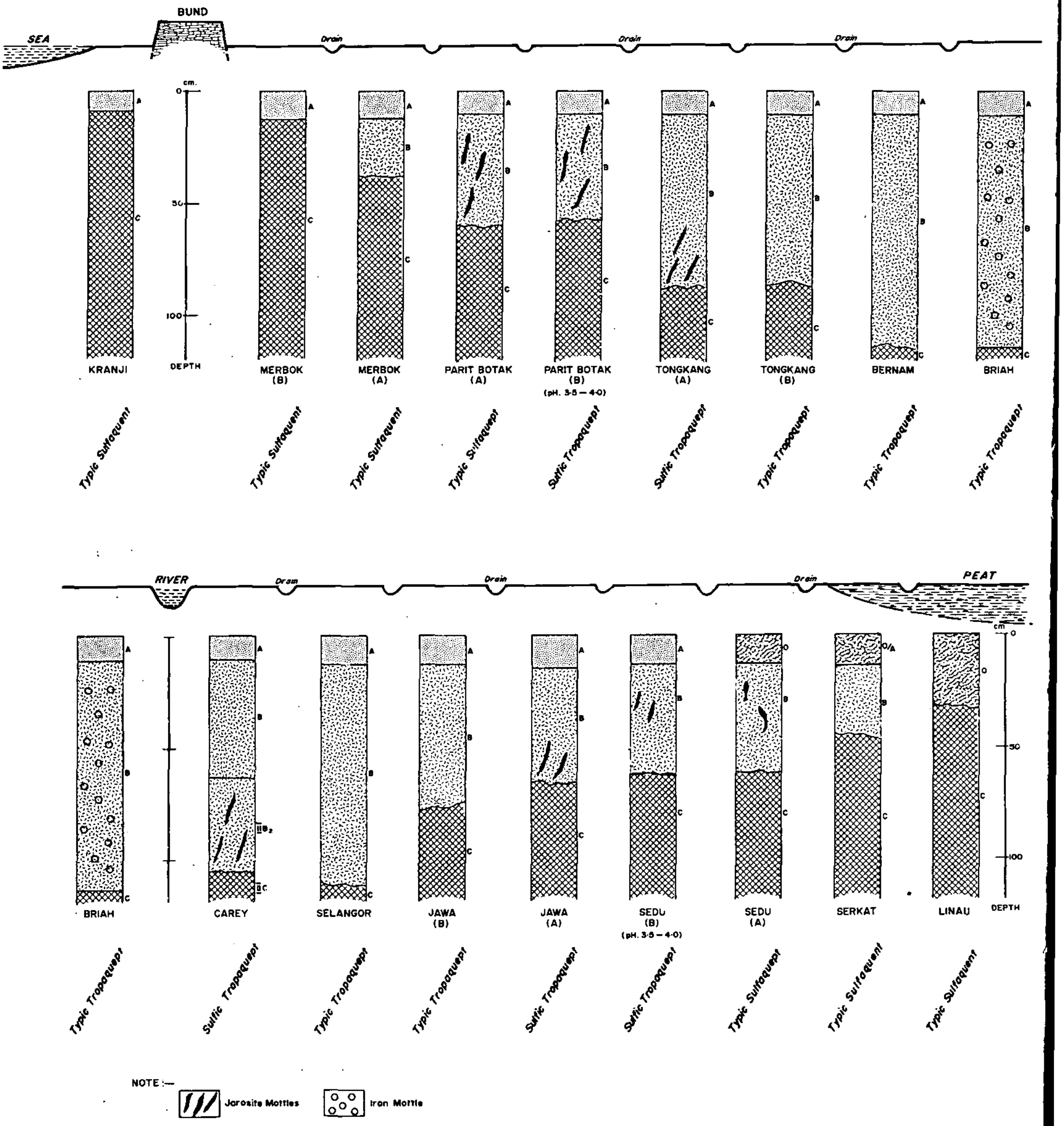


Figure 1. An acid sulfate soil sequence on coastal clays in peninsular Malaysia

4 Profile Development

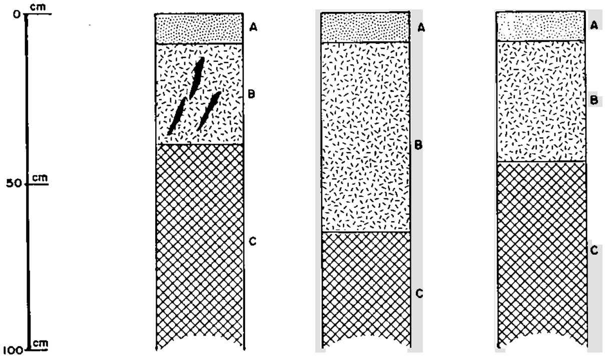
On ripening, the alluvial deposits give rise to the development of cambic or sulfuric horizons with a moderately developed structure and 'n' values < 0.7. Straw-yellow jarositic mottles with hue 2.5 or yellower and chroma of 6 or more are often seen together with strong brown (7.5YR 5/6-5/8) and brownish yellow (10YR 6/6-6/8) mottles, particularly on brackish water deposits, which normally have a high organic matter content. The brown mottles tend to dominate in the upper part of the diagnostic horizon, the straw-yellow in the lower part, the latter often being associated with old root channels. This distribution pattern is most obvious in Sulfic Tropaquepts like Tongkang A (Figure 1). The cambic or sulfuric horizon is normally underlain by a sulfidic C-horizon with 'n' values > 0.7, greenish gray (5GY 6/1) or dark blue (5B 5/1) in colour and with many decomposing pieces of wood and old root channels, through which water flows easily. Depth of the sulfidic C-horizon ranges from less than 50 cm to more than 1 meter.

5 Mapping and Classification

Identification of cambic horizons in the field is normally no problem; neither is the determination of their pH or the recognition of jarositic mottles. Identification of sulfidic soil material, however, remains a practical difficulty as it requires laboratory determinations of at least pH of fresh and incubated samples (Powlson 1976) and preferably, determination of total sulfur. This difficulty complicates identification of superficially developed soils in all clayey alluvial parent material but it can be overcome by organizational methods, and identification and delineation of mapping units henceforth can proceed as a routine operation, once locally applicable field criteria have been defined for the recognition of potential acid sulfate soil horizons.
Difficulties of a more fundamental nature need to be overcome when one tries to correlate mapping units based on local and practical distinguishing criteria, with a world-wide soil classification system, viz. Soil Taxonomy, which strives to express distinguishing criteria of general genetic significance. Acid sulfate soils are anomalous in the sense

that their intensive and rapid chemical dynamics may overrule the more slowly developing properties which are normally accepted as parameters for soil development. In Soil Taxonomy the cambic horizon, which normally is the main diagnostic horizon for the Inceptisols has been overruled in acid sulfate soils by the sulfidic subsoil where its upper limit occurs within 50 cm. The sulfidic material derives its importance from its chemical acidifying potential, to which the genetic significance of the cambic horizon has been sacrificed in this case. In Malaysia several soil series are recognized with sulfidic materials within 50 cm but overlain by well developed cambic and/or sulfuric horizons e.g. Sekat series, Sedu A series (Figure 1). With the present definitions these soil series would partly fit into Typic Sulfaquents, and partly into the Typic Sulfaquepts, although for practical and genetic reasons they are similar, and very different from Typic Sulfaquents without a cambic horizon such as the Linau series. Therefore it does not appear logical to separate them at the order level. A better solution would be to recognize the sulfidic soil material as an indicator of potential acidity, as a secondary diagnostic horizon for the distinction of classes at the subgroup level analogous to the sulfuric horizon, which is subordinate to the cambic horizon in Soil Taxonomy.

With this status also the presence of sulfidic material between 50 cm and 100 cm in Inceptisols without a clear sulfuric horizon, could be given due recognition. With the present criteria such soils are classified as Typic Tropaquepts, e.g. Jawa B and Tongkang B in Figure 1. Hence the authors propose that a sulfidic subgroup be established to indicate soils having a cambic horizon overlying sulfidic material within 1 meter. The above mentioned Jawa B and Tongkang B series would thus be classified as Sulfidic Tropaquept. Soils with sulfidic material within 50 cm but overlain by a well developed cambic and/or sulfuric horizons would then fall into the Sulfidic Tropaquepts and Typic Sulfaquepts respectively (Figure 2).



Soil Taxonomy	Typic Sulfaquent	Typic Tropaquept	Typic Sulfaquent
Proposed Changes	Typic Sulfaquept	Sulfidic Tropaquept	Sulfidic Tropaquept

NOTE:—

/// Jarosite Mottles

Figure 2. Profile morphology to illustrate proposed changes in the Soil Taxonomy

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ACID SULPHATE SOILS OF THE MANGROVE AREA OF SENEGAL AND GAMBIA

C. Marius
Office de la Recherche Scientifique et Technique
Outre-Mer, Paris

1 Summary

The mangrove area of Senegal and Gambia consists of intratidal flats with riverain mangrove forest and 'tannes', e.i. saline marshes partly with bare surfaces. Their soils are acid sulphate soils, very shallowly developed in peaty sulphidic mud clays and sands and subject to tidal flooding. The mangrove area covers a total of 500,000 ha and is concentrated in the estuaries of the Casamance, Gambia and the Saloum. At present mangrove forests are absent in the delta of the Senegal River. Tides are saline throughout the year in the Casamance and Saloum estuaries. In the Gambia and Senegal the river flow pushes back the saline tides during the short rainy season from June/July to September/October. Mean annual rainfall prior to 1972 ranged from 400 mm in the North (Senegal estuary) to 1550 mm in the South (Casamance) but since 1972 decreased to less than 250 and 1200 mm respectively. Over the same period soil salinity and acidity have increased and the tanne areas have expanded at the expense of the mangrove forest.

Soil studies have been conducted since 1960 and have been intensified since about 1967 when acidification problems in newly constructed polders became acute.

Traditional small-scale reclamation involved shallow drainage and controlled flooding with saline water to prevent drying of subsoils during dry seasons. Rice was grown on raised beds constructed with top soil only. The beds were desalinized seasonally with the first rains. Salinity used to be a more serious hazard than acidity in traditional

rice fields.

Modern, large-scale polders were designed to enable total exclusion of saline tides and desalinization of soils by deep drainage and leaching with fresh water stored in upstream reservoirs. This reclamation practice invoked an acidification of the soil that, with the available facilities for water management, could not be kept under control.

The diminishing fresh water supply since 1972 increased both salinity and acidity problems in traditional and modern rice polders. In part of the empoldered areas productivity might be restored by combining controlled saline flooding and cultivation on raised beds with a new system of fresh water management aimed at shallow desalinization and flooding.

2 Introduction

In Senegal and Gambia the mangroves are concentrated in the estuaries of the Saloum, Gambia and Casamance. The mangrove forests along banks and beaches make place inland for 'tannes' e.i. areas without or with only low herbaceous vegetation. Both areas occur on the same tidal flat. The tannes were originally also covered with mangrove forest, much the same as mangrove areas cleared for paddy and salt production. All together they are referred to in Senegal and Gambia as 'the mangrove' and as such cover a total surface of about 500,000 ha (Figure 1).

This includes the estuary of the Senegal River, where mangrove forests and tannes as such have disappeared, but where their sub-recent existence is evident from their remains in the soil.

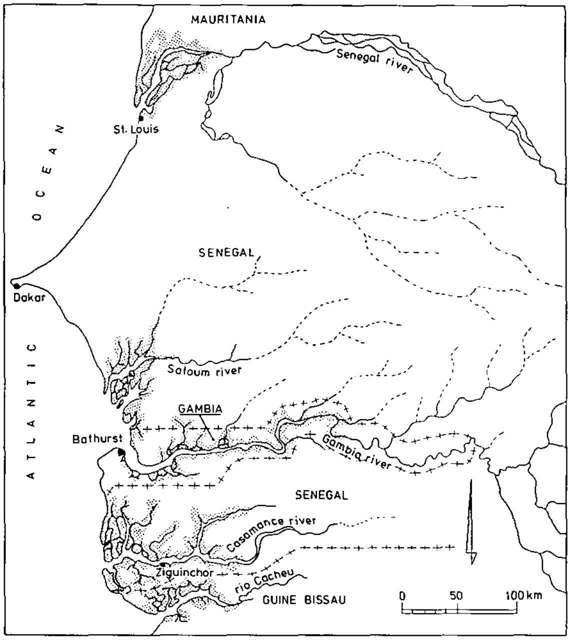

Figure 1. Mangrove area of Senegal and Gambia

The soils of the mangrove area have been studied since the early sixties, mainly in their physiographic context (Bonfils and Faure 1961, Cadillac 1965, Giglioli and Thornton 1965, Charreau et al. 1966, Gaucher 1967, Durand 1967). They were recognized to be predominantly saline acid sulphate soils after acute acidity problems developed in reclamation projects. These problems led to specific studies of the genesis (Vieillefon 1968ab, 1969, 1970a, 1971ab, 1972ab, 1973, 1974, Vieillefon et al. 1973) and the amelioration of these soils (Beye 1972, 1973abcd, Beye et al. 1968, 1975, 1979, Touré 1981, Khouma and Touré 1981). Systematic soil surveys have been conducted since 1972 and at present soil maps on scales 1/50,000 and 1/100,000 and relevant physiographic background information are available for the Casamance (Bodhisane 1974, Marius 1975, Vieillefon 1975, 1977), the Saloum (Marius 1975, Diop 1978), the Gambia (Marius 1976, Dent and Raiswell 1981, Thomas and Varley 1981) and the Senegal (Sedagri 1973, Marius 1975). Detailed maps (scale 1/20,000) have been made for specific reclamation projects (Brouwers 1980, Marius and Aubrun 1980, Daffé and Toujan 1979, Marius 1979, 1980).

The quaternary geology has been studied in detail by Kalck (1978). The dynamic character of the acid sulphate soils has become especially apparent since 1972 when the climate became drier. The concomitant changes in vegetation and soils have been followed by the author from 1973 to 1978. In this paper the main results of these latter studies and of the soil surveys are summarized.

3 Environment

Located between the latitudes 12° and 16° N, the mangroves of Senegal and Gambia are the most northern mangroves of Atlantic type on the West coast of Africa. They extend over about 500,000 ha, half of which are in the estuary of the Casamance and the remainder in the estuaries of the Gambia and the Saloum (Figure 1).

3.1 Climate

The climate is tropical with a long dry season of 7 to 9 months (October/November to May/June) contrasting with a short rainy season of 3 to 5 months (June/July to September/October). Mean annual rainfall (1931-1960) varies from more than 1500 mm in the Casamance (humid-tropical) to 800-1000 mm in The Gambia and Saloum (dry-tropical) to less than 400 mm in the Senegal (semi-arid-tropical). A climatic change toward aridity has taken place in the Sahelian zone since 1968, and has also affected the coastal areas (Table 1).

Table 1. Mean annual rainfall before 1960 and after 1968 (mm) in different deltas

Delta:	Casamance	Gambia	Saloum	Senegal
1931 - 1960	1546	1067	807	373
1968 - 1977	1182	680	605	247

3.2 Vegetation

The dominant tree species in the intertidal zone are characteristic for the West African mangroves: Rhizophora racemosa, Rhizophora mangle, Avicennia africana, Langundularia racemosa and Conocarpus erectus. Among herbaceous plants, mainly the supratidal and marshy 'tannes', the dominant species are Sesuvium portulacastrum, Philoxerus vermicularis, Paspalum vaginatum, Eleocharus mutata and E. Carribea.
Compared to the mangrove vegetation of the more humid coastal areas of Guinea and Sierra Leone, Avicennia nitida is scarce and the 'tanne' areas are larger and more frequently characterised by hyper salinity and the occurrence of bare flats with salt crusts.
A typical sequence of vegetation from river bank to central 'tannes' or to higher upland terraces is as follows (Vieillefon 1969) (Figure 8):

- a thin strip of Rhizophora racemosa;
- Rh. mangle forest;
- Avicennia africana mixed with Rh. mangle;
- a bare flat without any vegetation due to hyper saline conditions, locally called 'tanne vif' and here further on indicated as bare 'tanne';
- a herbaceous marshy flat, locally called 'tanne herbacé' and here: 'herbaceous tanne'.

The presence of fibrous roots of Rhizophora in the soil throughout the sequence indicates that the Avicennia forest and the tanne have replaced the Rhizophora forest. The vegetation sequence therefore has been described as a chronosequence by Vieillefon (1969). In this sequence the boundary between the tanne and the mangrove forest coincided, at the time of description, with the limit of the daily tidal inundations. In the bare 'tanne', only highest tides flooded the surface.
In this latter supratidal zone the salinity of groundwater and soil was the highest of the sequence. The mangrove forest-tanne limit was associated with a steep gradient in the soil salinity but not with any conspicuous drop in soil pH. Although the soils are potential acid sulphate soils, in the natural conditions prior to the recent climatic drying trend, the field pH of soils always exceeded 4.8 in the central tanne and 5.5 at the boundary of mangrove forest and tanne.

3.3 Hydrological patterns

Sedimentary and geomorphic characteristics in the mangrove areas of the Casamance, Gambia and Saloum are largely determined by the tidal currents and to a lesser extent by discharge of the rivers. In the Senegal delta continental influences e.g. wind blown sands, and fluviatile deposits dominate and tidal currents enter only during the dry season. Tidal currents are felt up to 526 km from the mouth of the Gambia, up to 217 km from the mouth of the Casamance. At present the Saloum is only an arm of the sea without appreciable fresh water discharge from the land. Mean tidal amplitudes are of the order of 1 to 1.5 meters, with spring tide amplitudes of maximally 2.5 meters. Storm floods do not occur, though winds and wave-action become forceful during rain storms and cause abrasion of windward banks and beaches. Undercutting of banks by tidal currents and accretion in quiet water are common phenomena.
Currents permanently carry heavy sedimentary loads and in the main channels and along the coast mud banks shift regularly. On wind-exposed banks and beaches sand is sorted out and thrown up as beach ridges by the surf and subsequently is blown up to form dunes.

Tidal flats with mangrove forest build up to slightly below mean high tide level with sediments consisting mainly of heavy clay, except in the Saloum estuary where clay contents are lower and very fine sand predominates.

The Gambia River has an important catchment basin (Figure 1) and a fresh water flow which pushes back the salinity frontier to near the river mouth in the rainy season and dilutes the saline tides in the dry season (Table 2). The Gambia has a main channel that widens regularly towards the ocean, taking up consequently all the affluents of its lower reaches. The mangrove flats line the creek and river banks over a width of a few kilometers and rarely extend to form minor and isolated deltas of islands and networks of channels.

Table 2. Salinity (mS/cm) of main channels (E.C sea water: 46 mS/cm)

	Saloum 1978 35 km upstream	Casamance 1978 60 km upstream	Gambia 1975 130 km upstream
Dry season	115.5	88.7	22.1
Rainy season	68.8	44.7	0.4

The Casamance River (Figure 1, Table 2) has a very small catchment basin and even in the rainy season its flow of fresh water is hardly able to dilute the saline tides. In the dry season the salinity in its main channel is higher than that of sea water. The mangrove areas of the upper tidal reaches are riverain flats of several kilometers width, extending towards the lower reaches to form deltas with islands and reticulate creek patterns and flats over tens of kilometers.

The Saloum estuary (Figure 1, Table 2) consists of large mangrove flats intersected by an intricate network of tidal channels, hardly influenced by river water even during the rainy season. Salinity of the waters exceeds that of sea water throughout the year.

Hydrological conditions in the Senegal estuary are marked by contrasting seasonal alternations of saline tidal regimes and fresh water flooding. Original clayey tidal flats are presently overrun by continental dunes and partly reworked by braiding river courses. Large areas have become land-locked and cut off from tidal influences. Ground waters, however, remain saline.

3.4 Geology

Figure 2 illustrates the typical relations between continental terminal and marine and fluvio-marine deposits of the mangrove area, according to Kalck (1978). In the mangrove area the continental bedrock, mainly sandstone, occurs under unconsolidated mud clays and sands with a depth up to 20 meters. The chemical composition of the muds varies little among the estuaries apart from their SiO_2 content, which is related to varying amounts of quartz (Table 3). The muds are relatively poor in Ca, K and most trace elements.

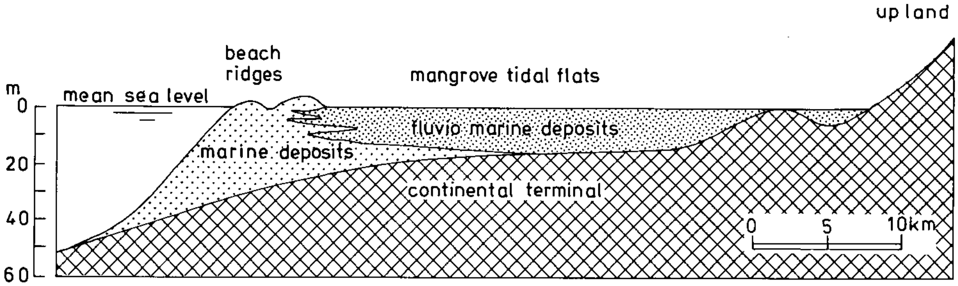

Figure 2. Schematic cross section of the Casamance estuary

Table 3. Mean chemical composition of mud samples

	Samples from mangrove flats			Marine deposits not influenced by mangrove vegetation	
	Casamance 67 samples (%)	Gambia 23 samples (%)	Senegal 15 samples (%)	Casamance 20 samples (%)	Saloum 11 samples (%)
SiO_2	57.7	58.7	64.4	80.2	74.5
Al_2O_3	14.7	15.0	11.1	6.8	7.5
MgO	1.12	0.93	1.30	0.75	0.87
CaO	0.27	0.29	0.78	0.80	2.34
Fe_2O_3	4.67	5.78	5.83	3.03	3.32
Mn_3O_4	0.036	0.101	0.059	0.019	0.015
TiO_2	0.93	1.02	0.63	0.50	0.57
Na_2O	2.53	1.16	2.38	1.15	1.99
K_2O	0.66	0.74	1.23	0.51	0.64
C	2.52	2.27	1.54	0.79	0.55
Loss on ignition	16.2	12.6	10.6	6.0	7.9
	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
Sr	110	116	113	161	271
Ba	95	173	245	60	115
V	85	120	104	68	74
Ni	51	50	50	36	35
Co	21	31	22	17	16
Cr	146	149	154	110	114
B	96	85	81	97	88
Zn	39	60	32	23	19
Ga	22	24	15	15	16
Cu	26	26	37	22	24
Pb	31	36	24	30	26
Sn	34	38	26	20	14

The clay fraction of 0.1-0.5 µm is composed mainly of kaolinite and smectite. The kaolinite is derived from the upland sandstones and the smectite is of marine origin. The relative proportion of these clay minerals in mud samples from all the estuaries enabled the reconstruction of the paleogeographical evolution of the mangrove area (Kalck 1978).

4 Soils

4.1 Profile development

In the Casamance and Gambia estuaries the parent material consists mainly of peaty, sulfidic mud clay; in the Saloum area peaty, sulfidic very fine sandy muds predominate. Total sulphur content is normally above 5%. Pure peat layers are common. The peat consists mainly of fibrous root remains of Rhizophora species. In the sandy muds of Saloum, shell fragments may occur at 80 cm below the present surface.
Profile development (Figure 3) is predominantly shallow and determined by frequent inundations of saline tides, by predominantly shallow ground watertables which exceed 50 cm depth only for short periods, and seasonal acid sulphate soil formation. Physical ripening of the parent material muds is incomplete even in most top soils and structural peds hardly develop. The more conspicuous morphometric differentiation in the profiles pertains to mottling, decomposition of organic matter, activity of living roots and animals and seasonal fluctuations in salinity and acidity. As tidal influence decreases, profile differentiation extends to a greater depth and has a more permanent character due to increased seasonal fluctuations of the ground watertables through precipitation and evapotranspiration. This results in a regular sequence of soil profiles from creek banks inland, concurrent with vegetation sequences which are determined by the same gradient of tidal influences (Figure 3). In the Senegal estuary, soil profile development in the fluviomarine clays is much more advanced due to large seasonal ground water fluctuations and exclusion of tidal influences.

4.2 Physical characteristics (Table 4 a,b)

The bulk of the soil material in the Casamance and the Gambia estuaries is made up of heavy clay with many inclusions of fibrous Rhizophora roots and of coarser woody material. The mineral fraction contains more than 50% clay. Bulk densities of 0.3 to 0.6 are common and water contents are normally above 100%. As a result of a high macroporosity, lateral and vertical permeability is high and tidal waves pervade soil bodies up to several hundreds of meters from the creek banks.

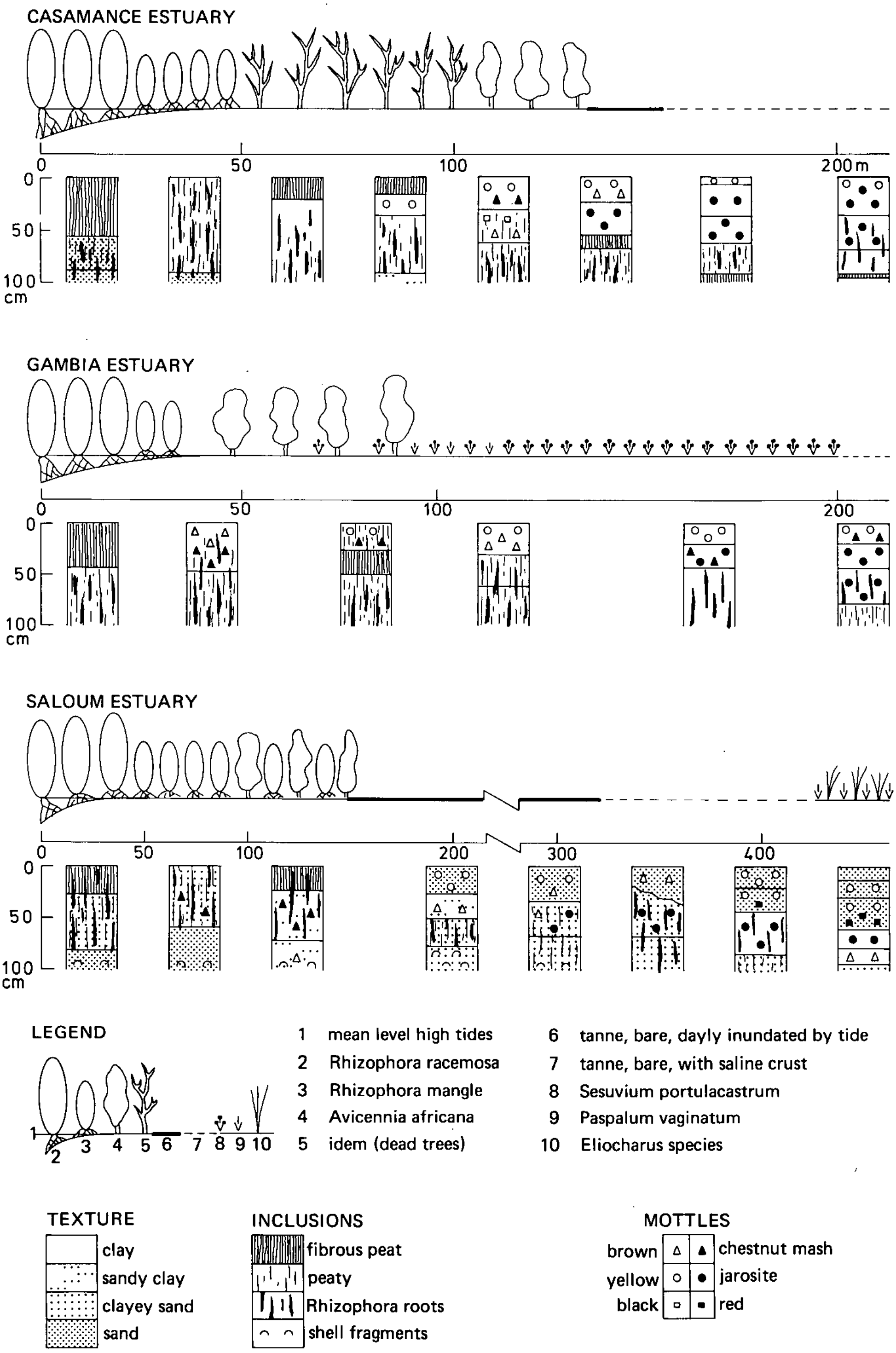

Figure 3. Soil profile development and vegetation sequence

Table 4a. Analytical data of some potentially acid sulphate soils

	Depth cm	Clay %	Silt %	Sand %	Moisture Content %	Bulk density	Eh mV	Soil pH Fresh	Soil pH Air-dried	C%o	N%o	C/N	Fulvic acid. C%o	Humic acid. C%o	Total S %	Saturated extract EC mS/cm	Saturated extract pH	Saturated extract Fe_2O_3 mg/l	Saturated extract Al_2O_3 mg/l
	HALIC SULFIHEMISTS																		
CASAMANCE	0- 20	69.3	23.	1.0	285	0.3	-160	7.	3.	151	4.6	26.	17.2	1.6	4.6	40	4.4		
	50- 70	66.6	29.5	1.1	155	0.4	-180	7.	2.7	97	2.2	16.6	18.7	3.6	4.1	155	2.4	5250	4800
	100-120	64.6	25.3	1.1	139	0.5	-200	6.6	2.7	57	1.7	9.8	20.7	2.2	6.1	160	2.2	2950	3280
GAMBIA	0- 20	54.8	40.8	4.4	320	0.21	-170	7.1	2.1	86	2.7	31.7			5.6				
	50- 70	58.6	37.2	4.2	138	0.43	-190	7.	2.4	44.4	1.6	28.1			5.9	85	3.4		
	80-100	62.1	32.7	5.1	150	0.38	-120	7.2	3.2	28.	1.2	23.1			4.1	61	2.6	785	780
	HALIC SULFAQUENTS																		
CASAMANCE	0- 20	70	27.2	2.8	130	0.56	-170	6.9	3.4	47.8	2.	23.9	2.68	1.88	3.1				
	20- 40	66.8	29.1	4.1			-180	6.6	2.5	47	1.5	31.1	3	2.36	8.8	260	2.6	2950	190
	60- 80	69.6	28.1	2.3	123	0.56	-180	6.6	2.3	25.4	1.	24.7	1.88	1.8	6.2	325	2.4	2300	190
	80-110	72	25.2	2.4			-180	6.6	2.6	22.6	1.	23.3	3.08	0.52	6.6				
GAMBIA	0- 20	64.6	31.2	4.0	85	0.59	-160	6.1	3.6	46.4	2.	22.5	2	1.9	2.6	64	3.7		
	20- 40	66.8	31.9	1.3	170	0.39	-200	6.1	2.5	78	2.8	27.8	4.	2.2	2.8	113	2.7		
	40- 60	66.5	31.7	1.8	173	0.39	-180	6.2	2.7	96	2.6	36.1	4.1	3.	6.0	118	2.5		
	80-100	66.8	32.5	0.7	180	0.38	-180	6.3	2.2	37	1.7	21.4	3.6	4.1	3.1	123	2.9		
SALOUM	0- 20	23	20	56.5	22			7.	3.5	18.2	1.27	14.3			2.1	70			
	20- 40	24	29	47.5	77			7.2	2.	24.2	1.52	15.9			3.2	70			
	60- 80	36.5	25.5	37	77			7.3	2.1	40.6	2.02	20.1			3.7	130			
	80-100	38.6	25	36	123			7.2	2.	52.6	2.75	19.1			3.3	130			
	SULFIC HALAQUENTS																		
SALOUM	0- 20	29.7	7	63.5	127	0.6		6.4	3.5	53.4	1.5	35.6	5.8	2.2	2.1	169	2.6		
	40- 60	27.3	8.4	64.3	108	0.7		6.4	2.7	29.6	0.8	36.4	3.6	1.6	1.9	107	7.7		
	80-100	34	14	52	25	1.5		6.3	6.5	11.7	0.4	31.6	1.08	0.3	0.7	41	7.1		

Table 4b. Analytical data of some acid sulphate soils

	Depth cm	Clay %	Silt %	Sand %	Moisture content %	Bulk density	Eh mV	Soil pH Fresh	Soil pH Air-dried	C‰	N‰	C/N	Fulvic acid. C‰	Humic acid. C‰	Total S %	Saturated extract EC mS/cm	Saturated extract pH	Saturated extract Fe_2O_3 mg/l	Saturated extract Al_2O_3 mg/l
HALIC SULFAQUEPTS																			
CASAMANCE	0- 20	65	29	4.3	67	0.86	380	3.5	3.6	9.8	0.52	18.8	0.6	0.14	2.6	100	3.9		33
	20- 40	63	28	2.9	42	0.91	430	3.2	3.4	13	0.65	20	1.95	1.38	3.8	185	3.4	15	70
	50- 70	62	33.2	2.7	129	0.51	290	3.6	2.6	30.2	1.	29	4.	3.5	3.9	245	2.7	510	1780
	90-110	66	31.2	2.6			210	3.7	2.8	22.2	0.86	25.8	2.36	1.5	4.9	260	2.3		2970
GAMBIA	0- 15	77.4	19.2	3.5	36	0.89	480	3.7	3.5	16	0.9	28.2			0.5	82.1	3.6	31.2	11
	20- 40	77.6	17.8	4.5	71	0.65	580	3.5	3.	8.4	0.5	15.8			2.0	80.	3.4	56.6	18
	50- 70	72.7	23.7	1.6	128	0.47	480	3.6	3.1	10	0.4	22.7			1.1				
	80-100	72	25	4.3	137	0.45	280	3.5	3.1	13.6	0.7	20			0.7				
SALOUM	0- 20	8.9	5.5	82.7				4.	3.6	1.72	0.1	17.2				299	3.5	50	21
	40- 60	32.5	9.8	56.6	51	0.97		3.5	3.6	7.9	0.27	29.3	5.2	4.6	3.9	281	3.1	1200	125
	60- 80	45.4	13.2	41.4	93	0.7		3.6	2.1	26.5	0.64	41.4	4.6	2.5	4.4	365	1.5	2000	1220
	80-100	26.3	15.9	7.8	26	1.3		3.5	2.3	3.1	0.25	12.4	4.3	1.4	2.4	275	1.7	3500	2400
SULFIC HALAQUEPTS																			
CASAMANCE	0- 20						80	5.5	5.4	23	1.3	17.3	1.08	1.08	0.4	27	5.6		
	20- 40				60	0.96	200	5.2	5.3	13.4	0.76	17.6	0.9	1.56	0.6	35	5.4		
	45- 65				81	0.67	250	4.5	2.9	30.2	1.16	26	2.8	3.6	3.2	180	3.1	390	872
	80-100				81	0.67	- 50	4.7	2.6	37.4	1.25	29.9	1.5	2.3	4.5	225	2.6	760	2430
GAMBIA	0- 20	54.6	24.4	21	92	0.62	230	5.6	5.4	34.8	1.7	21	1.7	0.53	0.3	55	7.1		
	20- 40	61.8	25.1	13.1	95	0.63	280	5.7	5.3	30	1.1	27	1.75	0.3	0.5	70	6.5		
	40- 60	67.4	29	3.7	146	0.45	- 10	6.	2.3	70	2.3	30.3	4.	1.27	4.6	142	2.7	276	265
	80-100	52.3	33.8	13.3	148	0.44	-180	6.2	2.1	58	1.8	32	3.95	0.9	6.1	163	2.6	252	645
SALOUM	0- 20	11.6	8.5	77.5					5.	1.6	0.12	13.7	2.85	0.35		150.4	5.8		
	20- 40	28.1	12	68.6	25	1.4		4.4	3.7	8.6	0.32	26.9	4.95	3.32		219	3.6		
	60- 80	32	12	56.2	66	0.9		4.3	2.7	14.4	0.43	33.5	5.2	1.8		274	2.2		
	100-120	43.1	9.7	51.7	75	0.8		5.2	2.4	19.8	0.63	31.4	2.36	0.6		320	2.2		

Physical ripening in this latter zone does not proceed beyond the nearly unripe and half ripe stages (N values 1.0 to 2.0). Deeper inland, in the 'tanne' areas, ripening in the upper 40 cm may reach the nearly ripe stage (N value 0.7 to 1.0), bulk densities, however, remain below 1.0.

The water content of clayey top soils in the 'tanne' areas may fall below 40% and salt crusts may be formed on the surface, but no significant cracking occurs and the structure remains massive with many pores. Soil colours do change with ripening. Matrix colours of the unripe clay are normally dark grey (10 YR 3/1 - 4/1 or N 3/0 - 4/0) and these turn to brownish grey (10 YR 4/2 - 5/2) in the half ripe and nearly ripe horizons. At the same time brown and yellow and, rarely, red mottles appear. Typical is the pale yellow jarosite, initially associated with root remains.

In the Saloum estuary and locally near the mouth of the Casamance River, the patchy occurrence of very fine sandy soil material causes irregular patterns of ripening, water content and bulk density. Textures vary widely among horizons and ripe surface soils and sandy subsoil layers may occur together with half ripe peaty sandy clay horizons.

Structure and mottling of top soils of these sandier soils are similar to those of heavy clay soils.

4.3 Chemical characteristics (Table 4 a,b)

Acidity

Nearly all of the soils of the mangrove area contain potential acid sulphate material within 40 cm of the surface, with total sulphur content exceeding 5% for heavy clay and 2% for sandy mud. Only in the deepest developed profiles potential acidity has about disappeared from the upper 40 cm. In some sandy subsoils potential acidity (pyrite) is exceeded by potential alkalinity (shell fragments). Except for these sediment layers rich in shells, all soil horizons acidify strongly on drying and as a rule air-dried samples give pH values of 2.0-3.5.

Prior to the decrease in annual rainfall since 1972, field pH reached such low levels only in polders and, temporally, in subsoils in the centre of 'tannes' during exceptionally pronounced dry seasons.

At present the field pH in soils of bare tannes with salt crusts, varies between 3.0 and 3.7 down to 100 cm, except for a temporary rise to pH 5 to 6 in the surface soil, shortly after rainstorms or spring tide inundations. In the daily inundated tidal flats field pH varies at present between 5 and 6 against formerly (before 1972) 6 and 7. Along the creek banks field pH values have not changed. Depending on the composition of the creek water, they range from 6.0 to 6.5 for weakly brackish and up to 7.3 for hypersaline tides.

Organic matter

In the soils under Rhizophora forest and in the reduced subsoils of 'tannes', fibrous root remains of Rhizophora are common and often are the most conspicuous constituant of the soil. Organic matter content expressed as C-content of these layers often exceeds 5% and may reach up to 15%. C/N ratios range between 20 and 40 indicating a low degree of decomposition. Fulvic acids normally predominate over humic acids.
In the partly ripened and oxidized top soils of the tannes, considerable decomposition of fibrous root remains has taken place as can be deduced from abundant open pinholes in the massive clay. C-contents in these horizons fall below 3% and C/N ratios below 20.

Sulphur

Sulphur contents of parent materials range from 1 to 4% for mud sands and 3-10% for mud clays. Most of the sulphur comes from micro crystalline clusters of pyrite embedded in organic matter, especially in fibrous root remains of Rhizophora. In the tanne zones, soil horizons with jarosite mottles have lower sulphur contents. The lowest S-contents (below 0.5%) are found in the half ripe or nearly ripe top soils without jarosite mottles. In the jarosite horizons sulphur comes mainly from the jarosite and near the surface from water soluble sulphates and gypsum.
In the Saloum estuary gypsum crystals also occur deeper in the profile.
Elsewhere conspicuous gypsum crystals are found in the powdery saline crusts of bare tannes. In the Casamance, recently with increasing

climatal aridity, at the basis of the powdery crust a thin gypsum bed is formed.

Soluble salts and salinity

All soils of the mangrove area are more or less saline in natural conditions. During the prolonged dry season losses by evapotranspiration are largely balanced by saline tidal water from the creeks. As a result ground waterlevels rarely fall below 50 cm under the surface except in the areas far from the creeks where tidal waves dampen and subsurface lateral influx of saline ground water only partially compensates evapotranspiration losses. Salinity of the ground water increases from the creek banks inward to a level several times that of sea water (Tables 5 and 6). Desalinization during the short rainy season proceeds only superficially in the modal vegetation and soil sequence (Table 5).

Table 5. Electrical conductivity (mS/cm) of saturation extracts of soil sampled at the end of the rainy season

	Mangrove forest		Bare tanne	
	Rhizophora species	Avicennia africana	Inundated daily	With salt crust
Casamance				
0- 20 cm	41	27	45	100
40- 60 cm	155	180	105	185
80-100 cm	160	225	175	260
Gambia				
0- 20 cm	61	45	80	84
50- 70 cm	85	72	82	247
Saloum				
0- 20 cm	169		151	281
40- 60 cm	108		219	299
80-100 cm	41		321	365

Table 6. Analytical data of creek and groundwater in typical vegetation and soil sequences

C = creek, M = mangrove forest with Rhizophora (r) or Avicennia (a),

T = tanne, daily inundated (i) or with saline surface crust (s)

Sequence	pH	EC mS/cm	Cl^-	$\frac{1}{2}\ SO_4^{2-}$	HCO_3	$\frac{1}{2}Ca^{2+}$	$\frac{1}{2}Mg^+$	K^+	Na^+	SiO_2
			mmol/liter							
Casamance Jan. 1978										
C	7.2	45.9	600	105	2.35	23.0	118.4	10.5	510	0.064
Mr	6.2	66.7	920	104	2.11	36.8	192.0	16.4	780	0.100
Mr+a	6.4	84.0	1260	128	1.66	42.8	262.4	22.0	1080	0.160
Ma	6.6	77.5	1120	122	1.55	44.8	233.6	19.6	940	0.136
Ti	4.3	86.2	1300	127	-	33.6	275.2	22.2	1090	1.060
Ts	3.6	103.1	1690	230	-	35.2	451.2	18.6	1430	1.340
Gambia May 1978										
C	7.6	43.7	360	51.4	0.9	11.6	72	10.5	340	0.18
Mr	7.9	40.1	344	42.9	2.0	11.2	72	9.6	310	0.19
Mr+a	7.9	45.3	400	60.0	1.5	13.2	112	11.9	350	0.12
Ma	8.0	49.7	424	51.4	1.6	13.6	84	12.8	380	0.60
Ti	3.5	75.0	676	85.7	-	28.4	148	16	590	1.06
Ts	2.8	107.8	1000	128.6	-	44.0	224	24	820	1.33
Saloum March 1978										
C	8.0	88.1	800	80.6	2.6	29.2	176	14.2	665	0.03
Mr	8.0	97.0	800	92.3	2.6	29.6	184	15.4	665	
Ma	8.0	127.0	1160	128.6	3.7	39.8	272	21.0	1000	0.20
Ti	7.5	197.2	1760	171.4	1.2	41.8	416	34	1500	0.42
Ti+s	4.3	212.3	1860	162.8	-	37.6	428	38	1600	0.70
Ts	3.5	283.0	2600	214.3	-	41.2	536	52	2300	1.09

Table 6 demonstrates that both highest salinity and acidity occur in the bare tannes with salt crusts at the surface e.i. in the zone where, during the dry season, evapotranspiration exceeds replenishment by tidal water and where the pyritic subsoil is liable to be exposed to the atmosphere to greater depth.

The increase in dissolved sulphate during the formation of hyper saline ground water is less than the increase in chloride, even though considerable amounts of sulphate must be liberated during pyrite oxidation under these conditions (Table 6). Sulphate concentrations are probably kept relatively low by precipitation of gypsum and jarosite, which are very conspicuous in these soils.

Dissolved SiO_2 in the ground water increases both absolutely and proportionally (to Cl^-) when going from creek banks to tanne centres. In view of the presence of silicified Rhizophora roots in bare tannes (Marius 1976) its concentration probably exceeds the amorphous silica solubility (2 mmol/l) at times. In the very acid tanne centres dissolution of silicates (clay minerals) is probably the source of dissolved silica.

In aqueous extracts of subsoil samples, which turn extremely acid (pH 2.5-3) in the laboratory, soluble iron and aluminum may reach contents of up to 3.5 g Fe or 2.5 g Al per litre. Under natural conditions in the field, the pH normally does not fall below 3.2 and concentrations will probably not rise above about 700 mg Fe/litre and 50 mg Al/litre. However, introduction of drainage systems might cause much more extreme acidification in the field, with concomitant higher levels of soluble Fe and Al.

4.4 Soil classification

The regular soil sequence between creek banks and tanne centres comprises potential and actual acid sulphate soils and sometimes para acid sulphate soils that are strongly saline and locally hypersaline. Soil samples from the whole profile under the mangrove forest and from depths below 40 cm in tanne areas usually have sulphur contents exceeding 0.75%, N values over 1.0 and a pH of the air-dried soil below 3.5. Soils in tannes may have jarosite mottles in the upper horizons. In terms of

Soil Taxonomy these acid sulphate soils are Halic Sulfaquepts and the potentially acid soils are Halic Sulfaquents. Where fibrous peaty sulfidic clays under Rhizophora have more than 30% organic matter over more than half of the profile depth, soils are classified as Halic Sulfihemists.
In the deepest developed soils the pH of the surface layer may be above 4.0, but decreases with depth to 3.5 at 50 cm below the surface and jarosite mottles are common. These soils are Sulfic Halaquepts.
Desalinized acid sulphate soils with very ripe brown and red mottled surface horizons, jarositic subsurface horizons and with a pH of the air-dried soil between 3.5 and 4.0 within 50 cm depth, occur locally in the Senegal delta and in some valleys of the Casamance (Baila) in older terraces. These soils are about the most developed acid sulphate soils of Senegal and belong to the Sulfic Tropaquepts of the Soil Taxonomy.

In literature on the soils of the mangrove area of Senegal and Gambia, frequently other soil classification systems have been applied. Table 7 presents an attempt to correlate the more commonly used of these systems.

Table 7. Correlation of soil classifications

Soil Taxonomy	FAO	CPCS[1]	ORSTOM[2]
Sulfihemist	Thionic Fluvisol	Sols hydromorphes organiques-tourbeux-eutrophe	Halithiosol organique
Halic Sulfaquent	Thionic Fluvisol	Sols hydromorphes moyennement organiques	Halithiosol halique
		Sols peu évolués non-climatiques-d'apport salés	
		Sols humiques à gley-salés	Halisol sulfuré
Halic Sulfaquept	Gleyic Solontchak	Sols halomorphes à structure non dégradée-salins-acidifiés	Halisulfosol halique
Sulfic Halaquept	Gleyic Solontchak	Sols halomorphes à structure non dégradée-salins-acidifiés	Halisol acidosulfaté
Sulfic Tropaquept	Dystric Gleysol	Sols hydromorphes minéraux -à gley	

[1] Commission de Pédologie et de Cartographie des Sols, Paris, 1967

[2] Office de la Récherche Scientifique et Technique Outre-Mer (Proposal) (Ségalen et al. 1979)

5 Changes in soil conditions as a result of increased climatic aridity

Since 1972 the annual rainfall in Senegal and Gambia has decreased by about 25-40% compared to the long term mean up to that year (Table 1). In the mangrove area changes in vegetation became conspicuous. The author monitored these environmental changes from 1973 through 1978 with special emphasis on a sequence of vegetation and soil in Lower Casamance that had been studied in detail earlier (1967-1971) by Vieillefon (1969, 1972b). The main changes observed will be summarized in the following. They are illustrated by Table 8.

Table 8. Changes in vegetation, pH of soil in situ and salinity of ground water (mS/cm) in the mangrove area of Senegal due to advance of climatal aridity since 1971

May 1971, dry season

Vegetation sequence:	Rhizophora forest	Avicennia africana	Tanne	
	Rh. racemosa Rh. mangle + Paspalum	+ Scirpus + Sesuvium + Philoxerus	Bare saline crust	Herbaceous Eleocharus
10 cm	6.6	6.9	6.7	5.6
pH 50 cm	7.1	5.8	5.8	5.4
90 cm	6.9	5.6	4.9	5.2
Salinity	50	70	90-100	80

May 1974, dry season

Vegetation sequence:	Dead trees	Tanne		
	Bare surface Patches of Sesuvium Paspalum+Eleocharus	Closed cover of Sesuvium	Bare saline crust	Bare saline crust
10 cm	5.7	5.5	3.3	4.3
pH 50 cm	5.9	3.5	3.0	4.6
90 cm	5.9	4.8	3.4	6.0
Salinity	95	115	130	130

May 1978, dry season

Vegetation sequence:	Bare surface	Tanne		
		Closed cover of Sesuvium + Eleocharus + Conocarpus	Bare saline crust	Bare saline crust
10 cm	5.3	4.1	3.0	5.3
pH 50 cm	5.3	3.6	3.2	3.4
90 cm	6.0	4.1	3.3	4.4
Salinity	150	150	125	105

November 1978, rainy season

Vegetation sequence:	Bare surface	Avicennia africana regrowth	Tanne		
		+ Sesuvium	Eleocharus, Sporobolus + Sesuvium + Bacopa	Bare saline crust	Bare saline crust
10 cm		6.2	5.2	3.5	3.2
pH 50 cm		5.6	4.5	3.4	3.3
90 cm		5.6	4.7	3.4	3.7
Salinity		20	35	115	90

As a result of the drought, evapotranspiration deficits during the dry season increased and in the mangrove area soil salinity increased. On the other hand the tidal effects were damped at closer distance from the creek banks so that groundwater fell to lower levels especially towards the central parts of the tannes.

In the Rhizophora zones along creek banks, the salinity used to be similar to that of the creek water, but tripled after the drought.

In the intermediate zone with Avicennia africana trees and halophitic herbs, both salinity and acidity increased.

The soils along the creek banks did not show conspicuous changes in horizon development, apart from the rise in salinity during the prolonged dry periods and a slight drop in pH. In the centre of the tannes the relative increase in salinity was less, but here lowering of the ground water level brought about further oxidation of sulphidic subsoil resulting in extreme acidification that even affected the top soil. At the same time the profile deepened slightly, and some ripening of subsoils and segregation of brown mottles took place. In the topsoil salt crusts replaced shallow Al horizons in places where the herbaceous vegetation had died. Gypsum crystals became very conspicuous near and on the surface and white powdered silicified roots, identified as opal-crystobalite, became a normal phenomenon.

The changes in vegetation were much more spectacular. The Rhizophora forest died leaving bare flats that later on were partly colonized by Avicennia africana trees together with herbaceous patches of Sesusivium portulacastrum from the adjacent land inward zone. In the original Avicennia africana zone all trees died and all herbaceous species except Sesuvium disappeared. In the original herbaceous tanne all vegetation died and the surface became encrusted with salts as in the adjacent bare tanne. Some of the herbaceous species later on reappeared in the Avicennia africana zone together with Sesuvium. The general trend was for the forest to disappear and for the bare flats, especially the salt crusted bare tanne, to expand at the cost of the herbaceous tanne (Figures 4, 5, 6, 7, 8 and 9).

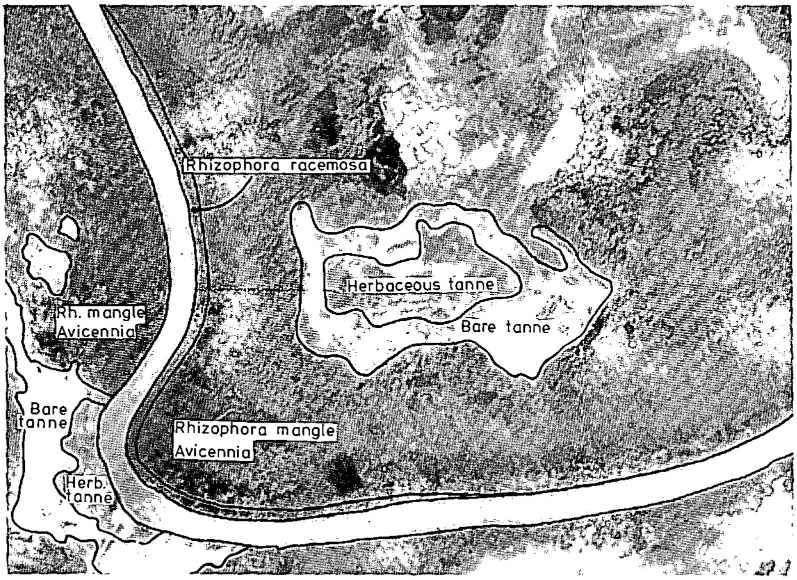

Figure 4. Aerial photograph of mangrove forest and tanne association near Balingoré (Casamance) in 1969

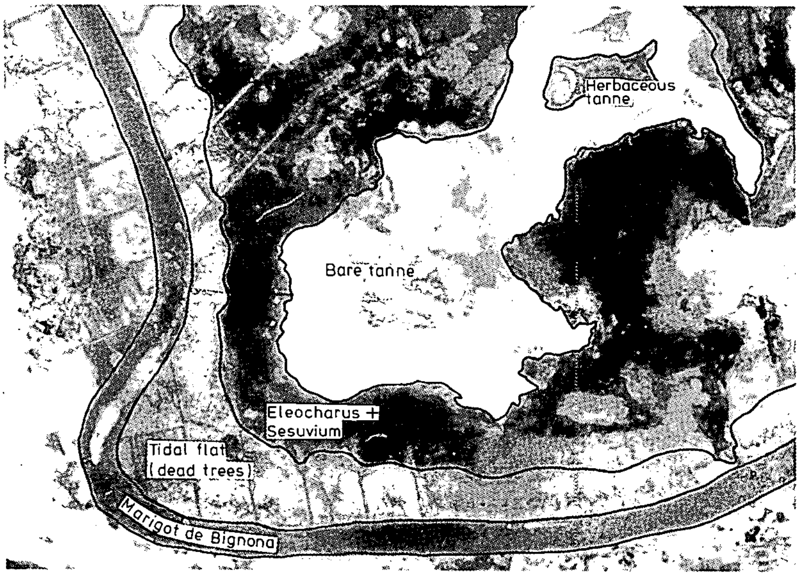

Figure 5. Aerial photograph of same area of Figure 4, but taken in 1978, showing shifts in vegetation boundaries

Figure 6. Changes in vegetation in mangrove area in the Casamance, Situation in 1978. Remains of former Rhizophora mangle and Avicennia africana forest, died since 1972 due to increasing soil salinity and acidity. In the background a narrow strip of surviving Rhizophora racemosa on the very bank of the creek.

Figure 7. Changes in vegetation in the mangrove area in the Casamance. Situation in 1978. Bare tanne. In the foreground algal remains on saline crust, which appears shiny white in the central section. The darker bare surface along the remaining forest prior to 1972 was covered with mangrove forest (Figure 6) and is daily inundated by the tide.

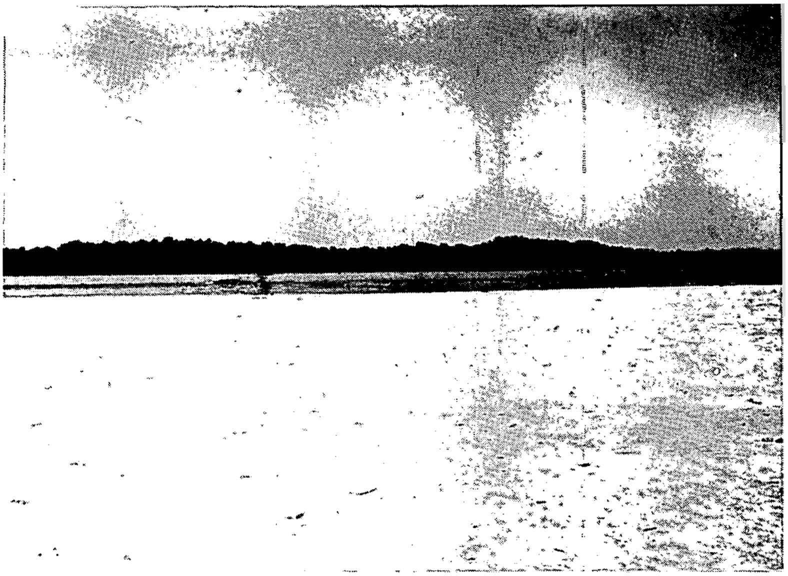

Figure 8. Soil sequence in Saloum estuary: Rh. racemosa, Rh. mangle, bare tanne daily inundated

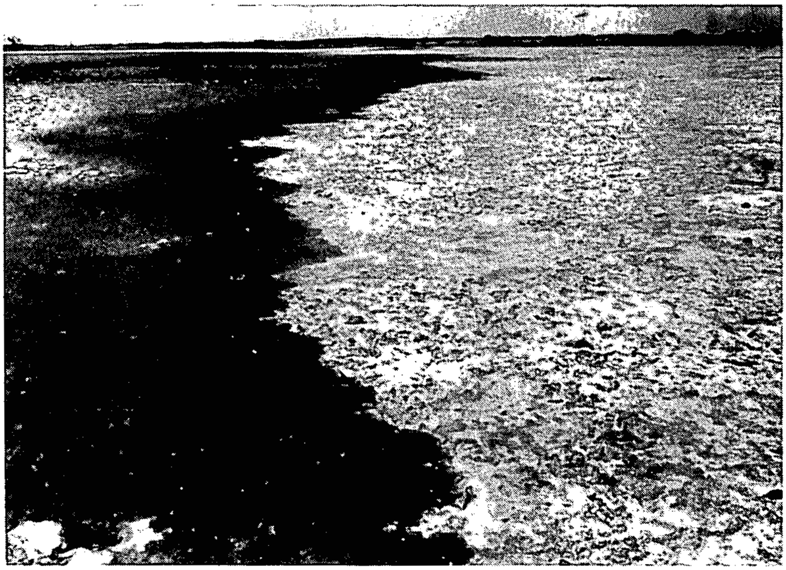

Figure 9. Saloum estuary:
left: bare tanne inundated
right: bare tanne with saline crust

These dramatic changes in vegetation and soil that were triggered off by a sequence of few dry years with annual mean rainfall 25% below that of prior periods, demonstrate the delicate character of the natural ecological equilibrium in the mangrove area. Similar changes have taken place in the past as is indicated by root remains in the soil. Reverse changes, towards less saline and less acid soil conditions and increased tree cover, might also have taken place in periods with either more precipitation or intensified flushing by tides or river water.

A new natural equilibrium of soil and vegetation will probably establish with time. The new salinity level has probably been reached already. Sulfuric acid will continue to be released temporarily as long as residual potential acidity remains in the subsoil horizon that is exposed to the atmosphere during lower ground water levels. Actual soil acidity during dry periods can be expected to decrease when the seasonal release of free acids has decreased to a level that can be balanced by neutralization or immobilization in the soil profile or by removal with floods. Ultimately a pH between 5 and 6 might be reached again.

6 Traditional rice polders and modern reclamation projects in the mangrove area

Seafood, seasalt and rice are the main products of the mangrove area in Senegal and Gambia. The flat relief of the intertidal clay flats and the regularity of tidal amplitudes facilitate the construction of small-scale polders, dikes and canals and the water management in salinas, paddy fields and fishponds. The mangrove forest provides wood for fuel, construction of boats, houses, sluices and implements. Transportation by boat is favoured by the omnipresence of interconnected waterways and the regularity of recurrent winds and tides.

At least 1500 mm of rain is required for a marginal crop of rainfed rice in the saline soils of the mangrove area. In the Senegal and Saloum estuaries the climate is too dry for rice and here fishery is the major traditional basis for subsistence. In the Gambia and the Casamance natural conditions at least were favourable for paddy production. In the Gambia fresh water is supplied by rain and river together, in the Casamance by rain alone. With the decrease of the mean annual precipitation from 1546 mm prior to 1972 to less than 1200 mm lately, rice production in the Casamance estuary has become risky.

The traditional water management and cultural practice in the Casamance were well adapted to the prevailing conditions. For rice polders Rhizophora forest zones were preferred, the salinity of which used to be the lowest of the normal soil sequence (Table 8, May 1971). Dikes of 1 to 1.5 m high with crests about 20 cm above maximum spring tide level, were built up with clay excavated from a trench along the dike. For sluices hollow tree trunks, preferable of palms, were embedded at various levels in the dike body, allowing maintenance of various water levels in the polder. The lowest sluice was situated below the original surface with its outlet in the trench. For gates fibrous stops impregnated with clay were used and sometimes wooden flap gates.

After closing the dike, clearing was done in the superficially drained polder. The cut wood was transported for use elsewhere, remaining stumps and roots were removed carefully from the soil and locally dried and burned. Then a grid of superficial ditches was dug and the excavated flat topsoil clods were laid on the interjacent surface areas to form raised cambered beds a few square meters each.

Desalinization by alternative flooding and flushing with rain water for one or two rainy seasons was necessary for successful growth of transplanted rice. Thorough drying of the soil during the dry season was prevented by letting in saline water into the superficial ditches, without flooding the beds. Regular annual desalinization of the topsoil could be taken care of by the first heavy rains of the season.

Empoldering normally started at the inland side of the Rhizophora zone and later expanded towards the river bank (Figure 10). In areas with strongly erosive tidal currents the rice polders were protected by a series of peripheral polders the forest of which would not be cut for several years, although initial desalinization would proceed. Moreover, outer dikes were constructed several tens of meters from the banks, leaving a fringe of mangrove forest in the front land.

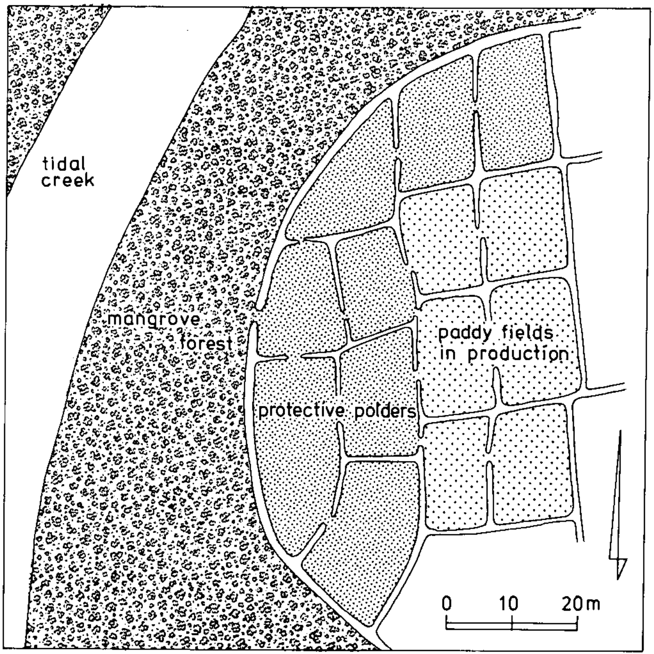

Figure 10. Traditional rice polders in the Casamance estuary (after Pelissier 1966)

This traditional system could not cope effectively with the enhanced salinity after the climatic drying started in 1972. Also the system was not well-suited for modern capital-intensive practices, such as transportation by road, irrigation from reservoirs, etc., which require organizational centralization.

Large-scale reclamation projects for paddy production have been proposed and realized even before 1972. The more important of these are situated in the Lower Casamance where the mangrove flats penetrate into the valleys of tributaries such as the Kamobeul, Guidel, Bignona, Baila and Soungrougrou. Upstream of the tidal area the valleys are dammed to regulate the fresh water supply. Downstreams where the valley widens to the estuary, a concrete dam with wooden gates is constructed in the riverbed to exclude saline tides and increase drainage capacity, for intensive leaching of salts from the upstream mangrove area, now provided with integrated drainage and road systems and cleared and prepared for paddy production. Soil salinity was considered the main problem and potential acidity was underestimated.

The intensive initial leaching and desalinization of the mangrove flats has provoked extreme acidification in several of these reclamation projects. In some polders reclaimed in 1967 the pH of the topsoil dropped as low as 2.7 in 1971 (Beye 1972). Since 1972 decreasing rainfall hampered desalinization and caused increased acidification. Many of the large polders were affected by the climatic change even much more severely than the traditional rainfed paddy fields, where deep drainage was never practised.

In retrospect one might conclude that the over-emphasis on correcting salinity in the polders led to over-drainage, and, like most overdosing of remedies applied to subtle dynamic systems, it resulted in the reverse of the effect aimed at.

In this context some other negative effects of the abrupt exclusion of saline tides should be pointed out. Open waters acidified or polluted otherwise, shrimp and seafood in general became scarce and diseases formerly nearly unknown in the mangrove area, e.g. dysentery, bilharziosis, typhoid fevers, became endemic.

It is evident that many of the rice polders cannot function well on the basis of the original criteria for reclamation, layout and water management. The changes in climate alone require that criteria be adapted to a situation in which less fresh water is available per surface unit and where potential soil acidity is at least as serious a limiting factor as hypersalinity. Increased competition for fresh water is likely to create also the need for organizational adaptation.

From the technical point of view and on the basis of the present knowledge of soils and their dynamics, some recommendations for improvement of the rice polders can be suggested. Improvement measures should involve more efficient use of available fresh water and a more superficial drainage system. These two requirements can be combined by limiting desalinization to the upper soil layers only and by developing and applying cultural practices that decrease the contamination of the topsoil with salts, acids and other toxic constituents from the subsoil. Rice varieties tolerant to the prevailing stresses, and cultural calenders adapted to periodicity of stresses, should also be developed and applied.

Separated irrigation and drainage systems could improve water use efficiency. Moderately saline water can be used to leach salts from more saline soils. Initial leaching of hypersaline subsoils should be done with brackish water or even normal saline seawater rather than with fresh irrigation water. Rainfall should be used as much as possible for leaching of topsoils as is done in the traditional rice polders.

Levels of water in canals and fields and their salinity and acidity should be monitored as measures for control and management. Presence and location and especially the depth of potentially acid pyritic soil layers should be known before reclamation projects are designed.

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CHEMICAL CHARACTERISTICS AND FERTILITY STATUS OF ACID SULPHATE SOILS OF THAILAND

Tasnee Attanandana & Sorasith Vacharotayan
Department of Soils, Kasetsart University
Bangkok, Thailand
Kazutake Kyuma
Laboratory of Soils, Kyoto University
Kyoto, Japan

1 Summary

Topsoils of two Typic Tropaquepts (Ratchaburi and Bangkok series) and three Sulfic Tropaquepts (Sena and Rangsit series and Rangsit very acid phase) were analysed and planted to rice in pots to study their intrinsic fertility status through response to N, P and K fertilizer and nutrient uptake of plants. Moreover, for Rangsit very acid soil the effect of liming on fertility status was tested.

The sampled soils are common rice soils of the Central Plain of Thailand. The Typic Tropaquepts are rated very well suited for paddy production, and the Sena, Rangsit and Rangsit very acid soils are rated respectively as well, moderately and poorly suited. Intrinsic chemical characteristics and fertility status of the topsoils as determined in laboratory and greenhouse are discussed in relation to these suitability ratings that pertain to plant performance in field conditions.

The chemical characteristics reflect mainly sedimentary origin and acidity of the topsoils. Rangsit very acid soil stands out by lowest pH (3.9), highest total S and extractable Al, and lowest values for total CaO and MnO_2, extractable Fe and Mn and available P, Ca and Si, contrasting with the opposite ranking for the least acid (pH 5.8) Ratchaburi soil.

Without fertilizers, rice planted in Rangsit very acid soil died shortly after transplanting also when lime was applied at a rate of 13 tons of marl per ha. On the other soils rice survived into maturity to give yields (expressed in dry matter) on the same level regardless of

variations in acidity or available nutrients.

All soils responded to complete NPK fertilization, but maximum yields for Rangsit very acid soil stayed 30% (with lime 20%) below the maximum level reached in the other soils, the latter being about 8 times the unfertilized yield.

On the Typic Tropaquepts maximum yields were reached at relatively low levels of N and especially of P. The Sulfic Tropaquepts required higher levels, especially of P. The Rangsit very acid soil, with or without lime, was the only soil not responding to any fertilization in the absence of P. A primary dosis of P alone raised its yield only to the level reached by the other soils in the unfertilized treatments.

The relatively poor performance of rice on Rangsit very acid soil was reflected in nutritional element composition of the plants. They were very high in Al, S and Na and low in P, Si, Mg, Ca and K, compared to plants grown on the other soils. With complete fertilizer and liming the differences for P, Mg, Ca, Al and S decreased but also the best performing plants on limed and fertilized Rangsit very acid soil remained relatively low in P and Si. No abnormally high Fe contents of plants nor symptoms of iron toxicity were observed.

From the combined results it is concluded that of the three acid sulfate soils studied, only Rangsit very acid soil has intrinsic topsoil properties that cause poor plant performance. The topsoils of Rangsit and Sena soils, although strongly acid, have a potential productivity at least equal to that of the moderately and weakly acid Bangkok and Ratchaburi soils. The differences in suitability ratings for these latter four soil series, based on plant performance in the field, must be due to external causes such as water management or subsoil influences.

Improving the productivity of Rangsit very acid soil requires changing the intrinsic properties of its topsoil, especially reducing its extreme acidity and subsequently raising its phosphorus status, e.g. by increasing the frequency of draining off overlying water combined with application of lime and subsequently of rock phosphate.

2 Introduction

The Bangkok Plain is the main rice growing area of Thailand. This plain is essentially a river valley widening to a coastal plain and crossed by various bifurcations of the rivers and tidal channels.

During the rice growing season the plain is inundated by river floods and rain water, water levels in dry seasons are predominantly below 100 cm under the surface. Under the prevailing conditions of individual water management for single rice fields, one crop per year is the rule and production ranges between 0.5-2.5 ton of paddy per ha. Lowest productivity (0.5-1.5 ton paddy/ha) is associated with a large complex of nearly 590,000 ha of acid sulphate soils in the central part of the Bangkok Plain.

These acid sulphate soils have predominantly well developed soil profiles with characteristics of Sulfic Tropaquepts. They developed in pyritic (1-2.5% sulphur) non calcareous gray clays, deposited in brackish tidal environment 3000-7000 years ago. More recent fluviatile and marine deposits of adjacent upstream and downstream parts of the Plain gave rise to soils without acid sulphate conditions, of higher productive potential, and characteristics of predominantly Typic Tropaquepts.

The relation between soil units and soil productivity has been established on the basis of mainly morphometric criteria and statistical data correlated during surveys of land and soil.

The processes involved in soil genesis of the acid sulphate soils of the Central Plain and their behaviour on flooding and drying have been studied by van Breemen (1976) and their fertility amelioration by Ponnamperuma et al. (1972) and Attanandana et al. (1977). Fertility studies concerned predominantly trials under greenhouse conditions.

These studies have shown that acid sulphate soils in the Central Plain in Thailand are generally well developed physically, but their high acidity retards microbiological activity, and their phosphorus absorption coefficient is high. As possible causes of poor plant performance in wet land rice cultivation have been distinguished aluminium and iron toxicity and deficiencies of N, P, Si and Mn. The degree of deficiencies and productive limitations varies widely, and the relation between plant performance under field conditions and conditions in the greenhouse has until recent not been systematically investigated. The present study is one of the first attempts in this direction.

This study is aimed at relating the productivity of some major acid sulphate soil units as established for field conditions, with chemical characteristics and fertility status of their topsoils as defined by laboratory analyses and greenhouse tests.

Van der Kevie and Yenmanas (1972) assign the soil series of the Central Plain to four classes of suitability for paddy production: poorly, moderately, well and very well suited for paddy production. The acid sulphate soils belong to the classes of poorly, moderately and well suited for paddy production (Table 1). For each of these three productivity classes the dominant acid sulphate soil unit was selected for sampling. To cover a complete series of productivity classes, in addition, two non-acid sulphate soil units, rated very well suited for paddy production, were selected, one with riverain parent material and one developed on calcareous marine deposits.

Table 1. Acid sulphate soils in the central plain of Thailand (modified from Van der Kevie and Yenmanas 1972)

Suitability for paddy production	Soil series	Area (ha)	% of total area
Well suited	1. Maha Phot	62,664	10.6
	2. Ayutthaya	78,205	13.3
	3. Ayutthaya/Maha Phot complex	7,475	1.3
	4. *Sena**	147,814	25.1
	5. Tha Khwang	419	-
	(subtotal	296,578)	(50.4)
Moderately to well suited	6. Sena/Rangsit complex	13,062	2.2
Moderately suited	7. *Rangsit**	180,222	30.6
	8. Rangsit high phase	168	-
	9. Thanyaburi	26,518	4.5
	(subtotal	206,909)	(35.1)
Poorly suited	10. *Rangsit very acid phase**	51,240	8.7
	11. Ongkharak	12,323	2.1
	12. Cha-am	8.811	1.5
	(subtotal	72,374)	(12.3)
	TOTAL	588,923	100.0

* Selected for sampling for this study

In this series the class of poorly suited for paddy production was represented by the soil unit named Rangsit very acid phase, a known problem soil occupying more than 50,000 ha. This soil was given special attention in the study in an attempt to assess the possibilities of its amelioration.

The study concentrated on topsoils, which were analysed for major inherent properties and their fertility tested in a pot trial including various nitrogen and phosphorus fertilization treatments and for Rangsit very acid phase also a liming treatment. Plant performance was determined by weighing plant dry matter and analysing plant material for nutrient elements.

3 Materials and procedures

The following soil units were sampled for the study:

Ratchaburi, a Typic Tropaquept with fluviatile parentmaterial, rated very well suited for paddy production.

Bangkok, Typic Tropaquept developed in marine clay with calcareous subsoil, rated very well suited for paddy production.

Sena, Sulfic Tropaquept, rated well suited for paddy production.

Rangsit, Sulfic Tropaquept, rated moderately suited for paddy production.

Rangsit, very acid phase (RVAP for short). Sulfic Tropaquept, rated poorly suited for paddy production.

These soil units and their productivity rating have been defined by Van der Kevie and Yenmanas (1972). The pedons sampled were identified by checking the profile at the sampling sites.

During sampling, ground water levels were at 150 cm beneath the soil surface, except in the Bangkok Soil, where the ground water level was at 80 cm.

Samples were taken in pits from each horizon by auger. About 1200 kg of topsoils (Apg or 0-25 cm) was collected with a spade for each soil unit, except in case of RVAP, of which about 2400 kg was collected. They were air-dried and lightly crushed for the pot experiment. Samples for analysis were also air-dried and stored in plastic bags.

Topsoil samples were analysed for relevant chemical constituents, texture and clay minerals. Results and analytical methods are given in Tables 2, 3 and 4.

Table 2. Textural class and clay mineral composition of surface soils

		Clay mineral composition in %		
Soil series	Textural class	7 Å clay min	10 Å clay min	14 Å clay min
Ratchaburi	silty clay loam	50	25	25
Bangkok	clay	25	20	55
Sena	clay	55	15	30
Rangsit	clay	50	10	40
Rangsit very acid phase (RVAP)	clay	65	10	25

Table 3. Contents of selected elements in the surface soils (by X-ray fluorescence, Norrish and Chappel 1977, Wakatsuki and Furkawa 1978)

Soil series	CaO %	MgO %	MnO_2 %	K_2O %	P_2O_5 %	S ppm	Zn ppm	Cu ppm
Ratchaburi	0.5	1.9	0.13	2.6	0.11	181	60	9
Bangkok	0.4	1.3	0.02	2.3	0.04	1131	46	63
Sena	0.6	2.3	0.05	1.6	0.06	1281	53	13
Rangsit	0.4	1.5	0.03	1.7	0.04	706	36	73
RVAP	0.05	2.2	0.02	1.7	0.05	5235	111	59

Table 4. Chemical and available nutrient characteristics of surface soils

	Soil series				
	Ratchaburi	Bangkok	Sena	Rangsit	RVAP
pH	5.8	5.2	4.7	4.8	3.9
Organic matter[1]	1.5	1.3	2.2	2.1	3.1
P (ppm)[2]	50.8	23.6	9.6	10.5	6.1
K (me/100 g)[3]	0.16	0.67	0.42	0.37	0.17
Na (me/100 g)[3]	0.76	2.70	0.60	1.20	3.70
Ca (me/100 g)[3]	7.5	10.0	13.1	10.0	2.5
Mg (me/100 g)[3]	2.7	9.3	4.0	8.5	5.6
Al (me/100 g)[4]	0.09	0.18	0.55	0.81	11.4
CEC (me/100 g)[5]	17.4	23.2	31.2	26.4	30.6
Si (me SiO_2/100 g)[6]	11.4	14.1	10.1	10.9	3.6
SO_4 (ppm S)[7]	0	520	440	176	400
Fe (ppm)[8]	305	170	200	220	50
Mn (ppm)[8]	58	30	60	39	15
Cu (ppm)[8]	2.2	1.7	2.5	1.5	0.1
Zu (ppm)[8]	3.0	2.5	2.5	2.5	2.5

[1] By Walkley-Black method

[2] Bray II

[3] Exchangeable cations by N NH_4OAc pH 7.0

[4] Extractable by N KCl

[5] By N NH_4OAc pH 7.0

[6] Extractable by N CH_3 COOH pH 4.0

[7] Water soluble (N. van Breemen 1971)

[8] Extractable by 0.005 M DTPA pH 7.30

The Rangsit very acid soil was limed at the rate of 13 ton/hectare of marl which would raise the pH of the soil to 5.0. The soil plus lime were incubated at field capacity (made up using tap water) for 1 month in plastic bags. The pH values of the limed soil were found to be 4.8 on the average. The limed soil was dried for two weeks. All of the soils except the limed soil were divided into 9 kg portions and put in the plastic bags and again put in earthen pots in the greenhouse. After flooding nitrogen was added in the form of urea (0,150,300,450 ppm N for RVAP and RVAP + lime and 0,250,500,750 ppm N for other soils). Phosphorus fertilizer was added in the form of $Ca(H_2PO_4)_2$ and NaH_2PO_4 (0,100,200 and 400 ppm P_2O_5). Potassium fertilizer was added in the form of KCl. The fertilizers were mixed with the soil by puddling. One day later two 3 week-old rice seedling of R.D.1 (a high yielding variety from Thailand) were transplanted into each pot. The treatments were replicated 4 times. The experiment, carried out in the dry season in a greenhouse, continued for 100 days through maximum tillering, booting and harvesting stages. Temperatures ranged from 27 to 36^{o}C. Water was applied every day, and twice daily during the booting stage. No iron or aluminum toxicity symptoms were observed in this experiment. Experimental results are listed in Tables 5 and 6.

At booting and harvesting stages (about 73 and 100 days after transplanting) samples of plant material were taken by cutting the whole plant. The plant material was cleaned by washing with water and dried in the oven at 70^{o}C, ground and subsequently analysed for P, K, Ca, Mg, S, Si, Al, Fe by XRF (Norrish and Hutton 1977). Na was determined by digesting the plants with $HClO_4$ after predigesting with HNO_3 and determined flame photometrically by autoanalyser. The analytical results are shown in Tables 7 and 8.

4 Chemical and physical characteristics

Results of mechanical analysis show that the acid sulphate soils are higher in clay than the other soils (Table 2).

Heaviest texture (66% clay) has the Rangsit very acid phase (RVAP) sample against a lightest texture (34.8% clay, 45.9% silt) for the Ratchaburi sample, reflecting the contrasting sedimentary environment of parent materials, respectively brackish backwater and flood plain. Data on clay mineral composition do not reflect this constrast but do show the contrast between the acid sulphate soil samples and the non-acid Bangkok sample that has also been observed by van Breemen (1976), with smectite being relatively low and partly interlayered with aluminium in acid sulphate soils.

The higher sand content of the non-acid samples concurs with higher total potassium content suggesting that feldspathic or other K-containing minerals occur in the sand fractions of the fluviatile (Ratchaburi) and marine (Bangkok) sediment (Table 3). The contrasting very low figures for available potassium in the Ratchaburi sample indicate that in this soil potassium fixation should be taken into account (Table 4).

Apart from the potassium figures, the most significant differences in contents of total elements are for S, CaO, Fe_2O_3, Mn O_2, P_2O_5.

Except for S, which is highest in RVAP, all of these constituents show lowest values for RVAP samples and the highest values for Ratchaburi samples.

The contrast is associated with the pH of the samples and with acid sulphate soil conditions for the more acid among them, as is also reflected by the figures for available P and extractable Fe, Mn and Al which are closely related to the pH of the samples (Table 4). Ranking the samples according to acidity one recognizes a series from
RVAP, pH 3.9 extremely acid
Rangsit and Sena, pH 4.8 and 4.7, strongly acid
Bangkok, pH 5.2 moderately acid to
Ratchaburi, pH 5.8 weakly acid

The difference between Bangkok and Ratchaburi in the figures for available nutrients, is only significant for phosphorus (with 50.8 ppm against 23.6 ppm, highest value for Ratchaburi) and potassium. The 0.16 me K/100 g for Ratchaburi against 0.67 me/100 g for Bangkok suggests K-fixation in the former soil. Both these soils are relatively low in organic matter (1.3-1.5%) and C.E.C. (17.4-23.2 me/100 g) which might be related with their relatively high sand and silt contents. Both Bangkok and Ratchaburi soils are rated very well suited for paddy production.

The analytical data show neither very high nor very low nutrient levels except for the very low level of available K in Ratchaburi. This and the differences for available P between the two topsoils indicate difference in fertility that might be of importance for cultivation practices and possible refinement of productivity ratings. The Sena and Rangsit samples are considerably lower in available phosphorus (9.6-10.5 ppm) and higher in extractable aluminum (0.55-0.81 me/100 g). These differences are evidently related to the much stronger acidity of Sena and Rangsit soils. No comparable differences between the non-acid and the acid soils were observed for exchangeable K, Ca, Mg and Si or for extractable Si, Fe, Mn, Cn and Zn.

The topsoil samples of Sena and of Rangsit soil showed no significant differences in pH or analysis for nutrients. The differences in productivity rating (Sena: well suited; Rangsit: moderately suited for paddy production) therefore is not reflected by the inherent properties of their topsoils. The difference in productivity rating might be the result of interactions between topsoil and subsoil and/or the irrigation water resulting in dynamic processes with unfavourable effects for plant performance.

The extremely acid RVAP soil has still lower figures for available P (6.1 ppm) and extractable Si (3.6 mg SiO_2/100 g). Likewise in the RVAP soil, extractable K, Ca, Fe, and Cu are lower and extractable Al (11.4 me/100 g) is much higher. These inherent properties of RVAP topsoil together with its pH of 3.9 do indicate a low fertility status and a potential for the release of soluble Al in toxic amounts upon flooding. The low productivity rating of this soil can be considered to be due to the inherent properties of the top soil and most probably of the soil body in its totality.

5 Plant performance in pot test

5.1 Presentation of data

Dry weight of complete rice plants at harvesting was used as a parameter for plant response in the fertilizer pot trial and will we presented here as yield. The term 'soil' will be reserved for the topsoil material in the pots unless specified otherwise. These soils are distinguished and named after the five soil units sampled, the limed variant of the Rangsit Very Acid Phase being treated as a sixth soil and indicated by the abbreviation 'RVAP + L'.

Yields are presented as means for each of the twenty treatments and for the six soils, in Table 5. Average response to each of the three fertilizer elements, (N, P and K) regardless of the levels of the other two elements, are presented in Table 6. Some data on concentrations of elements in the plants are given in Tables 7 and 8 and compared in Table

9 with yield data averaged for the RVAP, RVAP + L and the normal soils. Methods of data elaborations are indicated in the respective tables. Some observations of circumstantial phenomena which might be significant for plant performance, are presented in the following paragraphs together with an evaluation of the quantitative results.

Table 5. Mean dry weight of rice plants on six soils (g/pot)
Any two means followed by the same letter are not significantly different at P = 0.05

	Soils					
Treatments[1]	Ratchaburi	Bangkok	Sena	Rangsit	RVAP	RVAP + L
N_0 P_0 K_2	26.9 e	31.9 f	31.2 e	29.0 g	2.0 d	3.8 f
N_0 P_1 K_2	27.1 e	30.8 f	30.2 e	31.0 g	29.5 d	37.6 e
N_0 P_2 K_2	26.5 e	30.3 f	34.6 e	33.2 g	31.1 d	37.7 e
N_0 P_3 K_2	22.4 e	32.9 f	35.6 e	24.6 g	33.4 d	38.0 e
N_1 P_0 K_2	167.6 bc	102.7 de	79.2 e	105.1 f	1.7 d	2.0 f
N_1 P_1 K_2	177.8 abc	175.1 ab	189.5 cd	168.3 bcdef	73.0 c	116.3 d
N_1 P_2 K_2	158.2 bc	141.6 bcd	186.4 cd	164.2 bcdef	83.8 c	114.3 d
N_1 P_3 K_2	136.6 cd	145.9 bcd	170.6 d	151.7 cdef	100.9 bc	119.9 d
N_2 P_0 K_2	240.2 ab	118.7 cde	68.8 e	123.7 ef	1.8 d	1.8 f
N_2 P_1 K_2	235.6 ab	215.5 a	242.0 abc	218.7 abc	71.8 c	141.2 cd
N_2 P_2 K_2	258.0 a	226.0 a	233.2 abcd	220.6 abc	100.6 bc	172.3 bc
N_2 P_3 K_2	239.8 ab	220.3 a	218.2 abcd	201.5 abcd	163.2 a	180.1 ab
N_3 P_0 K_2	218.9 ab	86.3	52.8 e	125.5 ef	1.2 d	1.3 f
N_3 P_1 K_2	234.8 ab	200.8 a	196.5 bcd	173.4 abcdef	76.5 c	129.7 d
N_3 P_2 K_2	184.2 abc	212.1 a	245.8 abc	179.1 abcde	93.5 bc	164.2 bc
N_3 P_3 K_2	208.5 abc	202.2 a	257.7 ab	241.1 a	142.5 a	207.2 a
N_3 P_3 K_0	73.8 de	166.7 abc	184.5 cd	143.2 def	82.6 c	109.7 d
N_3 P_3 K_1	182.4 abc	198.1 a	249.7 abc	230.7 ab	129.5 ab	192.6 ab
N_3 P_3 K_3	212.2 abc	183.2 ab	266.9 a	239.4 a	159.1 a	181.4 ab
N_0 P_0 K_0	282.2 e	29.3 f	33.7 e	34.3 g	2.1 d	2.9 f

[1] Nutrient levels:

N_1, N_2 and N_3: for RVAP (= Rangsit very acid phase) and RVAP + L (line): 150, 300 and 450 ppm N/pot
for all other soils: 250, 500 and 750 ppm N/pot

P_1, P_2 and P_3: for all soils: 100, 200 and 400 ppm P_2O_5/pot

K_1, K_2 and K_3: for all soils: 120, 240 and 360 ppm K_2O/pot

Table 6. Average yield responses (g dry matter/pot) to application of N, P and K on six soils planted to rice

	Soils						
Level of	Ratchaburi	Bangkok	Sena	Rangsit	RVAP	RVAP + Lime	
nutrient	(g/pot)	(g/pot)	(g/pot)	(g/pot)	(g/pot)	(g/pot)	(% due to lime[1])
(ppm N/pot[2])	Average response to nitrogen (N) in combination with P_0, P_3 and K_2.						
N_0 (0)	25.7	31.5	32.9	29.5	24.0	29.3	(22)
N_1 (250)	160.0	141.3	156.4	147.3	64.9	88.1	(36)
N_2 (500)	243.4	195.1	190.6	191.1	84.4	123.9	(47)
N_3 (750)	211.6	175.4	188.2	179.8	78.4	125.6	(60)
							av. 40%
LSD .05	35.3	23.4	29.4	30.0	17.8	15.3	
.01	47.3	31.4	38.0	40.2	23.8	20.5	
(ppm P_2O_5/pot)	Average response to phosphorus (P_2O_5) in combination with N_0, N_3 and K_2.						
P_0 (0)	163.4	84.9	58.0	95.8	1.7	2.2	(29)
P_1 (100)	168.8	155.6	164.6	147.9	62.7	104.9	(67)
P_2 (200)	156.7	152.5	175.0	149.3	77.8	122.1	(57)
P_3 (400)	153.3	150.3	170.5	154.7	110.0	136.3	(24)
							av. 44%
LSD .05	-	23.4	28.4	30.0	17.8	15.3	
.01	-	31.4	38.0	40.2	23.8	20.5	
(ppm K_2O/pot)	Average response to potassium (K_2O) in combination with N_3 and P_3.						
K_0 (0)	73.8	166.7	184.5	143.2	82.6	109.7	(33)
K_1 (120)	182.6	198.1	249.7	230.7	129.5	192.6	(49)
K_2 (240)	208.5	202.2	257.7	241.1	142.5	207.2	(45)
K_3 (360)	212.2	183.2	266.9	239.4	159.1	181.4	(14)
							av. 35%
LSD .05	70.7	46.8	56.8	60.0	35.6	30.7	
.01	94.7	62.7	76.1	80.4	47.7	41.1	

[1] Due to 13 ton marl/ha. Percentage = $\frac{(\text{RVAP + L}) - \text{RVAP}}{\text{RVAP}} \times 100$

[2] N_1, N_2 and N_3 for RVAP and RVAP + Lime: 150, 300 and 450 ppm N/pot

5.2 Plant performance in the absence of fertilizers

Without fertilizers, yields are poor in all soils. But a striking contrast was observed between the RVAP with or without lime and the other four soils. On the latter, plants were healthy and reached a yield level ranging between 28.2 and 34.3 g/pot. The rice in RVAP and RVAP + L soils was stunted and no more development of growth after transplanting was

observed and yields reached only 2.1 and 2.9 g/pot.
The extremely low performance on RVAP and even RVAP+L is not surprising in view of the inherent acidity and very low levels of available nutrients, such as P and K indicated by the chemical analysis (Table 4).
The performance on the still strongly acid Sena and Rangsit soils is much better and comparable to or even superior to the performance on the moderately and weakly acid Bangkok and Ratchaburi soils. This points to limiting factors of other kind than in acid sulphate soil. Analytical data show large differences for available P in K among these latter soils, Ratchaburi being deficient in available K but well provided with P; the reverse holding for Sena and Rangsit. These relations in inherent soil properties and plant performance in the absence of fertilizers suggest that for all these four soils nitrogen might be the main limiting factor.

5.3 Responses to nitrogen, phosphorus and potassium

As demonstrated by Tables 5 and 6, on none of the soils there is a significant response to potassium, in the absence of nitrogen and phosphorus fertilization. In the presence of N and P, however, average response to K is a nearly tripling of the yield on Ratchaburi and a near doubling of the yield for RVAP and RVAP + L. The response to K on Bangkok, Sena and Rangsit was much less. The responses reflect the ranking sequence for the soil's available potassium figures. For RVAP and RVAP + L, the yields at 'complete' NPK fertilization (160 and 200 g/pot respectively) remain far below those of Bangkok (230 g/pot), Rangsit (240 g/pot), Ratchaburi (260 g/pot) and Sena (260 g/pot). Note that the soils sampled from Sulfic Tropaquepts perform equal to or better than the soils sampled from Typic Tropaquepts. Maximum yields for the latter, however, required lower levels of N, P and K.
The striking difference between the RVAP and RVAP + L and the other soils in terms of plant performance both for unfertilized and completely fertilized soil treatment, is also reflected in the effect of combining K application with either N or P.
On RVAP and RVAP + L, nitrogen fertilization has no positive effect unless P is given too, whereas phosphorus alone does raise the yield from

about the 2 g/pot to about the 30 g/pot level i.e. the level obtained without any fertilization by Sena, Rangsit, Bangkok and Ratchaburi soils. On these latter soils on the other hand plants hardly respond to P fertilization unless also nitrogen has been applied, whereas nitrogen alone results in yields which are twice, four times or even eight times the unfertilized control. The relative differences reflect the relatively good availability of phosphorus in each of these soils. Mere potassium application in the absence of both P and N, did not effect yield positively in any of the soils.

These indications for P-deficiency in RVAP and RVAP + L and of N deficiency in the other soils are expressed at lower and medium levels of combined N and P applications by a relative preponderance of P responses against N responses for the same respective groups of soils. On the Ratchaburi and Bangkok soils; plants did not respond positively to raising N and/or P levels to the highest levels. In the RVAP there was only a response to raising P, suggesting that at the highest dose P was still the limiting factor. On RVAP + L plants responded positively to all N and P applications, and the same held on Sena and Rangsit. Apparently liming of RVAP improved the efficiency of P fertilization to overcome the primary P-deficiency in the extremely acid soil.

It is interesting to note that to reach the maximum yield level on RVAP, (163 g/pot) 300 ppm N and 400 ppm P_2O_5 were required. To reach the same yield all the other soils required an equal amount of N fertilization but RVAP + L only 200 ppm P_2O_5, Bangkok, Sena and Rangsit 100 ppm P_2O_5 and Ratchaburi no P at all. RVAP + L reached its maximum yield of 207 g/pot in response to maximum applications of 450 ppm N and 400 ppm P_2O_5. The same yield level was reached for Sena, Rangsit, and Bangkok with 500 ppm N but only 100 ppm P_2O_5 while the Ratchaburi needed only 500 ppm N to give a similar yield.

Bangkok and Ratchaburi, the least acid soils, did not respond to raising N fertilization to highest levels nor to raising the P application above 200 ppm to reach their maximum yield levels of respectively 226 and 258 g/pot. On the more acid Sena and Rangsit soils (Sulfic Tropaquepts), plants responded also to the highest N (750 ppm) applications to reach yields of 240-260 g/pot, suggesting that still higher yields could be reached with heavier dressing of N and P. The same holds for RVAP + L. The positive response to K application suggests that such higher levels of N and P probably should be combined with more K fertilizer.

These relations allow the conclusion that the inherent productivity of the very acid Sena and Rangsit soils is at least equal to that of the less acid Ratchaburi and Bangkok soil. The productivity of the extremely acid RVAP soil is inherently lower, but can be ameliorated by combined liming and P-fertilization. Whether improvement up to the level of the Sena and Rangsit soils is possible, cannot be concluded from the present experiments, as no limit of response to raising application levels was observed.

In this experiment liming did improve the efficiency of combined N and P fertilization in RVAP soil, but it did not eliminate its primary P-deficiency. To reach yields of 150-200 g/pot RVAP+L requires equal amounts of N but double to thrice the amount of P needed on the still very acid Sena and Rangsit soils. As phosphorus deficiency is associated with phosphorus fixation and extreme acidity in the soil, potential acidity in acid sulphate soils can be expected to cause recurrent phosphorus-deficiency. Changing the intrinsic properties of RVAP soil to allow better plant performance and response to fertilizer dressings, would hence imply first alleviating its extreme acidity and second raising its level of available phosphorus to at least that of Sena and Rangsit soils.

Table 7. Concentrations of plant nutrients of rice grown on six soils (average of fertilized plots) at booting stage

Soils	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	S (%)	Si (%)	Al (ppm)	Fe (ppm)	Dry weight (g/pot)
Ratchaburi	0.35	1.36	0.66	0.39	0.58	0.23	3.0	68	156	146
Bangkok	0.29	2.31	0.60	0.42	0.63	0.38	4.0	61	174	141
Sena	0.30	2.53	0.73	0.45	0.39	0.48	3.0	144	176	142
Rangsit	0.29	2.05	0.62	0.50	0.61	0.42	3.5	99	195	133
RVAP	0.18	1.25	0.43	0.33	1.00	0.76	2.1	255	215	73
RVAP + L	0.22	1.85	0.70	0.42	0.53	0.49	2.0	133	152	91

Table 8. Concentrations of plant nutrients of rice grown on six soils (average of fertilized plots) at harvesting stage

Soils	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	S (%)	Si (%)	Al (ppm)	Fe (ppm)	Dry weight (g/pot)
Ratchaburi	0.25	1.20	0.59	0.40	0.74	0.27	2.7	209	334	192
Bangkok	0.23	1.64	0.55	0.38	0.69	0.37	3.7	266	341	191
Sena	0.23	1.71	0.62	0.37	0.61	0.40	2.5	233	310	220
Rangsit	0.22	1.46	0.56	0.39	0.64	0.39	3.1	225	340	194
RVAP	0.12	1.03	0.38	0.31	1.00	0.66	1.6	300	306	106
RVAP + L	0.16	1.27	0.57	0.40	0.71	0.46	1.7	300	379	152

Table 9. Correlation (Pearson correlation coefficient) between concentration of elements and yield dry matter of rice plants for 'problem' soils and 'normal' soils

	'Problem' soils		'Normal' soils (Ratchaburi, Bangkok, Sena and Rangsit combined)
Elements	RVAP	RVAP + L	
K	-0.8616**	-0.7222**	-0.4426**
Na	0.8155**	0.6393**	0.7087**
Ca	0.7637**	0.8145**	0.7449**
Mg	0.7814**	0.6393**	0.7087**
Al	-0.6428**	-0.7301**	-0.2007
S	-0.7850**	-0.5661**	0.5483**
Si	-0.9054**	-0.9033**	-0.9111**
P	0.4957*	0.5874*	0.2276*
Cl	-0.0127	-0.0125	-0.1402
Fe	-0.4657*	0.0537	0.3288**
Mn	-0.8064**	-0.8853**	0.3049**
Cu	-0.4642	-0.5384	0.1644
Zn	0.5570	0.2726	0.6584**

5.4 Relative elemental nutritional composition of plants

There are marked differences in nutrional elemental composition between plants grown on RVAP and plants grown on Sena, Rangsit, Bangkok and Ratchaburi soil (Tables 7 and 8). The former have the highest concentrations of Al, S and Na and the lowest concentrations of P, Si, Mg, Ca and K. Plant performance on RVAP and RVAP + L were positively correlated with P, Mg and Ca in the plants and negatively with their content of Al and S. These results corroborate the deficiencies in the soils indicated by soil analysis and the corresponding responses of plants on fertilizer treatments.

Analytical results at booting stage show that Si contents are equally low in plants grown on limed and unlimed RVAP. Liming somewhat increases the P- and K-contents, strongly increases the Ca- and Mg-contents, and strongly depresses Al-, S-, Na- and Fe-contents. At the harvesting stage these relations remained the same except for Al and Fe, which tend to be accumulated strongly by plants on all soils in this stage.

Compared to the plants grown on Sena, Rangsit, Bangkok and Ratchaburi, the RVAP + L grown plants were only lower in P and Si. This suggests that deficiency of these two nutritional elements was the main cause for poor plant performance on RVAP + L.

Mn- and Cu-contents in RVAP soil are relatively low but are taken up from the RVAP and RVAP + L by plants in amounts that are negatively correlated with plant performance on these soils (Table 9). A similar correlation was observed for Al and S. On the Sena, Rangsit, Bangkok and Ratchaburi, plant uptake of S and Mn showed a significant positive correlation with plant performance whereas no significant correlations were found for Al uptake.

The Fe-content decreased due to liming at booting stage but not at harvesting stage. The concentration of Fe in the plants was rather low and no iron toxicity symptoms were observed.

These relations suggest that excessive uptake of Al, S and Mn are decreased by liming.

6 Conclusions and recommendations

Among the three acid sulphate soil units sampled, only the Rangsit very acid phase (RVAP) (Typic Sulfaquept), has intrinsic properties of the topsoil that can be considered to be the cause of poor plant performance. The topsoils of Rangsit and Sena soil series (Sulfic Tropaquepts) have intrinsic properties and potential productivity equal or better than those of Bangkok and Ratchaburi series (Typic Tropaquepts). The relatively low productivity rating for Rangsit and Sena soils (respectively moderately and well suited for rice production) compared with the rating for Bangkok and Ratchaburi soils (very well suited) therefore must be due to external causes such as water management or subsoil influences.

We expect that the productivity of these Sulfic Tropaquepts can be raised by eliminating such unfavourable extrinsic influences, e.g. by good water management and by 'normal' cultural practices.

Improving the productivity of Rangsit very acid soil (RVAP), requires changing the intrinsic properties of the topsoil, especially reducing its extreme acidity and subsequently raising its phosphorus status. These practices might include increasing the frequency of draining off overlying water, combined with application of lime and subsequently of rock phosphate.

Only after such intrinsic amelioration of the topsoil, 'normal' cultural practices may be expected to have positive results.

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THE EFFECTS OF LIMING AND FERTILIZER APPLICATIONS TO ACID SULFATE SOILS FOR IMPROVEMENT OF RICE PRODUCTION IN THAILAND

Charoen Charoenchamratcheep, Boonthong Tantisira,
Phairoj Chitnuson and Vachara Sin-Aiem
Department of Land Development,
Ministry of Agriculture & Co-operatives
Thailand

1 Summary

Acid sulfate soils cover quite a large area in the Central Plain of Thailand which is an important rice producing region of the country. As a result of the low pH and the low fertility of these soils, rice yields are very low to low. To increase rice production and to maximize the net profit, improvement of acid sulfate soils by liming and fertilizer applications was studied and the results are reported in this paper.

Four acid sulfate soil series with different pH values, depths of jarosite and suitability classes for rice, namely Rangsit very acid phase, Rangsit, Maha Phot and Ayutthaya series were selected at eight different locations. The surface soil (0-20 cm) of each soil series was collected for chemical analysis before conducting the experiment. The high yielding and non-photoperiod sensitive variety 'RD-7' and a local photoperiod sensitive variety were planted. Marl (a liming material), ammonium sulfate, ammonium phosphate and Thai rock phosphate were applied in a randomized complete block design with 4 replicates.

In moderately acid soils, Maha Phot and Ayutthaya series, application of marl had little effect on yield. Applying ammonium sulfate alone (150 kg/ha) or with Thai rock phosphate (1.250 kg/ha) tended to give a high yield. Either marl at 6.25 to 12.5 tons/ha with ammonium phosphate at 187.5 kg/ha or ammonium sulfate alone may be applied to maximize net profit.

In the severely acid Rangsit soil, rice responded strongly to marl (6.25 to 18.75 tons/ha) with ammonium phosphate (187.5 kg/ha). A similar

response was obtained with 6.25 to 12.5 tons/ha of marl, 1250 kg/ha of Thai rock phosphate and 150 kg/ha of ammonium sulfate. The maximum profit obtained from these treatments depended upon the price of fertilizers and also fertility of soils.

In the extremely acid Rangsit soil - very acid phase, an application of 6.25 to 12.5 tons/ha of marl, 1250 kg/ha of Thai rock phosphate and 150 kg/ha of ammonium sulfate or 12.5 tons/ha of marl with 187.5 kg/ha of ammonium phosphate gave the highest yield response and the maximum profit.

In all soils at all locations, the results indicate that liming plays a significant role in increasing the efficiency of fertilizers.

2 Introduction

The worldwide area of acid sulfate soils is estimated to be roughly 8 million hectares (Bloomfield and Coulter 1973). In the Kingdom of Thailand, acid sulfate soils occur mainly in the Central Plain in an area of about 800,000 hectares, of which 95 percent is used for paddy production. Acid sulfate soils are identified by the pale yellow mottles of jarosite ($KFe_3(SO_4)_2(OH)_6$) in the soil profile and the low soil pH. In Thailand they are classified into various soil series and phases according to the depth at which jarosite appears and the degree of acidity (Van der Kevie and Yenmanas 1972, Pons and Van der Kevie 1969). There are 480,000 hectares of moderately acid soils, 208,000 hectares of severely acid soils and 80,000 hectares of extremely acid soils (Van der Kevie and Yenmanas 1972).

The yields of rice grown in acid sulfate soils are low to very low: between 500-1,500 kg/ha (Komes 1973). Pons and Van der Kevie (1969) reported that these poor rice crops showed symptoms of aluminum toxicity and phosphorus deficiency. The three main chemical deficiencies of acid sulfate soils of the Bangkok Plain are lime, phosphorus and nitrogen. However, rice does not respond to phosphate unless the soil pH is raised by liming. Similarly, applying nitrogen without raising the pH and the phosphorus level will have little effect.

There are various ways to consider reclamation and improvement of acid sulfate soils. Nhung and Ponnamperuma (1966) recommended as provisional reclamation measures:

a) leaching of the soil with fresh water to lower the concentration of salts, chiefly sulfates;

b) liming to an aerobic soil pH of 4.7 to prevent aluminum toxicity and to decrease iron toxicity;

c) applying manganese dioxide to counteract iron toxicity;

d) adding ferric oxide (red earth) to counteract hydrogen sulphide toxicity in soils low in active Fe;

e) maintaining continuous flooding after these combined treatments.

To alleviate acidity hazards, liming is becoming a general practice in Thailand paddy production. The liming materials used are marl from local sources (bog lime) or phosphate fertilizer as rock phosphate. Fertilizer experiments on severely acid Rangsit soils (FAO 1968b, 1969, 1970 and 1972) showed that the response to potassium fertilizer is insignificant, but that a maximum yield increase of 10 to 25 percent could be obtained with an application of 31.25 to 43.75 kg N and 25 to 37.5 kg P_2O_5 per hectare. A better response could be expected if the fertilizer application is combined with liming. Research by Thawornwong and Aphichonthivong (1980) indicated that significant and economic yield increases of rice are obtained in acid sulfate soils by using any kind of lime at a rate equivalent to 6.25 tons $CaCO_3$/ha combined with 26.25 kg N/ha and 25 kg P_2O_5/ha. Charoenchamratcheep et al. (1980) also found for the extremely acid Rangsit soil a marked increase in yield by applying 6.25 to 18.75 tons/ha of marl together with 25-100 kg P_2O_5/ha plus 100 kg N/ha. In this case application of rock phosphate or triple superphosphate without marl gave quite low increases.

This paper presents results of field trials combining applications of marl with various sources of NP fertilizers for rice on three classes of acid sulfate soils in different locations. In addition to yield data, by calculating production costs the results include financial returns of paddy production.

3 Materials and methods

3.1 Materials

Soil. Eight sites were selected varying from extremely acid to moderately acid. They had jarosite horizons at varying depths. The acidity varies with the depth of the jarosite or catclay horizon, which is the horizon containing characteristic yellow or pale yellow mottles of the mineral jarosite. This horizon is extremely acid. The Ayutthaya and Maha Phot series have a catclay horizon starting below 100 cm with pH of surface soils 5.0-6.0, while Rangsit series has catclay below 40 cm but within 100 cm with pH of surface soil 4.0-5.0. The Rangsit very acid phase has catclay at the same depth as the main series but pH of surface soil 3.5-4.5 and there is less calcium than in the Rangsit main series. Four of these sites were situated in experimental stations and four in farmer's fields. The location of the sites, the classification of their soils, their suitability of rating for rice production and some characteristics of soil and sites are given in Table 1. The descriptions of soil series are given by Van der Kevie and Yenmanas (1972).

Table 1. Site and soil characteristics of the experimental plots

Symbol	NNY	NNY Centre	PTN	KLG Station	PCR Station	PTN Centre	PCR	AYY
Location	Farmer's field Amphoe Pak Phli Ankorn Nayok province	Land Development Centre, Dept. of Land Development, Amphoe Ongkharak Nakorn Nayok province	Farmer's field, Amphoe Nong Sua Pathum Thani province	Klong Luang Exp. Sta., Dept. of Agriculture, Pathum Thani province	Prachin Buri Exp. Sta., Dept. of Agric. Prachin Buri province	Land Development Centre, Dept. of Land Development, Amphoe Thanyaburi Pathum Thani province	Farmer's field, Amphoe Ban-Sang Prachin Buri province	Farmer's field, Amphoe Bang Pa-in Ayutthaya province
Land use prior to experiment	paddy field	abandoned paddy field	paddy field	paddy field	paddy field	paddy field	paddy field	paddy field
Soil series	← Rangsit - very acid phase →			← Rangsit series →			Maha Phot series	Ayutthaya series
Acidity class	← Extremely acid →			← Severely acid →			← Moderately acid →	
pH top soil	4.0	4.0				4.2	4.9	4.6
Lime requirement (tons/ha)	18.0	17.6				10.7	6.2	9.8
OM %	4.5	4.8				3.3	1.9	2.5
Avail P (ppm)	16.8	6.0				6.0	3.7	11.0
Avail K (ppm)	117.0	156.0				234.0	211.0	195.0
Active Fe (%)	0.6	0.6				0.4	1.2	<0.1
Extr. Al me/100 g soil	5.9	6.7				2.0	<0.05	<0.05
Depth of jarosite	40-100 cm	40-100 cm	40-100 cm	40-100 cm	40-100 cm	40-100 cm	>100 cm	>100 cm
Flooded regime	Depth 60-70 cm 4-5 months	Depth 40-50 cm 3-4 months	Depth 40-50 cm 4-5 months	Depth 40-50 cm 4-5 months	Depth 80-200 cm 5-6 months	Depth 40-50 cm 5-6 months	Depth 80-120 cm 6-7 months	Depth 80-200 cm 6-7 months
Ground water level in dry season	below 100 cm	below 100 cm	below 100 cm	below 100 cm	below 100 cm	below 100 cm	below 150 cm	below 150 cm

Remarks: Methods of *chemical analysis of top soils*

1. pH by 1:1 in distilled water, air dry soil
2. Lime requirement by Woodruff's method
3. Organic matter by Walkley and Black wet oxidation method
4. Available P by Bray and Kurtz's No. 2 method
5. Available K by NH_4OAc 1N at pH 7.0
6. Active FE by Dithionite - E.D.T.A. extraction
7. Extr. Al by KCl extraction and aluminum by colorimetry

Soil amendments and fertilizers. Marl, a liming material with a calcium carbonate equivalent of 85%, was applied at the rate of 6.25, 12.5 and 18.75 tons/ha at two land development centres (NNY Centre and PTN Centre) and two rice experiment stations (KLG Station and PCR Station), and at a rate of 6.25 and 12.5 tons/ha in the experiments in farmer's fields. Various sources of fertilizer were used. Ammonium sulfate (21% N) at 150 kg/ha (31.25 kg N/ha), ammonium phosphate (grade 16-20-0) at 30 kg/ha (30 kg N/ha + 37.5 kg P_2O_5/ha) and Thai rock phosphate with three levels of 625, 1,250 and 1,875 kg/ha (25, 50 and 75 kg available P_2O_5/ha) were applied. A topdressing of ammonium sulfate fertilizer was given at 100 kg/ha (21 kg N/ha) for the local photoperiod sensitive variety and at 225 kg N/ha (47.25 kg N/ha) for the high yielding variety.
Rice variety. The high yielding variety RD-7 and local photoperiod-sensitive varieties, recommended by the government, were planted.

3.2 Methods

A randomized complete block design was used in the experiments with four replications. The lists of treatments used at each experimental site are given in Table 2.

Table 2. Treatments and rice varieties used at experimental sites

			Farmer's fields	
	Nakorn Nayok (NNY) Ctr. & Pathum Thani (PTN) Ctr.	Klong Luang (KLG) Sta. & Prachin Buri (PCR) Sta.	Pak Phli Ban Sang & Bang Pa-in	Nong Sua
Treatment	CK	CK	CK	CK
	AS		AS	L
	AP	AP	AP	AP
	AP+L_1	AP+L_1	AP+L_1	
	AP+L_2	AP+L_2	AP+L_2	AP+L_2
	AP+L_3	AP+L_3		
	AS+R_1	AS+R_1	AS+R_1	
	AS+R_2	AS+R_2	AS+R_2	AS+R_2
	AS+R_3	AS+R_3		
	AS+R_2+L_1			
	AS+R_2+L_2	AS+R_2+L_2		
	AS+R_2+L_3			
Rice variety	RD-7	RD-7 and Leb Mue Nang III	Kan Mali Hah-Ruang and RD-7	RD-7

Remarks:

CK = check or control

AS = ammonium sulfate at 150 kg/ha

AP = ammonium phosphate at 187.5 kg/ha

L_1, L_2 and L_3 = lime as marl at 6.25, 12.5 and 18.75 tons/ha respectively

R_1, R_2 and R_3 = Thai rock phospate at 625, 1,250 and 1,875 kg/ha respectively

The number of treatments possible at each site depended on the amount of land available and other facilities, especially supervision.

A composite surface soil sample at the depth of 20 cm was collected at each site except PTN, KLG Station and PCR Station, for chemical analysis before conducting the experiment. The fields selected were plowed and small levees were raised around each treatment plot. Marl was broadcast 15 to 30 days in dry soil before transplanting and fertilizers were applied within one to three days before transplanting. Three 30-day-old seedlings per hill were planted 25 by 25 cm apart in straight rows in puddled soil at all sites. Water was applied to the experimental plots about one week before planting. This was followed by rainfed surface flooding through the cropping season.

Top-dressing with ammonium sulfate was done at the panicle initiation stage. Weeding and pest control were practiced. Yield components at harvest were recorded for statistical analysis. Grain yield was measured by sampling 8 m^2 of each 12 m^2 plot.

The economic aspects were also evaluated. Production costs and returns were calculated by recording all variable and fixed costs at each site. The profit could then be calculated by deducting total costs from the gross crop value.

4 Results and discussion

4.1 Experimental results

The average yields of rough (unhulled) rice in 1979, at eight locations were statistically analysed as shown in Tables 3, 4, 5 and 6. Also production costs and returns are given in the same tables.

Table 3. Yield of RD-7 and production costs and returns of paddy affected by liming and fertilizer application at two land development centres (Department of Land Development) (means followed by the same letter are not significantly different at P = 0.05)

Treatment	Grain yield (tons/ha)		Cost and return (Baht/ha)[1]			
	Rangsit soil (PTN Ctr.)	Rangsit soil - very acid phase (NNY Ctr.)	Rangsit soil		Rangsit soil - very acid phase	
			Total cost	Net profit	Total cost	Net profit
CK	3.59 de	0.33 f	4,019	8,563	3,813	-2,650
AS	3.73 de	0.42 f	5,463	7,600	5,250	-3,781
AP	4.36 bcd	2.86 e	5,938	9,331	5,838	4,613
AP+L$_1$	5.09 ab	3.22 de	6,250	11,556	6,131	5,138
AP+L$_2$	4.49 bc	4.28 abc	6,475	9,231	6,463	8,525
AP+L$_3$	4.61 bc	3.78 bcd	6,750	9,375	6,694	6,519
AS+R$_1$	4.14 cde	3.73 bcd	6,613	7,869	6,590	6,450
AS+R$_2$	3.54 e	3.72 bcd	7,700	4,681	7,713	5,306
AS+R$_3$	4.05 cde	3.42 cde	8,863	5,313	8,819	3,150
AS+R$_2$+L$_1$	5.53 a	4.39 ab	8,094	11,244	8,019	7,363
AS+R$_2$+L$_2$	5.71 a	4.83 a	8,369	11,625	8,312	8,600
AS+R$_2$+L$_3$	4.74 bc	3.92 bcd	8,569	8,013	8,525	5,194
CV%	15.9	11.4				

[1] Determined by Office of Agricultural Economics

Remarks:
1. Price of rough rice = 3.5 Baht/kg
2. 20 Baht = 1 U.S. dollar

Table 4. Yield responses and production costs and returns of paddy in Rangsit soil affected by liming and fertilizer application at two experiment stations of Department of Agriculture[1] (means followed by the same letter are not significantly different at P = 0.05)

Treatment	Grain yield (tons/ha)[2]		Cost and return (Baht/ha)[3]			
			KLG Sta.		PCR Sta.	
	KLG Sta.	PCR Sta.	Total cost	Net profit	Total cost	Net profit
CK	1.55 e	1.76 e	3,888	1,538	3,738	2,431
AP	3.10 cd	2.13 cd	5,394	5,456	5,163	2,300
AP+L$_1$	3.52 abcd	1.89 d	5,688	6,631	5,419	1,188
AP+L$_2$	3.59 abc	2.53 ab	5,950	6,606	5,719	3,144
AP+L$_3$	3.76 a	2.69 a	6,263	6,888	6,000	3,431
AS+R$_1$	3.23 bcd	2.19 bcd	6,094	5,194	5,863	1,794
AS+R$_2$	3.04 d	2.12 cde	7,206	3,425	6,981	438
AS+R$_3$	3.01 d	2.18 bcd	8,331	2,213	8,113	-500
AS+R$_2$+L$_2$	3.64 ab	2.47 abc	7,775	4,956	7,538	1,106
CV%	11	11.2				

[1] Courtesy of Rice Division

[2] Transplanted RD-7 rice variety of Klong Luang Station and Leb Meu-Nang 111 (floating local rice variety) by germinated seeds broadcasting at Prachin Buri Station

[3] Determined by Office of Agricultural Economics

Remarks:
1. Price of rough rice = 3.50 Baht/kg
2. 20 Baht = 1 U.S. dollar

Table 5. Yield responses and production costs and returns of paddy affected by liming and fertilizer application in farmers' fields at two locations in Rangsit soil - very acid phase (means followed by the same letter are not significantly different at P = 0.05)

Treatment	Grain yield (tons/ha)[1]		Cost and return (Baht/ha)[2]			
			Nong Sua		Pak Phli	
	Nong Sua	Pak Phli	Total cost	Net profit	Total cost	Net profit
CK	2.43 c	1.60 c	3,944	4,569	2,600	3,000
L_2	2.67 bc		4,494	4,850		
AS		1.76 c			4,213	1,956
AP	3.55 ab	2.99 ab	5,888	6,538	4,725	5,731
AS+R_1		2.64			5,388	3,844
AS+R_2	3.54 ab	3.03 ab	7,700	4,681	6,544	4,044
AP+L_1		3.34 a			5,013	6,694
AP+L_2	4.02 a	3.21 a	6,450	7,619	5,269	5,956
CV%	18	9.6				

[1] Transplanted RD-7 rice at Nong Sua-PTN (Courtesy of Office of Agricultural Economics); transplanted Kan Mali (a local rice variety) at Pak Phli (NNY)

[2] Determined by Office of Agricultural Economics

Remarks:
1. Price of rough rice = 3.50 Baht/kg
2. 20 Baht = 1 U.S. dollar

Table 6. Yield responses and production costs and returns of paddy affected by liming and fertilizer application in farmers' fields at two locations in moderately acid soils (Maha Phot series at Ban Sang, Ayutthaya series at Bang Pa-in)
(means followed by the same letter are not significantly different at P = 0.05)

Treatment	Grain yield (tons/ha)		Cost and return (Baht/ha)[3]			
	Maha Phot soil[1]	Ayutthaya soil[2]	Maha Phot soil		Ayutthaya soil	
	(Ban Sang)	(Bang Pa-in)	Total cost	Net profit	Total cost	Net profit
CK	3.29 c	4.09 c	3,338	8,194	4,988	9,319
AS	4.29 ab	5.09 a	4,369	10,663	6,488	11,344
AP	4.07 b	4.69 b	4,794	9,450	6,894	9,513
AS+R_1	4.52 a	4.83 ab	5,506	10,313	7,594	9,314
AS+R_2	4.56 a	4.81 ab	6,644	9,306	8,719	8,106
AP+L_1	4.46 a	5.09 a	5,088	10,531	7,188	10,619
AP+L_2	4.61 a	4.98 ab	5,356	10,769	7,581	9,856
CV%	7.9	5.8				

[1] Transplanted Hah Ruang (a local rice variety) at Ban Sang

[2] Transplanted RD-7 rice variety at Bang Pa-in

[3] Determined by Office of Agricultural Economics

Remarks:
1. Price of rough rice = 3.50 Baht/kg
2. 20 Baht = 1 U.S. dollar

Results of experiments at the land development centres. In the Rangsit soil with RD-7 a significant yield increase of about 50% was obtained by applying ammonium phosphate plus lime. Yields with ammonium phosphate or ammonium sulfate alone or with ammonium sulfate combined with rock phosphate were not significantly higher than the control (Table 3). The highest yields were obtained from ammonium sulfate plus 1,250 kg/ha of rock phosphate and 6.25 or 12.5 tons/ha of marl.

In Rangsit soil - very acid phase with the same variety, the effects of the various amendments showed the same trends (Table 3). However, the yield increase over that in the control plot was much greater than in the Rangsit soil. Moreover, ammonium phosphate alone, but not ammonium sulfate alone, had a very strong positive effect on the yield.

Results at the experiment stations of the Department of Agriculture. Experiments were conducted in Rangsit soils at two locations (Table 4). The results were quite similar at both locations. The highest yields are obtained after applying 12.5 or 18.75 tons/ha of marl with 187.5 kg/ha of ammonium phosphate or 12.5 tons/ha of marl with 1,250 kg/ha of rock phosphate and 150 kg/ha of ammonium sulfate. Application of ammonium sulfate alone gave a high yield that was not significantly different from the yield obtained after adding rock phosphate with 150 kg/ha of ammonium sulfate.

Results in the farmer's fields. In Rangsit soil - very acid phase at Nong Sua, all treatments except liming alone had a significant effect. Ammonium phosphate plus liming gave the highest yield. At Pak Phli too, marl plus ammonium phosphate gave the highest response. Different liming rates (0, 6.25 or 12.5 tons/ha) gave no significant differences in yield (Table 5).

In moderately acid soils, there were only slight variations in the yields due to different treatments (Table 6). The application at 150 kg/ha of ammonium sulfate gave a considerable yield increase in both soils and adding phosphate with or without lime gave no further yield increase. At both locations, farmers have applied ammonium phosphate for a number of years before the experiments were carried out. The residual effect of the fertilizers may have influenced the experimental results.

4.2 Combined agronomic results

The four acid sulfate soils selected differed in degree of fertility, acidity, depth of jarosite, presence of gypsum, soil suitability and management, etc. This is reflected by the greatly different yield responses to various treatments. In most strongly acid soil fertilizer application must be preceded by liming for optimal agronomic results. The lime application that is necessary will vary according to soil conditions.

It is interesting to note that these results agree with the research conducted by Chang (1961), and Chang and Puh (1951). They concluded that on fertile soils or soils receiving sufficient chemical fertilizers, rice did not respond to lime as much as on less fertile soils or soils receiving only some compost manure. Correspondingly, the available phosphorus content of the soil and plant uptake from soil of applied phosphorus increased very markedly with liming. The better yields were obtained when phosphate and lime were applied in combination.

4.3 Economic results

The results of these trials showed that the financial benefits of using marl and fertilizers were considerable (Tables 3, 4, 5 and 6).

Rangsit soils. At Pathum Thani (Table 3), the highest net profit (11,625 Baht/ha) was obtained from using 12.5 tons/ha of marl together with 1,250 kg/ha of rock phosphate and 150 kg/ha of ammonium sulfate. The second and third ranks of net profit were 11,556 and 11,244 Baht/ha from 6.25 tons/ha of marl combined with 187.5 kg/ha of ammonium phosphate, and 6.25 tons/ha of marl with 1,250 kg/ha of rock phosphate plus ammonium sulfate respectively.

At both Klong Luang and Prachin Buri Experiment Stations (Table 4) 18.75 tons/ha of marl with ammonium phosphate gave the highest yields and also the highest net profits which were 6,888 and 3,431 Baht/ha respectively. The application of 12.5 tons/ha of marl at both stations and 6.25 tons/ha at Klong Luang with ammonium phosphate gave returns quite close to the maximum.

Rangsit soil - very acid phase. Negative returns were obtained from the control and from ammonium sulfate alone, at the Land Development Centre in Nakorn Nayok Province. The highest net profit (8,600 Baht/ha) was recorded when marl at 12.5 tons/ha was combined with 1,250 kg/ha of rock phosphate plus 150 kg/ha of sulfate (Table 3). Application of 12.5 tons/ha of marl with ammonium phosphate gave the second rank of the profit which was 8,525 Baht/ha. Three rates of rock phosphate with ammonium sulfate or ammonium phosphate alone gave rather low profit. In the farmer's field at Nong Sua, 12.5 tons/ha of marl with ammonium phosphate gave the highest net profit but ammonium phosphate alone also gave a markedly higher profit than the control. In the Pak Phli trial, 6.25 tons/ha of marl with ammonium phosphate gave the highest profit followed by 12.5 tons/ha of marl with ammonium phosphate and ammonium phosphate alone (Table 5).

Maha Phot and Ayutthaya soils. The two trials did not give much extra profit from adding marl to ammonium phosphate (Table 6). Ammonium sulfate alone and, to a lesser extent, ammonium phosphate alone gave a higher net profit than the control. Rock phosphate with ammonium sulfate generally gave the lowest profit.

5 Conclusions

In all trials, rock phosphate with ammonium sulfate showed a lower net profit than marl with ammonium phosphate. The result was strongly influenced by the fact that the price of rock phosphate is about 40 times as high as that of marl (1,600 Baht VS. 40 Baht per ton).

It is recognized that lime and fertilizer are only two of the many factors needed for high production.

If a farmer has inadequate resources to finance the best treatment indicated by these results he can select the one giving the optimum return based on money he can invest in his planting.

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STUDY ON RATES OF MARL FOR RICE PRODUCTION ON ACID SULPHATE SOILS IN THAILAND

Methee Maneewon, Nakorn Thawornwong and Boonthong Tantisira
Department of Land Development
Bangkok, Thailand

1 Summary

Field experiments were conducted in three series of acid sulphate soils which varied in soil acidity and land capability classes for paddy. In an extremely acid soil, application of both marl and fertilizers greatly increased grain yield of rice, and produced a significant increase in profit.

In a severely acid soil, marl alone gave no significant effect on total yield over four years, but in some years there were indications that liming is beneficial for the soil. This needs to be studied in relation to climatic patterns. Liming the soil at the rate of 3.1 tons per hectare with fertilizers gave the highest profit.

In a moderately acid sulphate soil, fertilizers alone are enough for improving yields. However, marling the soil at the rate of 3.1 tons per hectare together with fertilizers was superior over application of fertilizers alone, and gave the highest profit. The extra money revenue could cover the cost of marling.

2 Introduction

Acid sulphate soils in Thailand occur mainly in the central plains, but some are found along the eastern and southern coasts. The total area of these soils in the central plains is approximately 800,000 hectares. The most important crop in these areas is rice, which is also the most suitable one for these soils. Kevie and Yenmanas (1972) grouped the soils of the southern central plains into land capability classes for upland crops and for paddy. The acid sulphate soils of the area fall into three classes:

1) P - IIa, soils well suited for paddy, having slight limitations, due to acidity, that restrict their use for rice production;
2) P - IIIa, soil moderately suited for paddy, having moderate limitations (usually severe acidity) that restrict their use for rice production and/or require special management;
3) P - IVa, soils that are poorly suited for rice, having extreme acidity which severely restricts rice production. The soils also require very careful management.

Fertilization alone will not give the best yield in acid soils (Tisdale and Nelson 1967). Some management practices such as leaching, presubmergence and application of some chemicals may be impractical for farmers and are not always economic (Nhung and Ponnamperuma 1961). Liming is a practical way to improve the acid soils of the central plains because marl, a liming material, is found relatively close to the northern part of this area. Liming will decrease organic acids, carbon dioxide, soluble iron and aluminum that are harmful to rice, and will release calcium for plant growth (Berrera 1937, Koch 1947, Ponnamperuma 1960). By lowering the levels of soluble forms of iron and aluminum, liming should also increase the efficiency of phosphatic fertilizers. In very acid soils, the growth of micro-organisms is not normal (Alexander 1961). The micro-organisms cannot decompose organic matter and release nitrogen for plant growth. Liming will raise the pH and thus promote the growth of soil organisms. This should increase the mineralization of organically bound nitrogen as well as promote fixation of atmospheric nitrogen. The purpose of this study was to find the optimum rates of marl that give the most economic returns in improving the acid sulphate soils for rice growing for each of the three land capability classes.

3 Materials and methods

Field experiments were conducted in three series of acid sulphate soils. These varied in soil acidity and land capability classes for paddy.

1) Rangsit, very acid phase, an extremely acid soil with pH of 4.0 (dry top soil) and a lime requirement of 17.8 tons per hectare. The experimental site is at Ongkharak Experimental Station, a station of the Land Development Department in Nakorn Nayok Province. Due to the excessive soil acidity the land had been fallow for a long time before the experiment started. Land capability class for paddy is P - IVa. Much of the surrounding area is fallow because of high acidity. A considerable area has now been planted with casuarina trees.

2) Rangsit series, a representative of the severely acid group. The soil pH at the site where the research was conducted was 4.2 with a lime requirement of 13.8 tons per hectare. This site is at Pathumtani Land Development Centre, a centre of the Land Development Department. Land capability class for paddy is P - IIIa. The area around the centre is used for rice cultivation and horticulture.

3) Maha Phot series, an acid sulphate soil which is moderately acid. The research was done in a farmer's field in Prachinburi Province. The soil pH was 4.7 and the lime requirement was 6.5 tons per hectare. Land capability class for paddy is P - IIa. This site is in a rice growing area.

Additional analytical data characterizing these soils are given in Tables 1 and 2.

Table 1. Analytical data for top soils at start of experiment

Soil	Rangsit v. acid ph.		Rangsit series		Maha Phot series	
Site	Ongkharak Exp. St. plots sampled at end of first season		Pathumtani Land Devel. Centre soil survey data		Prachin Buri Province soil survey data	
	L_0	L_3[1]	range	(mean)	range	(mean)
pH (water 1:1)	5.3	7.5	4.2 -4.4	(4.25)	4.7 -4.9	(4.75)
pH (KCl 1:1)	4.2	6.7			-	
Org. carbon %	2.6		1.3 -2.5	(2.0)	1.0 -1.2	(1.1)
Active Fe %	0.62		0.27-0.87	(0.38)	1.15-1.28	(1.22)
Extr. Al, me/100 g	7.0	<0.2	0.7 -3.3	(1.6)	<0.05	
Available P., ppm	4		1 -5	(2.6)	2 -4	(3.1)
Extr. K, me/100 g	0.41		0.4 -0.65	(0.53)	0.64-1.05	(0.82)

[1] L_0 = without liming; L_3 = marled to lime requirement

Methods of analysis:

Organic carbon: *Walkley Black*. Active Fe: *dithionate-EDTA extraction*.
Extractable Al: *KCl extraction*. Available P: *Bray and Kurtz No. 2*.
Extractable K: *extraction with ammonium acetate at pH 7*.

Table 2. Analytical data for top soils (0-20 cm) after four years of experimentation

Soil		Rangsit v.acid ph.		Rangsit series	Maha Phot series
Site		Ongkharak Exp. St. plot sampled		Pathumtani LDC	Prachin Buri Pr.
		L_0	L_3[1]	nearby profiles	nearby profiles
pH (water 1:1)		3.9	4.3	4.15	4.6
pH (KCl 1:1)		3.2	3.6	3.45	n.d.
Org. matter %		3.5		2.47	1.0
Available P, ppm		4		5.5	6
Active Fe, %		0.83		0.43	1.6
Extr. Al	me/100 g	8.7	2.8	3.3	<0.1
Titr.acidity	"	26.6	21.1	18.6	10.3
Extr. Ca	"	2.2	9.4	9.7	6.4
" Mg	"	6.3		11.5	7.8
" Na	"	2.8		5.1	2.1
" K	"	0.61		0.53	0.35
Total N	%	0.16		0.18	0.08
" S	"	0.178		0.103	0.055
" Si	"	22.9		21.6	26.6
" Al	"	10.5		11.4	7.9
" Fe	"	3.25		2.8	3.74
" K	"	1.25		1.47	1.05
" Mg	"	0.46		0.54	0.62
" Ca	"	0.110	0.291	0.252	0.263
" Na	"	0.173		0.194	0.340
Total P	ppm	234		207	242
" Mn	"	178		113	525
" Cl	"	150		350	135
" Zn	"	52		68	79
" Cu	"	23		31	27

[1] L_0 = without liming; L_3 = marled to lime requirement

The experiments comprise eight treatments (Table 3) combining four rates of marl with and without fertilizers. Marl (70% passing through sieve No. 5 and C.C.E. = 85%) was used as a liming material. This was applied only in the first year of the experiments at least 15 days before the first transplanting. The marl was applied at rates of 0, 3.125 and 6.25 tons per hectare and also at the lime requirement rate as measured by Woodruff's (1948) method.

Table 3. Treatment codes

L_0 = No marl
L_1 = 3.125 tons marl per hectare
L_2 = 6.25 " " " "
L_3 = marled to lime requirement (except in Prachinburi Province where the rate was 12.6 tons/ha)
F_0 = No fertilizer
F_1 = Ammonium phosphate (16-20-0) 156.25 kg/ha at transplanting ammonium sulphate (21% N) 6.25 kg/ha as to topdressing before booting stage

In all three sites ammonium phosphate (16-20-0) was applied at each transplanting (156.25 kg/ha) and ammonium sulphate (65 kg/ha) as a top dressing before the booting stage.

The experiments were carried out in the wet season (July - November). The recommended variety of rice, RD - 7, was transplanted in plots of 15 sq. metres in Rangsit, very acid phase and Rangsit soils, using a spacing of 25 × 25 centimetres. In the Maha-Phot soil, a native variety named Ha-ruang was used in order to reduce losses from pests. Furadan 3 G was applied to all experiments for insect control.

In Ongkharak Experimental Station, a second crop was grown twice a year to see if this would reduce acid formation during the dry season. Unfortunately, yields were extremely low and the data were not statistically analysed. (Only a few farmers in this area grow a second rice crop in the dry season.)

All treatments were arranged in a randomized complete block design with four replications. The harvest area was 8 sq. metres. Actual grain weights were adjusted to a 14% moisture content.

The grain yield data (adjusted as above) by treatments are presented in Tables 4 to 7. The normal analyses of variance were performed but in the experiment at Ongkharak Station the standard error of treatment means exceeded some of the treatment yields due to the high variability and therefore the normal analysis is not valid.

Economic assessment was made by calculating the income from the grain yields in terms of extra crop over the control treatment and subtracting the costs of applying the marl and fertilizers. This information is presented in Tables 8 to 10.

Table 4. Rice yields in tons per hectare on acid sulphate soil with extreme acidity (Rangsit very acid phase)

Treatment	1976	1977	1978	1979	Mean	4-year total
L_0 F_0	0.09	0.10	0.04	0.21	0.11	0.44
L_1 F_0	0.43	0.38	0.74	0.73	0.57	2.28
L_2 F_0	0.06	0.08	0.15	0.21	0.13	0.50
L_3 F_0	0.07	0.42	0.62	0.57	0.42	1.68
L_0 F_1	<0.01	0.85	0.81	1.08	0.68	2.73
Mean of above	0.13	0.36	0.47	0.56	0.38	1.53
S.E. trtmt. mean	0.18	0.20	0.36	0.25	0.23	0.93
CV%	274.1	110.6	153.4	89.3	121.8	121.8
L_1 F_1	1.37	1.38	2.26	2.26	1.82	7.28
L_2 F_1	1.46	1.23	2.23	2.43	1.84	7.35
L_3 F_1	1.70	1.73	3.13	2.54	2.28	9.11
Mean of above	1.51	1.45	2.54	2.41	1.98	7.91
S.E. trtmt. mean	0.58	0.26	0.65	0.62	0.49	1.96
CV%	76.9	36.5	51.3	51.4	49.5	49.5

Table 5. Rice yields in tons per hectare on acid sulphate soil with extreme acidity (Rangsit very acid phase), adjusted by covariance to reduce effects of fertility variation in experimental site

Treatment	1976	1977	1978	1979	Mean	4-year total	
	A	A	A	A	A	A	B
L_0 F_0	0.08	0.08	0.01	0.19	0.09	0.36	0.88
L_1 F_0	0.35	0.26	0.58	0.63	0.46	1.82	3.17
L_2 F_0	-0.01	-0.04	-0.01	0.11	0.01	0.05	0.67
L_3 F_0	0.13	0.50	0.73	0.63	0.50	1.99	1.42
L_0 F_1	0.12	1.02	1.05	1.22	0.85	3.39	1.30
Mean	0.13	0.36	0.47	0.56	0.38	1.53	1.49
S.E. trtmt. mean	0.18	0.18	0.35	0.25	0.23	0.88	0.88
CV%	266.5	100.8	148.5	88.1	116.0	116.0	114.8
L_1 F_1	1.47	1.43	2.41	2.38	1.92	7.69	7.24
L_2 F_1	1.25	1.14	1.94	2.20	1.63	6.53	7.63
L_3 F_1	1.80	1.77	3.28	2.66	2.38	9.51	9.08
Mean	1.51	1.45	2.54	2.41	1.98	7.91	7.98
S.E. trtmt. mean	0.46	0.22	0.33	0.49	0.32	1.26	1.20
CV%	76.9	30.0	26.1	40.3	31.9	31.9	30.2

A - adjusted by covariance to account for fertility variation between first four rows and second four rows, with analyses of variance on first five treatments and last three treatments

B - adjusted by covariance with total sulphur content of 0-20 cm

Table 6. Rice yield in tons per hectare on acid sulphate soil with severe acidity (Rangsit series)

Treatment	1976	1977	1978	1979	Mean	4-year total
L_0 F_0	1.34	1.47	0.74	0.61	1.04	4.17
L_1 F_0	1.31	1.46	0.73	0.68	1.04	4.17
L_2 F_0	1.23	1.60	0.65	0.71	1.05	4.19
L_3 F_0	1.37	1.97	0.93	0.87	1.28	5.14
L_0 F_1	1.82	1.62	1.37	0.74	1.39	5.56
L_1 F_1	1.78	1.87	1.50	1.03	1.55	6.18
L_2 F_1	1.73	2.22	1.17	0.93	1.51	6.05
L_3 F_1	1.87	2.37	1.24	0.95	1.61	6.42
CV%	24.1	16.6	15.8	10.2	9.9	9.9
HSD 0.05	0.89	0.72	0.39	0.20	0.31	1.23
0.01	1.06	0.86	0.47	0.24	0.37	1.47
F_0	1.31	1.62	0.76	0.72	1.10	4.42
F_1	1.80	2.02	1.32	0.91	1.51	6.05
LSD 0.05	0.28	0.22	0.12	0.06	0.10	0.76
0.01	0.38	0.30	0.17	0.08	0.13	1.04
L_0	1.58	1.54	1.06	0.68	1.22	4.86
L_1	1.55	1.66	1.11	0.85	1.29	5.18
L_2	1.48	1.91	0.91	0.82	1.28	5.12
L_3	1.62	2.17	1.09	0.91	1.44	5.78
HSD 0.05	0.74	0.60	0.32	0.16	0.26	1.02
0.01				0.21		

NB: In this and following tables LSD is t × $\sqrt{\frac{\text{error variance} \times 2}{\text{no. of reps}}}$

HSD is q_α × SE trtmt. mean × $\sqrt{\frac{\text{error variance}}{\text{no. of reps}}}$

Table 7. Rice yields in tons per hectare on acid sulphate soil with moderate acidity (Maha Phot series)

Treatment	1976	1977	1978*	1979	Mean	4-year total
L_0 F_0	3.84	2.85	1.74	4.00	3.11	12.43
L_1 F_0	4.31	2.88	1.79	3.81	3.20	12.79
L_2 F_0	4.58	2.91	1.92	3.86	3.32	13.27
L_3 F_0	4.56	3.76	1.88	3.81	3.25	13.01
L_0 F_1	4.80	3.40	2.10	5.06	3.84	15.36
L_1 F_1	4.81	3.84	2.32	5.12	4.02	16.09
L_2 F_1	4.94	3.49	2.52	4.90	3.96	15.85
L_3 F_1	4.92	3.46	2.37	4.98	3.93	15.72
CV%	8.8	7.6	7.8	6.6	5.9	5.9
HSD 0.05	0.96	0.58	0.39	0.70	0.50	2.00
0.01	1.14	0.69	0.46	0.83	0.60	2.38
F_0	4.32	2.85	1.83	3.87	3.22	12.88
F_1	4.81	3.84	2.33	5.01	3.94	15.76
LSD 0.05	0.30	0.18	0.12	0.22	0.15	0.62
0.01	0.40	0.24	0.16	0.29	0.21	0.34
L_0	4.32	3.12	1.92	4.53	3.47	13.89
L_1	4.56	3.36	2.05	4.47	3.61	14.44
L_2	4.76	3.20	2.22	4.38	3.64	14.56
L_3	4.74	3.11	2.12	4.39	3.59	14.37
HSD 0.05	0.79	0.48	0.32	0.58	0.42	1.66

* No top dressing because of flooding

Table 8. Additional income received from improving acid sulphate soil with extreme acidity (Rangsit very acid phase)

Treatment	Cost baht/ha (1 application of marl, 4 of fertilizers)	Extra crop over L_0 F_0 (4-year total) kg/ha	Extra revenue baht/ha	Profit baht/ha
L_1 F_0	781	1842	6446	5665
L_2 F_0	1,563	66	231	-1332
L_3 F_0	4,448	1248	4370	-79
L_0 F_1	2.813	2298	8044	5232
L_1 F_1	3,594	6846	23962	20368
L_2 F_1	4,375	6915	24202	19827
L_3 F_1	7,261	8672	30351	23091
HSD P = 0.05		6334		22169
0.01		7534		27116

(20 baht = US $ 1)

Table 9. Additional income received from improving acid sulphate soil with severe acidity (Rangsit series)

Treatment	Cost baht/ha (1 application of marl, 4 of fertilizers)	Extra crop over L_0 F_0 (4-year total) kg/ha	Extra revenue baht/ha	Profit baht/ha
L_1 F_0	781	7	25	-756
L_2 F_0	1,563	20	69	-1494
L_3 F_0	3,438	970	3394	-43
L_0 F_1	2,813	1392	4873	2060
L_1 F_1	3,594	2016	7057	3463
L_2 F_1	4,375	1879	6577	2202
L_3 F_1	6,250	2258	7901	1651
LSD P = 0.05		763		2670
0.01		1038		3635

(20 baht = US $ 1)

Table 10. Additional income received from improving acid sulphate soil with moderate acidity (Maha Phot series)

Treatment	Cost baht/ha (1 application of marl, 4 of fertilizers)	Extra crop over L_0 F_0 (4-year total) kg/ha	Extra revenue baht/ha	Profit baht/ha
L_1 F_0	781	362	1267	485
L_2 F_0	1,563	844	2954	1391
L_3 F_0	3,156	580	2031	-1126
L_0 F_1	2,813	2932	10262	7450
L_1 F_1	3,594	3660	12811	9217
L_2 F_1	4,375	3423	11979	7604
L_3 F_1	5,969	3295	11533	5564
HSD P = 0.05		2002		7006
0.01		2381		8334

(20 baht = US $ 1)

4 Results and discussions

In the extremely acid soil (Tables 4 and 5), four years' records showed that application of both lime and fertilizers invariably increased the grain yield of rice. Application of marl equal to the lime requirement of the soil (17.8 tons/ha) plus fertilizers gave the highest yield but this was not statistically different from applications of marl in lesser rates plus fertilizers.

Unfortunately the results from the trial on the extremely acid soil show very high coefficients of variation. There are several reasons for this:

1) Because of the extreme acidity there were losses due to plant deaths in the plots receiving no marl (control and fertilizer only).
2) The relatively high yield of the L_1 F_0 treatment is partly attributable to heavy rain in the first year immediately after the application of fertilizer which resulted in flooding and some fertilizer from neighbouring plots spreading into one plot of this treatment as indicated by subsequent growth of the crop.

3) An appraisal of the results by rows across the blocks showed that there is a high variation in fertility down the rows of the blocks. This is confirmed by soil analyses carried out after the four-year period reported in this paper.

Splitting the analyses of variances into the groups of five and three treatments showed no significant differences of treatments within the groups. Direct comparisons of pairs of treatments showed that L_0 F_1 was significantly higher than L_0 F_0 for 1977, 1979 and over the four years but the increases for L_3 F_0 were not.

The increase in yield with years is noteworthy. This can be attributed to possible reduction in acidity by leaching after the fallow period and also to the fact that after prolonged flooding soil acidity is lowered by chemical reduction processes.

Table 8 shows that the marl plus fertilizer treatments are the only ones to give a significant increase in profit on the extremely acid soil.

A pot experiment study by Attanandana et al. (1981) also demonstrated that liming is required on the Rangsit soil, very acid phase, to achieve optimum response to fertilization.

In the severely acid soil (Table 6) response of rice yield to lime shows relatively the same trend as in the extremely acid soil. The highest yield was obtained from application of marl at lime requirement rate of the soil (13.8 tons/ha) plus fertilizers. This yield is not statistically different from yields for application of marl at lesser rates together with fertilizers or from the yield with fertilizers but without liming. Acidity in these soils may not play such an important role in fixing fertilizers into insoluble forms. In 1977 and 1979 fertilizers alone gave a lower yield than when applied together with marl. Marling may have improved soil properties and the availability of the fertilizers applied. Regardless of the rates, applying marl alone does not give significant increases in paddy yield over the four years. At present the decline in yields in the third and fourth years cannot be explained, nor can the lower yields for treatments receiving lime and fertilizers, compared to the experiment on the Rangsit very acid soil.

On the severely acid soil liming at the rate of 3.125 tons per hectare and applying fertilizer gives the highest profit (Table 9). The yield of that treatment showed some superiority over the treatment receiving only fertilizer, although the difference is not significant. In 1977 and

1979, it was found that marling played an important role in significantly increasing grain yield of rice and in 1979 there was a significant interaction with fertilizers. It may be that these effects can be explained by variation in the climatic patterns.

These results indicate that similar areas should be limed at the rate of approximately 3 tons per hectare to improve the soil.

The soil of the Maha Phot series is not extremely acid. Application of lime had little effect overall on the yield of rice (Table 7). Fertilizer applications play a very important role in increasing grain yield in this soil. The highest yield was obtained by application of fertilizers with lime at the rate of 3.125 tons per hectare. This also gave the highest net profit (Table 10).

The higher overall yield at this site compared to the other two may be due to the fact that the trial was on land which had been fertilized by the farmer in previous years.

Acknowledgements

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ROCK PHOSPHATE IN RICE PRODUCTION ON ACID SULPHATE SOILS IN VIETNAM

Le Van Can
Faculty of Agriculture, University of Cantho
Vietnam

1 Summary

In Vietnam acid sulphate soils cover over 2 million hectares in the Mekong Delta in the South and over 200,000 ha in the Delta of the Red River in the North. Rock phosphate is mined from large deposits at Lao Cai in the North and has been tried there as fertilizer for paddy production on various soils since 1960, with positive results on acid soils low in phosphorous, especially on acid sulphate soils. On these latter soils low grade Lao Cai phosphate gives a strong residual effect which is explained by the formation of iron hydroxide coatings on its microcristalline grains.
Since 1975 the Lao Cai phosphate has been introduced successfully in paddy production on acid sulphate soils in the Mekong Delta as a replacement of imported phosphates. Demand for Lao Cai phosphate in the South is now increasing rapidly and the government is giving high priority to its transportation and distribution as well as to exploration for local deposits of natural phosphate.

2 Phosphate deposits of Vietnam

In the Socialist Republic of Vietnam known phosphate deposits are mainly located in the North. The most important of these is mined in Lao Cai province near the boundary with China. It has been studied amply (Delucidier 1928, Lacroix 1938, Fromaget 1941, Neumann 1958) and is considered to be one of the largest reserves in the world. The Lao Cai phosphate is of Paleozoic sedimentary origin and has a micro-cristalline nature (Neumann 1958).

Lao Cai phosphate comes in various grades according to its P_2O_5 content, but for agricultural practices normally only high and low grades are distinguished. The average chemical composition is as follows (Table 1).

Table 1. Average chemical composition (in %) of Lao Cai phosphate

	Total	Citric sol.	Total							Loss on
	P_2O_5	P_2O_5	CaO	MgO	R_2O_3	SiO_2	Mn	B	Cu	Ign.
High grade	35-40	4.5-5.7	48-54	2-5	1- 3	1- 4	0.1-0.3	0.001-0.003	0.001-0.003	0.5-1.2
Low grade	15-28	3.8-4.3	30-45	1-4	4-10	6-22	1-3	0.001	0.001-0.003	1.2-8.5

3 Acid sulphate soils in Vietnam

In the North of the country acid sulphate soils are present in the Delta of the Red River. Well developed acid sulphate soils occur in the eastern part of the delta along the coast in a complex of so called acid saline soils characterized by very strong acidity due to free aluminum. Potential acid sulphate soils occur in swamps in the southern part of the delta. Precise delineation of soil limits has as yet not been completed but estimates for the total area of acid sulphate soils in the Red River Delta range between 200,000 and 250,000 ha (Vu Ngoc Tuyen et al. 1963).

In the South of the country acid sulphate soils are concentrated in the Mekong Delta. Various estimates of surface areas have been made (Moormann 1960, Pham-Huu Anh 1966, Truong Dinh Phu 1967). Taking into account developed and potential acid sulphate soils and areas that are affected periodically by strong acid surface water, the total area comes to an estimated 2,600,000 ha (Vo-tong Xuan et al. 1981).

Fertilizer research for rice production was well on its way in Vietnam already before 1960 when the country became divided as a result of the Geneva treaty. In the North it became centred on the application of Lao Cai phosphate which was available locally and in large quantities. A program of long term field trials was conducted in twenty three provincial experimental stations and thousands of complementary experimental fields of youth organizations, together representing a wide range of pedo-climatic situations. The program was supported by basic and routine laboratory work, and the results made it possible to draw general conclusions pertaining to phosphate fertilization in wet-land rice production in the northern part of Vietnam. The following conclusions are of special interest for the present subject:

1) The effect of phosphate fertilizer in wet-land rice production depends strongly on the total P_2O_5 content of the soils under consideration, and hardly on the type of fertilizer used, viz. mono-superphosphate, fused phosphate, Japanese thermophosphate, various natural phosphates from local origin (Le Van Can 1977a).
2) Lao Cai phosphate ground to particle size smaller than 0.17 mm gives significant yield increases for nearly all paddy soils with a pH below 5 and with a total P_2O_5 content lower than 0.06%.
3) On five of the ten soil types involved (Table 2), Lao Cai phosphate, alone or combined with N fertilizer in various proportions and doses, and for different rice varieties, did not contribute significantly to yield increases, although in some trials on these soils it was shown to improve biological performance of the rice plants.
4) The best response to Lao Cai phosphate was observed on acid sulphate soils (Table 2).

Table 2. Effect of Lao Cai phosphate applications on rice yield for various kinds of soil in the North of Vietnam

Soils			Mean increase of rice yields	
Type	pH (Kcl)	tot. P_2O_5%	kg paddy/ha	significance[1]
1) Recent alluvium Red River	7.2	0.12	0	0
2) Brackish soil Ninh Binh	7.5	0.12	0	0
3) Gley soil Nam Ha	4.2	0.08	110	0
4) Alluvial soil Ma River	5.6	0.09	120	0
5) Degraded soil Tam thien Mau	4.1	0.03	160	0
6) Alluvial soil Thai Binh River	4.5	0.06	210	+
7) Degraded soil Vinh Phu	4.8	0.05	220	+
8) Swamp soil Vinh Phu	4.5	0.07	270	+
9) Acid coastal soil Ha Finh	4.1	0.03	370	+
10) Acid sulphate soil Hai Kien	4.2	0.04	420	++

[1] 0: not significant; +: significant; ++: highly significant

Rice yield increases are generally higher with application of high grade Lao Cai phosphate than with low grade, at equal doses of P_2O_5. On acid sulphate soil, however, the difference is relatively small and residual effects from the second season onward are virtually equal for both grades as is demonstrated by experimental results (Table 3).

Table 3. Direct and residual effect of high and low grade Lao Cai phosphate application on rice yield in acid sulphate soils of the Red River Delta

Treatment	Composition of phosphate in %			Paddy yield in t/ha			Effect of phosph. t/ha Direct	Effect of phosph. t/ha Residual
	P_2O_5	CaO	R_2O_3	Season 1	Season 2	Season 3	Season 1	Seasons 2+3
No phosphate	-	-	-	17.6	21.4	34.1	-	-
160 kg/ha high grade phosphate	37.3	53.6	0.92	22.2	29.2	36.9	4.6	10.6
320 kg/ha low grade phosphate	18.5	27.3	9.36	20.1	28.6	36.7	2.5	9.8
LSD 0.05				1.9	2.1	3.2		

Micromorphological examination of the Lao Cai phosphate revealed that the particles of the high grade fertilizer are agglomerates of granules consisting entirely of calcium phosphate, whereas in the low grade the agglomerates contain inclusions of quartz and amphibole and the calcium phosphate granules are coated with iron hydroxide, probably transformed magnetite (Figure 1). The presence of iron hydroxide in low grade Lao Cai phosphate is confirmed by Thermal Analysis producing a distinct minimum at 240°C in the DTA curve, corresponding with the loss of water of cristallisation of iron hydroxide (Figure 2).

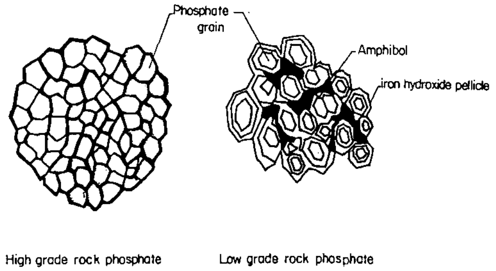

Figure 1. Micromorphological structure of Lao Cai Rock phosphate

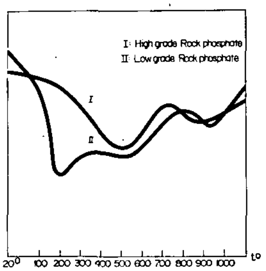

Figure 2. DTA curves for Lao Cai Rock phosphate

The iron hydroxide coatings in low grade phosphate reduce the availability of the phosphate, but in acid sulphate soils they are probably dissolved gradually under the influence of recurrent acidification between growing seasons. Thus would explain why the residual effect of both grades of phosphate in acid sulphate soils are similar.

In the South of Vietnam all phosphate fertilizers used to be imported. Natural phosphate came from as far as Tunesia or Florida. Lime was more easily available and has been tried out as an amendment on acid sulphate soils in the Mekong Delta. These trials confirmed the experience in other tropical areas that lime alone has no or negative effects on acid sulphate soils, but when combined with N + P fertilizer it increases the efficiency of the N + P application. For a period this combination was standard practice in fertilizing acid sulphate paddy soils in the Mekong Delta. The efficiency of the imported fertilizers, however, varied widely with proportion and solubility of the phosphate component and the residual effect of lime was small and usually lasted less than three crops. These agronomic disadvantages are partly related to the very low phosphorus status of the acid sulphate soils of the Mekong Delta (Moormann 1960, Kyuma 1976).

After the reunion of the country, alternative fertilizing practices were developed for the Mekong Delta using high grade Lao Cai phosphate instead of the imported phosphates. The results were satisfactory (Le Van Can 1977b). This is illustrated by the results of experiments on acid sulphate soil at An Lac, 30 km from Ho Chi Minh City shown in Table 4.

Table 4. Direct and residual effect of high grade Lao Cai phosphate with and without N + K on rice yield in acid sulphate soil at An Lac experiment station (Mekong Delta)

Treatment	First season Paddy yield t/ha	First season Direct effect t/ha	Second season Paddy yield t/ha	Second season Residual effect t/ha	Combined effect of two seasons t/ha	Combined effect per 100 kg of phosphate (kg paddy)
1) Control	1.57	-	0.87	-	-	
2) Phosphate 600 kg/ha	1.60	0.03	1.41	0.54	0.57	95
3) $N_{60}K_{30}$	1.48	-	1.08	-	-	
4) $N_{60}K_{30}$ + phosphate 600 kg/ha	2.82	1.34	1.91	0.83	2.17	361
LSD 0.05	0.12		0.18			

The data of Table 4 demonstrate that Lao Cai phosphate alone had no significant effect in the first season, but its residual effect was remarkable: an increase of rice yield of 62% in the second year. Nitrogen + potassium fertilizer, in the absence of phosphate also had no effect in the first season and only a small positive effect in the second season. Both the direct and the residual effect of phosphate was greatly increased by applying N and K.

Experiments in other stations (Lathi Hien et al. 1979) demonstrated that on acid sulphate soils in the Mekong Delta, where rice plants died without phosphate, more than 2 ton paddy per hectare was produced with an application of Lao Cai phosphate at a rate of 1-2 tons/ha.

Similar positive results have been obtained in the farmer's field, and the demand for Lao Cai phosphate is increasing rapidly in the southern provinces with acid sulphate soils. In view of this the government is giving high priority to transportation and distribution of Lao Cai phosphate. Also the exploration for possible phosphate deposits in the South is promoted to increase the availability of natural phosphates for improving the acid sulphate soils of the Mekong Delta.

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MANAGEMENT OF ACID SULPHATE SOILS IN THE MUDA IRRIGATION SCHEME, KEDAH, PENINSULAR MALAYSIA

Xaviar Arulandoo
Rice Research Branch, MARDI
Kam Suan Pheng
University Sains Malaysia, PENANG

1 Summary

Field trials were conducted to study the influence of rice straw, lime and fertilizers on rice grown on acid sulphate soils. Rice frequently shows iron toxicity symptoms in unamended fields, particularly during the dry season. Lime application at the rate of 2.5 tons/ha increased rice yields substantially through a general improvement in crop growth and plant nutrient status. There was a clear residual effect of lime in the subsequent rice crop. Incorporation of crop residue increased dry matter production, plant potassium content and grain yield. There was no residual effect of rice straw incorporation in the subsequent rice crop. Nitrogen, phosphorus and potassium fertilizers are needed for maximizing rice yields. Favourable responses were obtained with the application of 90 kg N/ha, 50 kg P_2O_5/ha and 40 kg K_2O/ha. In the absence of phosphorus application, phosphorus deficiency symptoms were prevalent and caused a delay in maturity of the crop by about two weeks. Potassium application at the tillering stage of rice growth increased rice grain yield.

2 Introduction

The soils of the Kedah-Perlis coastal plain are predominantly marine alluvia with strips of riverine alluvia further inland and therefore are suited for the cultivation of rice. However, there are two main areas of acid sulphate soils (Figure 1). They have been identified as the Telok and Guar soil series with an area of 20,650 ha and 5,000 ha respectively (Soo 1972).

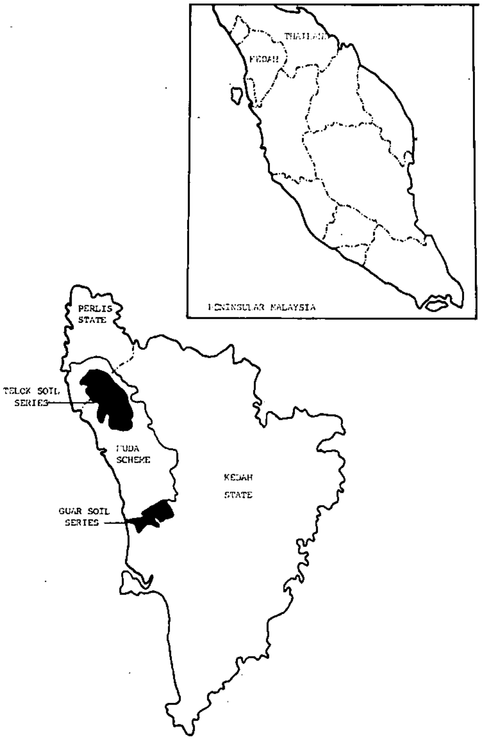

Figure 1. Distribution of acid sulphate soils in the Muda Irrigation Scheme, Kedah, Peninsular Malaysia

The Telok and Guar soil series are characterized by low pH (1:2.5 in distilled water) not exceeding 4.0, sulphurous condition, high organic top soil as well as high clay contents. The Telok soil series developed under 'gelam' (local name for *Melaleuca leucodendron*) swamp conditions has a relatively lower organic content in the top soil than the more recently developed Guar soil series which originates from mangrove swamp conditions.

In the past rice yields in the Guar and Telok soil series were the lowest in the MUDA scheme area. Responses to fertilizer application without incorporation of lime were poor and inconsistent. The results of the early liming and fertilizer trials showed that favourable responses were obtainable with lime applications of 1-2 tons/ ha for the first crop and a maintenance dose of 1 ton/ha lime for the succeeding crop

(MADA 1970, Leong 1972). Nitrogen fertilizer at the rate of 60-70 kg N/ha with an early application of lime was sufficient for maximizing yield for a single crop in the acid sulphate soils.

The implementation of the MUDA irrigation scheme in 1970 has enabled double cropping of rice in about 100,000 ha of land within the plain. The shift from a single rice crop to the more intensive cultivation has led to an overall improvement of the acid sulphate soils. The Telok soil series have been observed to give grain yields comparable to non-acid sulphate soils. This can be attributed to the introduction of lime subsidy into the area.

Ariffin (1974) reported an estimated yield increase of 43% as a result of liming in the Telok soil series. Less liming was done in the Guar area where acid sulphate phenomena are more severe than in the Telok area. Rice yields were poor on the Guar soils showing iron toxicity symptoms, particularly in the dry season and after droughts in 1977-1978.

An integrated approach involving research into both agronomic and plant breeding aspects has been adopted to alleviate the problems of rice cultivation in acid sulphate soils. This paper reports the agronomic trials pertaining to management and fertilizer practices conducted from 1975 to 1980.

3 Description of study area

The important characteristics of the soil are given in Table 1.

A soil profile description is given in Table 2.

Table 1. Some important characteristics of the Guar soil series

Soil properties	Soil depth (cm)	
	0-15	15-30
Sand %	1.5	
Silt %	45.5	
Clay %	53.0	
pH (1:2.5 in distilled water), air dry soil	3.45	3.22
pH (1:2.5 in 1N KCl), air dry soil	2.97	2.74
EC of 1:5 water extract, mmhos/cm	0.24	0.28
Organic matter %	7.71	4.00
CEC, meq/100 g soil	21.60	20.20
Exchangeable cations, meq/100 g soil		
Na	0.21	0.21
K	0.31	0.33
Ca	0.35	0.30
Mg	0.47	0.52
Available P, ppm (Bray & Kurtz No. 2)	6.74	4.88
Water soluble sulphate %	0.09	0.09
Free iron oxides %	2.81	3.32

Table 2. Profile description of Guar soil series (Gopinathan 1979)

Horizon	Depth (cm)	Description
Ap	0-20	Dark brown (10 YR 3/3) organic clay, weak medium and fine subangular blocky, firm, many medium distinct strong brown (7.5 YR 5/8) mottles along root channels; many medium and fine roots; abrupt boundary.
B 2g	20-65	Dark brown (10 YR 3/3) organic clay; moderate medium angular blocky; friable; few fine distinct brownish yellow (10 YR 6/8) mottles; common patches of partly decomposed medium roots and other plant remain; few fine roots; diffuse, wavy, boundary.
B 3g	65-77	Very dark greyish brown (5 Y 3/1) organic clay; massive structureless, slightly sticky; few fine distinct brownish yellow (10 YR 6/8) mottles mainly along roots channels; common patches of partly decomposed medium roots and other plant remains; diffuse wavy boundary.
Cg	77	Very dark greyish brown (5 Y 3/1) organic clay, massive structureless; many raw and partially decomposed plant remains.

Mean temperature values range from 26°C to 28°C while mean relative humidity values range between 71% and 87%. The annual rainfall averages 2300 mm and the rainfall pattern is characterized by a relatively dry period from December to March (monthly rainfall below 100 mm), followed by a period of moderately high rainfall from April to July (monthly average of 180 - 230 mm) and a wet period from August to November (monthly average of 200 - 300 mm).

The area is used only for rice cultivation with two crops per year. The dry-season crop from February/March to August/ September is irrigated while the wet season crop from September/October to December/-

January is rainfed. During the dry fallow period in the months of February and March, the soil surface develops wide, deep cracks and the ground water table is often observed to be more than 2 meters below the ground surface. In contrast, during the short period between the harvesting of the dry season crop and the transplanting of the wet season crop, the soil remains saturated. Therefore drying of the soil and the accompanying acidification occur only during the dry fallow months of February/March, before the dry season crop.

4 Studies on management practices

A field trial was initiated in the dry season 1979 to evaluate the performance of 2 rice varieties under restricted drainage (once at one week before transplanting), lime application and rice straw incorporation. In the subsequent wet season 1979, the trial was maintained to study the residual and cumulative effects of the treatments.
In the dry season the effect of restricted drainage on crop growth and yield was not conclusive due to block effects and replicate differences. The water control treatment was discontinued in the subsequent rice growing season (wet season 1979) and the trial was continued to study the residual and cumulative effects of liming and crop residue treatments. Thus, only the results of the effects of lime and crop residue treatments and the varietal differences in crop performance are discussed.

4.1 Effect of lime and crop residue incorporation in the dry season crop

Lime application at the rate of 2.5 tons/ha in the dry season significantly increased rice yields ($p = 0.01$) mainly by increasing the spikelet number and to a lesser extent by increasing panicle number and grain weight (Table 3). There was a general improvement in crop growth and nutrient content of the rice plant. These were clearly evident at the panicle initiation stage of rice growth. There was a marked increase in the plant dry matter production ($p = 0.01$). The plant dry weight also increased with crop residue incorporation (p = 0.05), but in the presence of crop residue, the response of dry matter production to lime was lowered. Ca and P content in the plant were increased by liming whilst the K content increased with crop residue treatment (all significant at p = 0.01). Liming also significantly reduced the plant Fe content (p = 0.01).

Differences in grain yield between the variety Setanjung (IR 22/Pazudofusu) and 'Seribu Gantang' (IR 8/Engkatek/Sacupak) were insignificant. The higher grain weight of Setanjung compensated for its lower spikelet number and higher percentage of unfilled grains.

4.2 Residual effect of lime and crop residues in the wet season crop

The data in Table 4 indicate a significant residual effect of liming on dry matter production, N, Ca and Fe contents at panicle initiation and on the grain yield, the spikelet number (all at p = 0.01) and percentage of unfilled grains (p = 0.05) at harvest.

Table 3. The influence of liming and incorporation of crop residues on dry matter production and nutrient element contents at panicle initiation, and on grain yield and yield attributes of two rice varieties, dry season, 1979

Variety	Crop residue applied (ton/ha)	Lime applied (ton/ha)	Plant samples at panicle initiation stage						Grain yield (g/plot^2)	Panicle number (per hill)	Spikelet number (per panicle)	% of unfilled grains	Grain weight (g/1000)
			Dry matter^1 (g)	N	P	K	Ca	Fe					
				–	% of dry matter		–	ppm					
Setanjung	0	0	12.1	2.14	0.15	2.42	0.13	1764	624	8.4	74	43.8	23.0
	0	2.5	34.7	1.72	0.19	2.45	0.33	1379	1428	11.9	88	48.4	27.3
	0	5.0	37.2	1.99	0.20	2.46	0.41	1058	1383	11.6	92	44.4	27.4
	5	0	22.9	1.94	0.18	3.03	0.14	1956	1368	11.2	92	37.0	25.5
	5	2.5	36.3	2.02	0.19	3.10	0.31	1452	1635	11.6	104	40.3	27.6
	5	5.0	40.6	1.98	0.19	2.88	0.33	1007	1626	10.9	106	40.4	27.5
Seribu Gantang	0	0	19.0	1.84	0.12	2.12	0.12	1591	786	11.1	97	44.0	18.3
	0	2.5	37.6	1.84	0.16	2.19	0.28	1348	1528	11.6	121	29.9	19.1
	0	5.0	38.6	2.03	0.16	2.11	0.33	1366	1595	11.6	132	36.1	19.0
	5	0	29.6	1.80	0.15	2.61	0.11	2058	1245	10.6	115	44.4	17.8
	5	2.5	35.4	1.49	0.16	2.53	0.25	1174	1609	10.5	140	32.7	19.5
	5	5.0	40.1	1.70	0.17	2.60	0.29	1404	1644	11.5	147	35.6	19.4
Overall mean			32.0	1.88	0.17	2.54	0.25	1510	1370	11.0	109	39.7	22.6
C.V. (%)			19.6	16.5	11.8	13.4	10.8	34.9	15.3	11.5	13.5	19.4	4.5

[1] The dry weight was taken from 4 sampled hills per plot

[2] The harvest area in a plot was 3.36 m^2, comprising 84 hills

Table 4. The residual effects of lime and crop residue on plant dry matter production and nutrient element contents at panicle initiation, and on grain yield and yield attributes of two rice varieties, wet season, 1979-1980

			Plant samples at panicle initiation stage										
Variety	Crop residue applied[1] (ton/ha)	Lime applied[1] (ton/ha)	Dry matter[2] (g)	N -	P % of dry matter	K	Ca -	Fe ppm	Grain yield (g/plot[3])	Panicle number (per hill)	Spikelet number (per panicle)	% of unfilled grains	Grain weight (g/1000)
Setanjung	0	0	31.9	2.81	0.27	2.05	0.18	1491	1387	11.3	86	30.9	23.2
	0	2.5	65.9	2.20	0.30	1.95	0.28	739	2040	11.6	109	18.6	25.2
	0	5.0	56.2	2.43	0.29	1.87	0.33	658	2105	11.3	114	20.3	24.6
	5	0	43.4	2.72	0.27	2.54	0.16	980	1650	10.6	90	26.3	24.3
	5	2.5	61.4	2.17	0.28	2.39	0.27	801	2056	10.3	107	15.4	24.8
	5	5.0	71.7	2.12	0.26	2.38	0.35	574	2056	11.4	115	15.1	25.3
Seribu Gantang	0	0	57.9	2.50	0.26	1.80	0.16	911	1668	10.7	124	26.3	17.6
	0	2.5	61.8	2.31	0.25	1.66	0.27	706	1632	10.2	135	29.4	18.3
	0	5.0	89.3	2.30	0.27	1.82	0.28	449	1861	10.8	138	26.7	17.6
	5	0	67.1	2.44	0.27	1.99	0.15	637	1711	11.7	133	28.4	17.8
	5	2.5	63.0	2.09	0.26	1.97	0.24	518	1833	10.8	141	26.5	18.4
	5	5.0	72.8	2.39	0.28	1.97	0.26	565	1969	11.0	137	24.3	18.4
Overall mean			61.9	2.38	0.27	2.03	0.24	752	1830	11.0	119	24.0	21.3
C.V. (%)			16.8	9.7	5.5	17.8	8.3	31.5	10.2	6.1	10.9	20.7	12.7

[1] Treatments applied only in the dry season 1979. No additional treatments applied in the wet season 1979/1980

[2] The dry weight was taken from 4 sampled hills per plot

[3] The harvest area in a plot was 3.36 m^2, comprising 84 hills

The variety Setanjung showed a greater response in its dry matter production to the first than to the second residual lime level. The reverse is true for Seribu Gantang. Residual effects of liming included an increase in the plants Ca content and a decrease in the N and Fe contents and a positive response in grain yield. The general grain yield response to residual lime is due to an increase in spikelet number and a reduction in the percentage of unfilled grains. There was no significant difference in the grain yields of the two varieties; although Seribu Gantang had a higher spikelet number, it had the setback of a lower grain weight and lesser extent of grain filling compared with Setanjung.

Crop residue incorporation had no direct influence on crop growth and yield in the second season after application, but led to a significant increase in plant K content.

4.3 Effects of continued application of lime and crop residues

Liming and crop residue incorporation for two consecutive seasons did not further improve the grain yield. The crop residue treatment increased the plant dry weight, the plant K content especially for Seribu Gantang and to a lesser extent the plant P content especially for Setanjung (all at $p = 0.01$; Table 5). Two consecutive limings further increased the plant Ca content ($p = 0.01$).

Table 5. The effects of applying lime and crop residues for two consecutive seasons on plant dry matter production and nutrient element contents at panicle initiation; main season 1979-1980

	Crop residue applied[1] (ton/ha)	Lime applied[1] (ton/ha)	Plant samples at panicle initiation stage				
			Dry matter[2] (g)	N	P	K	Ca
Variety				- % of the dry matter -			
Setanjung	0	0	45.5	2.63	0.27	2.41	0.18
		2.5	57.2	2.41	0.27	2.24	0.36
		5.0	61.9	2.24	0.26	2.13	0.39
	5	0	60.3	2.23	0.31	2.86	0.18
		2.5	76.0	2.35	0.31	2.52	0.35
		5.0	88.6	2.15	0.30	2.24	0.35
Seribu Gantang	0	0	59.2	2.46	0.23	1.63	0.17
		2.5	72.7	2.04	0.27	1.67	0.29
		5.0	85.7	2.12	0.27	1.63	0.36
	5	0	65.9	2.32	0.26	2.36	0.18
		2.5	83.0	1.80	0.27	2.25	0.29
		5.0	83.2	2.01	0.28	2.39	0.35
Overall mean			70.0	2.23	0.27	2.19	0.29
C.V. (%)			12.0	7.4	7.9	11.6	8.0

[1] Treatments applied in both the dry season 1979 and the wet season 1979/1980

[2] The dry weight was taken from 4 sampled hills per plot

4.4 Effect of seasons

It is evident that production is higher in the wet season than in the dry season, even in the untreated plots. The higher spikelet number and improved grain filling contributed largely to the higher grain yields in the wet season. The plant Fe contents were also lower in the wet season and visual iron toxicity symptoms were less severe than in the dry season.

5 Response of rice to lime and phosphorus fertilizer application

In the wet season 1979 a field trial was conducted to study the response of rice to liming (0 and 2 tons/ha) and soluble phosphate application (0, 50 and 100 kg P_2O_5/ha).

There was a marked increase in grain yield ($p = 0.05$) with application of 2 tons/ha lime together with 100 kg P_2O_5/ha (Table 6). Application of either lime or phosphorus alone did not cause significant grain yield increases.

Table 6. Effect of lime and phosphorus application on grain yield of padi Seribu Gantang (wet season 1979/1980)

Treatments		Grain yield
Lime (tons/ha)	P_2O_5 (kg/ha)	(kg/ha)
0	0	3561
0	50	3747
0	100	3763
2.0	0	3836
2.0	50	3964
2.0	100	4086
	Mean	3826
	CV$\bar{x}$ %	8.1
	LSD 5%	467.0

Yet the number of tillers and plant height at maximum tillering were increased considerably ($p = 0.01$) with application of phosphorus fertilizer (Table 7). The application of lime had no influence on plant growth parameters.

Table 7. Effect of lime and phosphorus application on plant growth parameters

Treatments Lime (tons/ha)	P_2O_5 (kg/ha)	Plant height at max. tillering (cm)	Tiller number at maximum tillering	Number of days to 50% heading stage
0	0	50.9	17.9	83
0	50	60.3	19.6	80
0	100	66.9	17.7	69
2.0	0	53.4	16.7	84
2.0	50	64.5	18.0	73
2.0	100	65.0	18.2	73
Mean		60.2	18.0	77.0
$CV\bar{x}$ %		5.8	12.0	5.0
LSD 5%		5.2	3.7	6.0
LSD 1%		7.2	5.1	8.0

Phosphorus deficiency symptoms were very well exhibited in the control plots at about 2-3 weeks after transplanting. The rice plants were stunted, had narrow leaves and an erect canopy. The maximum tillering stage was delayed and the rice plants had a dirty dark green appearance. Phosphorus application clearly shortened the growing season. In normal circumstances, rice plants are harvested at about 30 days after 50% heading. In the control plots the 50% heading stage occurred about 14 days later than when phosphorus had been applied.

The application of lime at 2 tons/ha increased the soil exchangeable calcium by about 1.8 meq/100 g soil (analysed after harvest), indicating a potential residual effect of lime application. Available phosphorus was not influenced by the application of soluble phosphate fertilizer. The soil remained deficient in phosphorus with available phosphorus contents of the soil after harvest of less than 3 ppm (Bray & Kurtz no: 2) in all the plots.

6 Nitrogen and potassium fertilizer studies

Appropriate management and fertilizer practices are a prerequisite for establishing normal rice growth on the acid sulphate soils. Application of fertilizer alone, i.e. without liming, has detrimental effects on the growth of the rice crop. The role of various management practices and phosphorus fertilizer have been illustrated. In this section response to nitrogen and potassium fertilizer are discussed. In all the experiments lime was applied at the rate of 2 tons/ha prior to the fertilizer treatments.

Responses to nitrogen were more marked (p = 0.01) in the wet season than in the dry season and rice grain yields were correspondingly higher in the wet season (Figure 2). Prior to the dry season irrigated crop, the field is subjected to a drying state, promoting oxidative processes favouring the development of a more severe acid sulphate condition. Hence, responses to fertilizer are poor and yield relatively lower in the dry season. During the dry season crop, a score of 5 (following the scale from Ponnamperuma, F.N. 1979, IRRI) in the scale for scoring iron toxicity is not uncommon. In most instances growth and tillering were retarded, with many discouloured leaves and were especially observed to occur at about 3-4 weeks after transplanting.

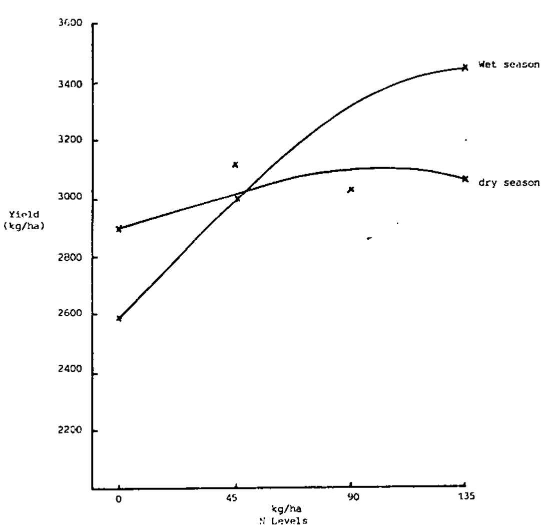

Figure 2. Response of rice to nitrogen in the Guar soil series (average of 4 seasons)

Responses to potash application in the Guar soil series was more evident during the dry season crop (p = 0.01) especially at the highest applications of nitrogen (Table 8). There was no significant increase in grain yield due to potash application in the wet season.

Table 8. Effect of various levels of nitrogen and potassium on grain yield of padi Sekencang[1]

Treatment kg/ha		Grain yield kg/ha	
N	K_2O	Dry season 1977	Wet season 1977/78
0	0	2390	2521
0	30	2683	3391
0	60	3374	2892
45	0	3489	3082
45	30	3469	3978
45	60	3274	3542
90	0	3589	3829
90	30	4139	3337
90	60	4559	3506
135	0	4031	3806
135	30	3885	3750
135	60	4682	3587
	Mean	3603	3435
	CV$\bar{x}$ %	11.0	10.4

[1] C4-63/Tadukan

Potash top dressing at about the maximum tillering stage of rice increases grain yield ($p = 0.05$; Table 9). The effect of a split application at low rates was inferior to that of a single application of potash at the maximum tillering stage.

Table 9. Effect of split application of potassium on grain yield of padi Sekencang (N: 80 kg/ha; P_2O_5: 40 kg/ha; K_2O: 40 kg/ha)

Time of potassium application				Grain yield (kg/ha)
B	AT	MT-PI	H	wet season 1978/1979
-	-	-	-	2576
40	-	-	-	2897
-	40	-	-	2852
-	-	40	-	3547
-	-	-	40	2734
20	-	20	-	3251
-	20	-	20	2831
-	20	20	-	2941
-	13.3	13.3	13.3	3200
10	10	10	10	2675
			Mean	2950
			CV$\bar{x}$ %	17.8

B - Basal, AT - Active tillering, MT-PI - Maximum tillering to panicle initiation, H - 10% heading

7 Recommendations

Hitherto, there has been no recommendation for management practices and fertilizer levels for rice grown on the acid sulphate soils of the MUDA scheme. Based on the studies discussed in this paper, the following set of practices are recommended for rice growing on acid sulphate soils of the Guar:

- incorporation of lime at the rate of 2 tons/ha in the dry season;
- nitrogen, phosphorus and potassium application at the rate of 90 kg N/ha as urea; 50 kg P_2O_5/ha as soluble phosphates and 40 kg K_2 as muriate of potash.

  Nitrogen is to be applied in two split doses; half at tillering stage and half at reproductive stage. Phosphorus should be applied as a basal dressing whilst potash should be applied at the tillering stage.

  In the study, incorporation of rice straw at the rate of 5 tons/ha, two weeks before transplanting did not have any adverse effects on rice plant performance. On the contrary rice straw incorporation increased rice grain yield. Rice straw could be utilized beneficially if incorporated into the soil a few weeks prior to transplanting particularly for the dry season crop.

With the above management practices, it has been observed that even the rice variety MR 1 (IR 22/Pazudofusu) which is relatively susceptible to the acid sulphate conditions has normal growth and produces yields at par to the tolerant variety Seribu Gantang (IR 8/Engkatek/Sacupak).

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FIELD AMELIORATION OF AN ACID SULFATE SOIL FOR RICE WITH MANGANESE DIOXIDE AND LIME

F.N. Ponnamperuma and J.L. Solivas
The International Rice Research Institute
Los Baños, Philippines

1 Summary

The effects of MnO_2 (100 kg/ha) and $CaCO_3$ (5 t/ha) on iron toxicity symptoms and yield of IR26 and IR43 on a flooded acid sulfate soil were studied in a replicated factorial experiment in a farmer's field.
The best treatment according to symptoms at 4 and 8 weeks after transplanting was IR43 (a moderately tolerant variety) in the presence of $CaCO_3$ and MnO_2. The worst was IR26 (a moderately susceptible variety) in the absence of $CaCO_3$ and MnO_2. Analysis of variance of the symptoms scores revealed no significant response to $CaCO_3$, a significant difference between the two varieties, and a highly significant positive response to MnO_2.
The best treatment based on grain yield was IR43 in the presence of MnO_2, regardless of the presence of $CaCO_3$. The worst was IR26 without $CaCO_3$ and MnO_2. Analysis of variance revealed a non-significant response to $CaCO_3$, a highly significant varietal difference, a highly significant positive response to MnO_2, and a highly significant variety × MnO_2 interaction.
IR26 gave a response of 1.2 t/ha to MnO_2 in the presence of $CaCO_3$ whereas IR43 showed a response of 2.2 t/ha to MnO_2 in the absence of $CaCO_3$. In the presence of MnO_2, $CaCO_3$ increased the yield of IR26 by 0.9 t/ha but not at all of IR43 which, however, gave a response of 1.3 t/ha to $CaCO_3$ in the absence of MnO_2.
The benefits of MnO_2 are attributed to manganese, assisted by $CaCO_3$, counteracting physiologically the toxic effects of excess iron.

MnO_2, coupled with a tolerant variety and $CaCO_3$, may be an inexpensive ameliorant for acid sulfate soils.

2 Introduction

In densely populated South and Southeast Asia where both food and arable land are scarce (Ponnamperuma 1980), over 5 million ha of lands which are climatically, physiographically, and hydrologically suited for rice lie idle or are cultivated with poor results largely because of strong acidity (van Breemen and Pons 1978). There are probably millions more ha of potential acid sulfate lands under mangrove vegetation (Moormann and Pons 1974). If the productivity of cultivated acid sulfate soils is increased, and if idle acid sulfate soils and potential acid sulfate soils where environmental stresses are not severe are brought under rice, the food deficits expected in South and Southeast Asia in the 1980s (Asian Development Bank 1977, International Food Policy Research Institute 1977) may be reduced.

Acid sulfate soils are usually clays with a pH of < 4.0 and are characterized by the presence of yellow jarosite mottles. But according to Pons (1972) the term 'Acid Sulphate Soils' embraces all materials and soils in which sulfuric acid produced has a lasting effect on main soil characteristics. The organic carbon content varies from 1.5 to 18%. The cation exchange capacity is 10-25 meq/100 g. The soils may contain > 0.5% water-soluble sulfate and as much as 150 ppm water-soluble aluminum. Available nitrogen and phosphorus are low. Acid sulfate soils often have a high electrolyte content because of the presence of water-soluble sulfates. Coastal acid sulfate soils subject to tides may, in addition, contain other salts, chiefly sodium chloride. When submerged, acid sulfate soils build up water-soluble iron concentrations of about 200-4000 mg/l (Ponnamperuma et al. 1973). That increases the electrolyte content and may aggravate salt injury.

Some of the growth-limiting factors in acid sulfate soils for wetland rice according to Nhung and Ponnamperuma (1966), Tanaka and Navasero (1967), Coulter (1972) and Ponnamperuma et al. (1972) are aluminum toxicity, iron toxicity, high electrolyte content and deficiencies of available nitrogen and phosphorus.

Nhung and Ponnamperuma (1966) and Ponnamperuma et al. (1972) recommended leaching, liming, and adding manganese dioxide, alone or in combination, as ameliorants, but field tests of manganese dioxide have not been reported.

This paper reports the effects of $CaCO_3$ and MnO_2, alone and in combination, on iron toxicity symptoms and the yield of two rice varieties on an acid sulfate soil in a farmer's field at Malinao, Albay province, Philippines, in the 1980 dry season.

3 Materials and methods

The soil is a Sulfaquept developed in a recent sulfurous alluvial fan sediment of volcanic origin. Chemically and morphologically it is an acid sulfate soil (van Breemen 1978). The chemical characteristics are in Table 1.

Table 1. Some chemical characteristics of the soil at the experimental site, Malinao, Albay, Philippines

pH of dry soil (1:1 H_2O)	3.5
EC_e (mmho/cm)	1.0
CEC (meq/100 g)	9.5
Organic C (%)	1.23
Total N (%)	0.15
Active Fe (%)	2.50
Active Mn (%)	0.001
Ex. K^+ (meq/100 g)	0.17
Ex. SO_4^{2-} (%)	0.27
Available (Olsen) P (ppm)	7.0

The design was a 2^3 split split plot factorial with $CaCO_3$ as main plots, varieties as subplots, and MnO_2 as subsubplots, replicated four times. The $CaCO_3$ levels were 0 and sufficient $CaCO_3$ (5 t/ha) to raise the pH of the dry soil to about 5.0. The MnO_2 treatments were 0 and 100 kg commercial MnO_2/ha. The varieties were IR26 (a variety moderately susceptible to iron toxicity) and IR43 (a moderately resistant variety).

The area was plowed dry and ground limestone was broadcast on the appropriate plots. The plots were harrowed dry. Two weeks later the field was flooded and puddled. All plots received a basal incorporation of 50 kg N/ha as urea, 25 kg P/ha as concentrated superphosphate and 25 kg K/ha as muriate and a top dressing of 50 kg N/ha at panicle initiation. MnO_2 was incorporated in the appropriate plots. Three-week old seedlings were transplanted at 20 cm × 20 cm in 2 m × 3 m plots. The plots were kept submerged with irrigation water from a nearby stream. The plants were scored on the scale 1 to 9 (1 = nearly normal plant; 9 = dead or nearly dead plant) for iron toxicity, 4 and 8 weeks after transplanting. The yield of grain was measured.

4 Results and discussion

The mean scores and mean yields of grain for each of the treatment combinations are in Table 2. Tables 3 and 4 give the analysis of variance.

Table 2 shows that, on the basis of iron toxicity scores, the best treatment was IR43 (the moderately tolerant variety) in the presence of $CaCO_3$ and MnO_2 and the worst was IR26 (the moderately susceptible variety) in the absence of $CaCO_3$ and MnO_2. The scores at 8 weeks after transplanting were consistent with those at 4 weeks but indicated greater injury. Analysis of variance of the symptoms scores at 4 weeks after transplanting (Table 3) showed no significant response to $CaCO_3$, a significant difference between the two varieties, and a highly significant positive response to MnO_2.

Yield data in Table 2 generally agreed with the scores for symptoms. The best treatment was IR43 in the presence of MnO_2 regardless of the presence of $CaCO_3$; the worst was IR26 without $CaCO_3$ and MnO_2. Analysis of variance for grain yield revealed (Table 4) a non-significant response to $CaCO_3$, a highly significant varietal difference, a highly significant response to MnO_2, and a highly significant variety × MnO_2 interaction.

Table 2. Effects of $CaCO_3$ and MnO_2 on the severity of iron toxicity symptoms 4 and 8 weeks after transplanting and grain yield of two rice varieties on an acid sulfate soil, Malinao, Albay, Philippines, 1980 dry season

Treatment			Iron toxicity score[1]		Yield
$CaCO_3$	MnO_2	Variety	4 weeks[2]	8 weeks	(t/ha)
No	No	IR26	5.8 d	6.0 a	3.6 d
No	Yes	IR26	4.8 cd	5.2 ab	3.9 d
No	No	IR43	4.8 cd	5.5 ab	4.0 cd
No	Yes	IR43	3.5 ab	4.2 bc	6.2 a
Yes	No	IR26	5.2 cd	5.8 a	4.3 cd
Yes	Yes	IR26	4.2 bc	4.8 ab	4.8 bc
Yes	No	IR43	3.5 ab	4.2 bc	5.3 b
Yes	Yes	IR43	3.0 a	4.0 c	6.2 a

[1] On the scale 1 to 9 based on foliar symptoms and general appearance (1 = nearly normal plant; 9 = dead or nearly dead plant)

[2] Weeks after transplanting

(Any two means in a column followed by the same letter are not significantly different at the 5% level by DMRT.)

Table 3. Analysis of variance for the scores at 4 weeks after transplanting, according to foliar symptoms of Fe-toxicity and general appearance in the acid sulfate amelioration plots, Malinao, Albay, Philippines, 1980 dry season

SV	df	SS	MS	F(obs)
Block	3	7.091	2.364	
$CaCO_3$ (L)	1	3.781	3.781	$< 1^{ns}$
ERROR a	3	11.597	3.866	
Variety (V)	1	13.781	13.781	6.78*
L × V	1	0.282	0.282	$< 1^{ns}$
ERROR b	6	12.187	2.031	
MnO_2 (M)	1	7.03	7.030	12.27**
L × M	1	0.283	0.283	$< 1^{ns}$
V × M	1	0.033	0.033	$< 1^{ns}$
L × V × M	1	0.279	0.279	$< 1^{ns}$
ERROR c	12	6.875	0.573	
Total	31	63.219		

CV (a) = 45.30%   CV (b) = 32.84%   CV (c) = 17.44%

s.e. = 0.38

Table 4. Analysis of variance for grain yield from the acid sulfate amelioration plots, Malinao, Albay, Philippines, 1980 dry season

SV	df	SS	MS	F(obs)
Block	3	2.601	0.867	
$CaCO_3$ (L)	1	4.100	4.100	5.04^{ns}
ERROR a	3	0.814	0.271	
Variety (V)	1	13.120	13.120	16.84**
L × V	1	0.061	0.061	$< 1^{ns}$
ERROR b	6	4.674	0.779	
MnO_2 (M)	1	7.576	7.576	24.52**
L × M	1	0.567	0.567	1.83^{ns}
V × M	1	3.032	3.032	9.81**
L × V × M	1	1.050	1.050	3.40^{ns}
ERROR c	12	3.711	0.309	
Total	31	41.306		

CV (a) = 10.82% CV (b) = 18.35% CV (c) = 11.56%

s.e. = 0.28

IR26 gave a significant response of 1.2 t/ha to MnO_2 in the presence of $CaCO_3$ but a non-significant increase of only 0.3 t/ha in its absence. IR43 produced a significant response of 2.2 t/ha to MnO_2 in the absence of $CaCO_3$ and a significant increase of 0.9 t/ha in its presence. With IR26 $CaCO_3$ gave a non-significant increase of 0.7 t/ha in the absence of MnO_2 but a significant response of 0.9 t/ha in its presence. IR43 increased its yield significantly by 1.3 t/ha when $CaCO_3$ was added in the absence of MnO_2 but not at all in the presence of MnO_2. Although averaged for all treatments the $CaCO_3$ effect was non-significant, it reduced the severity of iron toxicity and increased yield.

Ponnamperuma et al. (1972) argued that aluminum toxicity is averted by liming and that the buildup of high concentrations of water-soluble iron is prevented by liming and retarded by MnO_2. They also drew attention to a report by Tanaka and Navasero (1966) that manganese counteracts physiologically the adverse effects of excess iron.

Ponnamperuma et al. (1972) reported experimental data showing the beneficial effects of $CaCO_3$ and MnO_2 on rice on two acid sulfate soils in the greenhouse. The concentration of MnO_2 they used (0.5%) is too high for practical use.

A review of the analyses of iron-toxic soils revealed that they are very low in total and water-soluble manganese. This suggested that the severity of iron toxicity can be reduced by increasing the concentration of water-soluble Mn. This was confirmed by preliminary culture solution experiments (International Rice Research Institute 1979). The marked increase in yield brought about by MnO_2 may be due to manganese counteracting iron toxicity physiologically. The quantity applied (100 kg MnO_2/ha) is too small to retard soil reduction.

If the benefits of applying MnO_2 at about 100 kg/ha are demonstrated on a wide range of acid sulfate soils, MnO_2, coupled with an iron toxicity tolerant variety, may prove an effective and economic ameliorant for acid sulfate soils. Lime may be a beneficial supplement. Further studies are needed to ascertain whether smaller amounts of MnO_2 would suffice, how long the residual effects would last, and to what extent a small amount of MnO_2 can replace the tons of limestone used as an ameliorant.

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IMPROVEMENT OF ACID SULFATE SOILS:
EFFECTS OF LIME, WOOD ASH, GREEN MANURE AND PREFLOODING

Moctar Touré
Djibélor Rice Research Station
Institut Senegalais de Recherches Agricoles

1 Summary

Attempts to reclaim tropical mangrove swamps for rice production often have resulted in the development of unproductive acid sulfate soils. In Senegal plant performance on these soils is hampered by strong acidity, high salinity and high levels of inorganic and organic toxins. The strategy for improving the soil conditions for rice involves leaching of toxins and subsequently minimizing renewed toxin production through stabilization of the electrochemical situation in the soil. To this end green manure, lime and wood ash were tested as amendments in leached acid sulfate soil material planted to rice in the greenhouse, with and without preflooding. Plant performance, nutrient uptake and kinetics of the soil solution were monitored.
Leaching was more beneficial than any of the amendments. Green manure and lime lead to strong reduction and high toxin levels. Wood ash in combination with preflooding decreased the levels of the toxins iron and organic acids.

2 Introduction

The tidal swamps of the Casamance have always been considered difficult to reclaim and have been used only marginally until the mid sixties, when in several locations mangrove areas were reclaimed for rice production. The emphasis in polder design and management was on exclusion of saline tides and desalinization of the land but, on leaching and drainage, the land unexpectedly turned extremely acid and sterile. It was established afterwards (Beye 1972, Vieillefon 1974, Marius 1979) that this acidification is due to the prevalence of acid sulfate soil conditions in the mangrove areas of Senegal. This is now known to be a common feature of tropical tidal areas. The reduced muds contain large amounts of pyrite that on drainage oxidizes to release sulfuric acid. The resulting acid sulfate soils are extremely acid and very high in soluble salts.

The basic soil forming processes involved are relatively well known (Van Breemen 1976). Methods to control the acidification during reclamation and to prevent or improve collateral adverse soil conditions, should be developed to suit specific agro-ecological situations.

In Senegal this development is on its way since 1970 (Beye 1971, 1972, 1973, Beye et al. 1975, 1979, Khouma and Touré 1981) and is concentrated on improving the acid sulfate soils of the Lower Casamance for rice cultivation.

The adverse soil conditions predominantly faced in this context are (Beye 1972, Beye et al. 1975, Coulter 1972, IRRI 1971, Marius 1979, Ponnamperuma 1972):

- excess of (Al^{3+}, Mn^{2+}, and Fe^{2+});
- high content of soluble chloride, sulfate and sodium and a Mg-dominated adsorption complex;
- high actual or potential acidity;
- low fertility status especially N and P deficiency.

In the Casamance the strategy for improving the acid sulfate soils for wetland rice production is aimed at:

- lowering the levels of toxins by leaching and
- raising the soil reaction to just above lethal levels for rice (sublethal level).

In a first round of investigations it was found (Beye et al. 1975) that a combination of fresh water leaching and liming significantly lowered soil acidity but it did not prevent iron toxicity in the flooded condition. Oxidizable materials continued to form and the mineralization of plant available nitrogen remained inhibited. The resulting conditions were very unfavourable for the growth of young rice plants. This situation became even worse on incorporating weeds into the soil, a common practice in land preparation in the lower Casamance. Investigations (Beye 1973) showed that this cultural practice induces strong and sudden reduction in the soil accompanied by massive release of reduced toxic substances.

The present experiments are aimed mainly at developing alternative practices that avoid, prevent or moderate the toxicity peaks in the flooded rice fields, with emphasis on:

- alternative cultural schedules timed to avoid the peaks mainly of iron toxicity i.e. introduction of preflooding;
- incorporation in the soil of oxidizing materials that might moderate reducing processes.

3 Materials and methods

The soil material in the present experiment is the surface layer of the 'Tobor soil' representative for the potential acid sulfate soils of the Rhizophora forest along the banks of tidal channels of the Casamance. It has been described by Marius (1979) as a Typic Sulfaquent, with a uniformly dark grey profile consisting of pyritic mud rich in organic matter with high C/N ratio and high content of fulvic acids. The pH in situ is 6.3 and drops to 2 or less on drying.

Table 1 compares analytical characteristics of the fresh Tobor soil, determined by Marius (1979) with those of the air-dried soil determined by the author. For all determinations conventional methods were used (Black et al. 1965). The changes in pH, organic matter and electrical conductivity confirm its susceptibility to extreme acidification on exposure to the atmosphere.

Table 1. Analytical characteristics of Tobor soil (analytical methods according to Black et al. 1965)

	Samples	
	Fresh*	Air-dried**
Granular analysis:		
clay %	34	38
silt %	15	17
very fine sand %	7	12
fine sand %	4	8
coarse sand %	2	1
pH	6.3	2.6
EC 1/10 mS/cm	28.8	40.0
Organic matter %	13.7	8.4
N o/oo	3.3	1.8
C o/oo	79.6	48.7
Exchangeable Ca meq/100 g	2.6	-
" Mg meq/100 g	8.2	-
" Na meq/100 g	45.1	-
" K meq/100 g	0.7	-
Active iron o/oo	-	8.9
Active manganese o/oo	-	0.1
Total P_2O_5 o/oo	-	0.4

* Marius 1979

** Sampled and used for this study

Tobor soil material was dried and leached with distilled water until its electrical conductivity remained below 2 mS/cm after 72 hours of flooding.

The soil was dried again and 10 kg portions were placed in micro rice fields (pots), flooded with distilled water and transplanted with 3 weeks old IR8 seedlings. Lime, wood ash (from sawdust) and green manure (pulverized, dried weeds) were tested as soil amendments in a randomized complete block trial. The treatments were:

- T0 control, no amendments (leaching only), no preflooding;
- T1 green manure (1 g per 100 g of dry soil), combined with 4 weeks preflooding;
- T2 lime at a rate of 12 t/ha combined with 4 weeks preflooding;
- T3 lime 28 t/ha, no preflooding;
- T4 wood ash 4 t/ha with 4 weeks preflooding;
- T5 wood ash 16 t/ha, no preflooding.

Mineral fertilizer (100 ppm of NPK per pot) as urea, super-triple-phosphate and KCl, was applied before transplanting. One month after transplanting, at the booting stage, 30 ppm N was applied.

At regular intervals the soil solution was sampled with a device allowing storage under inert (N) atmospheric conditions, and analyzed for:

- pH, Eh and EC (under N atmosphere, using a Ponsel pH-meter and a Cencq-conductivimeter);
- iron and manganese (by atomic absorption, in collaboration with the Bambey soils laboratory);
- oxidizable matter (by A.P.M.A. method, modified by Ponnamperuma);
- bicarbonates and organic acids (by alcalimetry);
- sulfates and phosphorus (by turbidimetry and colorimetry respectively);
- nitrogen (Keeney and Bremmer);
- plant analysis (leaves, straw, grains) for Fe, Mn, Si, P and K (following Yoshida et al. 1971).

4 Results and discussion

4.1 Plant performance

Plant performance and the dynamics of components of the soil solution show marked differences for the various treatments. Table 2 demonstrates that all of the components added had a negative effect on plant performance compared to leaching only. The worst effect had green manure and lime combined with preflooding (T1 and T2). In these treatments all plants died. Wood ash with preflooding (T4) had a less negative effect. It allowed the plants to survive and to mature, but grain yields reached only 40% of that of the control.

Table 2. Yields and yield components

Treatment	Number of plants per pot	Yield in g/pot grains	Yield in g/pot total dry matter
T0 control	6	3.16	5.45
T1 green manure + preflooding	-	-	-
T2 lime, 12 t/ha + preflooding	-	-	-
T3 lime, 28 t/ha	5	1.05	2.57
T4 wood ash, 4 t/ha + preflooding	5	1.18	5.06
T5 wood ash, 16 t/ha	1	-	0.71

A similar effect had lime without preflooding (T3). Contrary to the initial hypothesis this latter treatment (T3) was superior to wood ash without preflooding (T5).

4.2 Uptake of nutrients

The rather unexpected results in terms of plant performance can be traced back to changes in the root environment caused by the various treatments. This is also illustrated by the nutrient contents of the plants (Table 3).

Table 3. Chemical components of leaves at the panicle stage (L) and of straw at harvest (S)

	% P_2O_5		% K_2O		% SiO_2		ppm Fe		ppm Mn	
Treatment	L	S	L	S	L	S	L	S	L	S
T0 control	5.1	1.9	2.6	4.3	8.8	10.1	200	925	40	20
T3 lime, 28 t/ha	5.6	4.4	3.6	4.5	6.2	9.9	320	3160	40	27
T4 wood ash, 4 t/ha + preflooding	4.4	1.7	2.5	2.9	7.8	10.2	190	840	40	20
T5 wood ash, 16 t/ha	-	2.0	-	3.0	-	11.1	-	2400	-	33

The strong doses of lime (T3) and wood ash (T5) apparently caused a very high concentration of soluble iron and excessive uptake of iron. The iron content of the straw also for the other treatments must be considered higher than normal (Yoshida et al. 1971). P_2O_5 and K_2O contents are the highest in the plants subjected to the lime treatment. The data in Table 3 shows a preferential uptake of K, Si and Fe in the straw and of P in the grain.

As for electrochemical indices, neither the time of submersion nor the different doses of amendments, had an effect on the changes of the electrochemical parameters with time. On the other hand, the additives visibly modified the level of the parameters, compared to the leached control (Figure 1).

The average values of the pH, Eh and E.C. after 8.5 weeks of flooding (Table 4) show that:

- liming increased the pH and the electrical conductivity and decreased the redox potential. Incorporation of green manure had the same effects but to a lesser degree;
- ash had only slight effects on pH, Eh and EC.

Table 4. Electrochemical situation at 8.5 weeks after submersion

Treatments		pH	Eh (mV)	EC mS/cm
T0	control	4.0	360	3.9
T4 + T5	wood ash	4.2	342	4.5
T1	green manure	4.6	286	7.5
T2 + T3	lime	5.1	211	8.4

The relative constancy of pH and Eh with time in the control (Figure 1) illustrates the general sluggishness of acid sulfate soils to undergo chemical reduction upon submergence. It is explained by the weak microbiological activity, the high initial acidity, and by the presence in these soils of numerous mineral systems buffering pH and Eh. In the present case, basic sulfates probably play an important role in keeping the pH low.

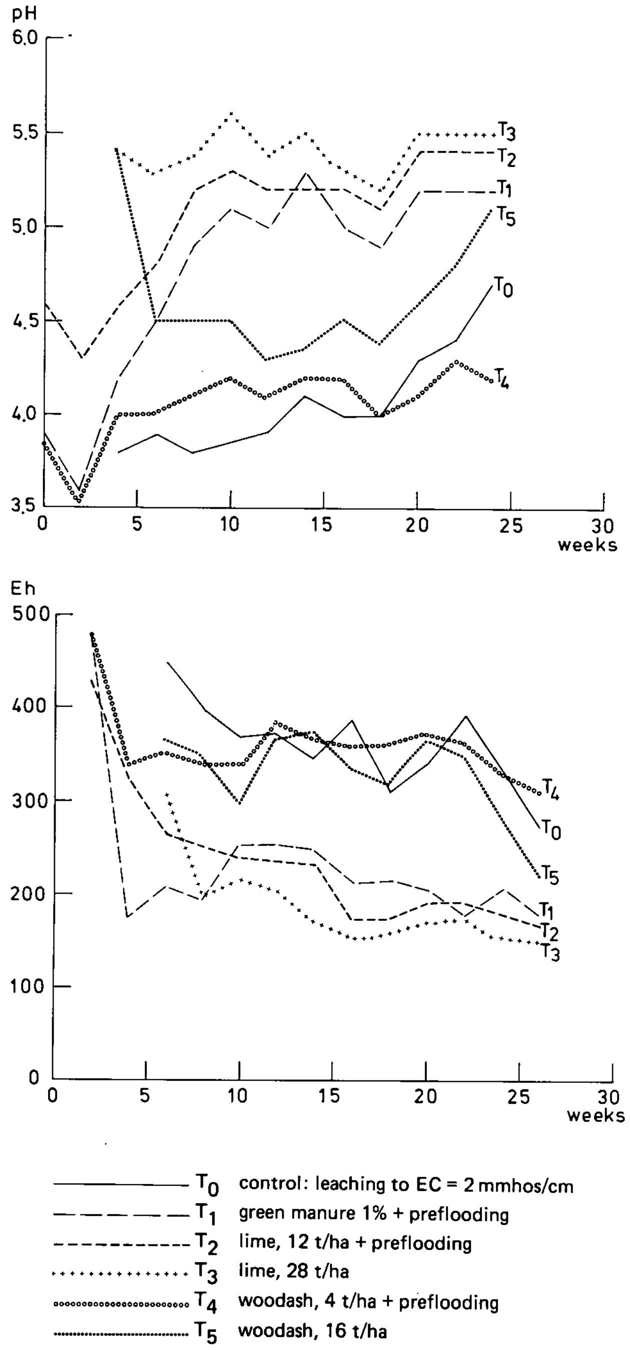

Figure 1. Kinetics of electrochemical parameters

Lime and green manure apparently stimulate bacterial activity, causing strong reduction and a decrease of the Eh leading to a massive liberation of reduced, mineral and organic compounds, and contributing directly or indirectly to the increase of the electrical conductivity of the soil solution. The mechanism of this biological reactivation is not clearly understood.

4.3 Development of toxins

Figure 2 and Table 5 characterize the general trends of toxin development under different treatments. The unfavourable influence of lime and green manure can be traced back to a large increase in the levels of toxins.

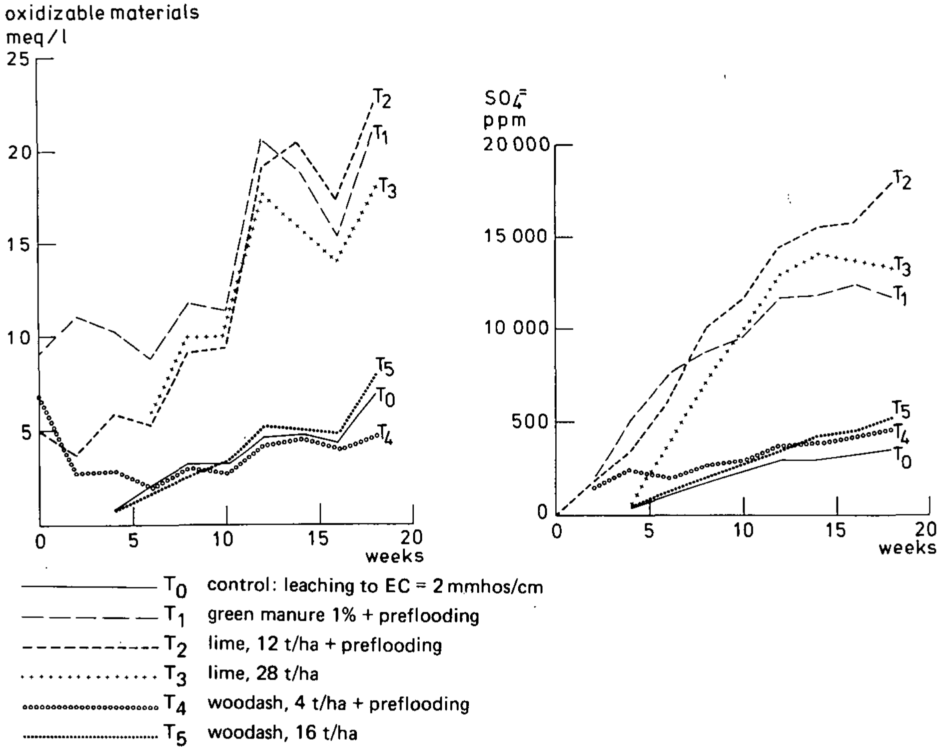

Figure 2. Kinetics of toxins

Table 5. Development of toxins 8.5 weeks after submersion

Treatment		Fe^{++}	$SO_4^{=}$	Oxidizable matter	Organic acids
		ppm		meq/l	
T0	control	113	2292	3.6	9.0
T4 + T5	ash	187	2823	3.8	12.0
T1	green manure	590	8745	11.8	24.0
T2 + T3	lime	395	8393	13.8	28.0

The development of iron followed a parabolic curve for the lime and green manure treatments and an exponential curve for wood ash and control. Peak levels between 800 and 1300 ppm were reached. For the preflooded treatments the levels were about 20% lower.

The gradual increase of soluble sulfates in all treatments at least up to the fourth month (Figure 2) indicates that the initial leaching was not sufficient to prevent further sulfate production. With lime and green manure sulfate production was at least three times that of the control and the ash treatments.

Dissolved oxidizable matter gradually increased in the woodash treatment and the control and reached much higher levels in the green manure and lime treatments, with peak values at about three months after submersion.

Organic acid concentrations showed maxima between the second and third month at levels of 40, 18 and 10 meq/liter respectively for lime, ash and control.

4.4 Availability of nutrients

Table 6 gives the average levels of available nutrients over the growing season and Figure 3 illustrates the changes in availability of N and K. The lime and green manure treatments cause an increase in the available P and K, whereas wood ash depresses the availability of P. As for nitrogen, the differences are small. Figure 3 shows that only the strong dose of lime significantly improves the nitrogen mineralization of the control, whereas green manure and wood ash tend to block the nitrogen mineralization.

Table 6. Average availability of nutrients

Treatment		NH_4-N ppm	P_2O_5 ppm	K_2O ppm
T0	control	48.7	0.34	168
T4 + T5	wood ash	36.3	0.26	186
T1	green manure	33.5	0.58	783
T2 + T3	lime	50.1	0.48	788

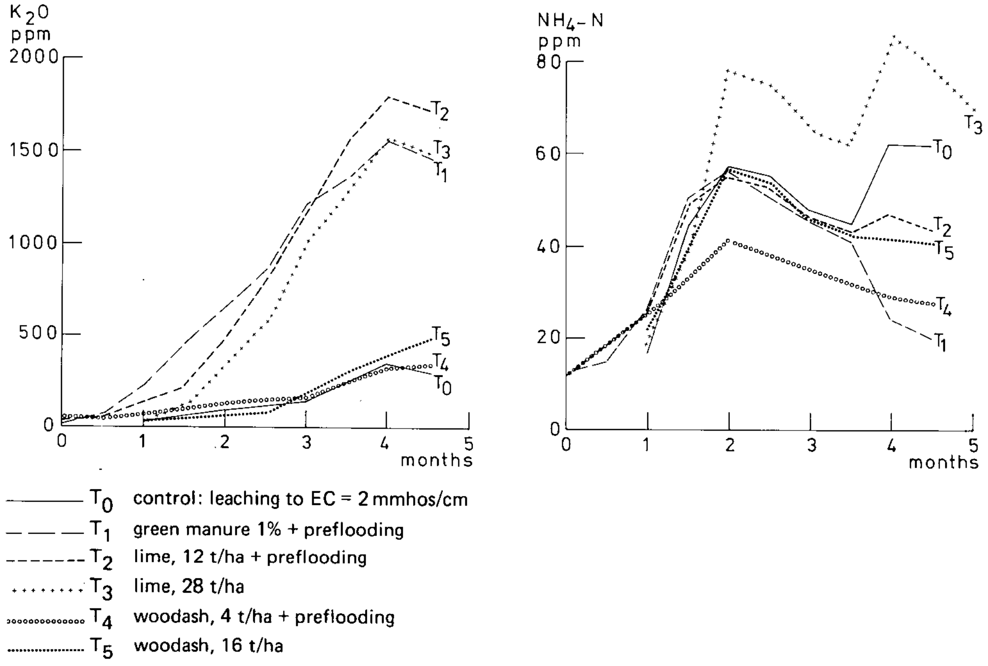

Figure 3. Kinetics of nutritional elements N and K

5 Conclusions

The improvement of acid sulfate soils of the Tobor type (Typic Sulfaquent) is complicated by many and various disturbances of chemical and biological nature resulting from unchecked oxidation of pyrites in the parent material.

The main obstacle to the improvement of acid sulfate soils of the Tobor type is that the chemical composition of these soils remains instable even after very thorough leaching. Various reactions continue to take place among phases and cause high concentrations of toxins in the soil solution. Highly specific microbiological components have an essential part in these processes but are poorly understood.

The soil amendments tested as alternatives for or improvements on leaching did not have the expected results.

- Incorporation of lime and of green manure deteriorated soil conditions.
- Incorporation of wood ash in general barely sustained the beneficial effects of leaching, but in combination with preflooding tended to depress the development of some toxins.
- Adding wood ash and preflooding merit further testing for improving acid sulfate soils.

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EFFECTS OF LIME AND PHOSPHORUS ON THE GROWTH AND YIELD OF RICE IN ACID SULPHATE SOILS OF THE CASAMANCE (SENEGAL)

Mamadou Khouma and Moctar Touré
Institute for Rice Research of Senegal
Djibélor Rice Research Station

1 Summary

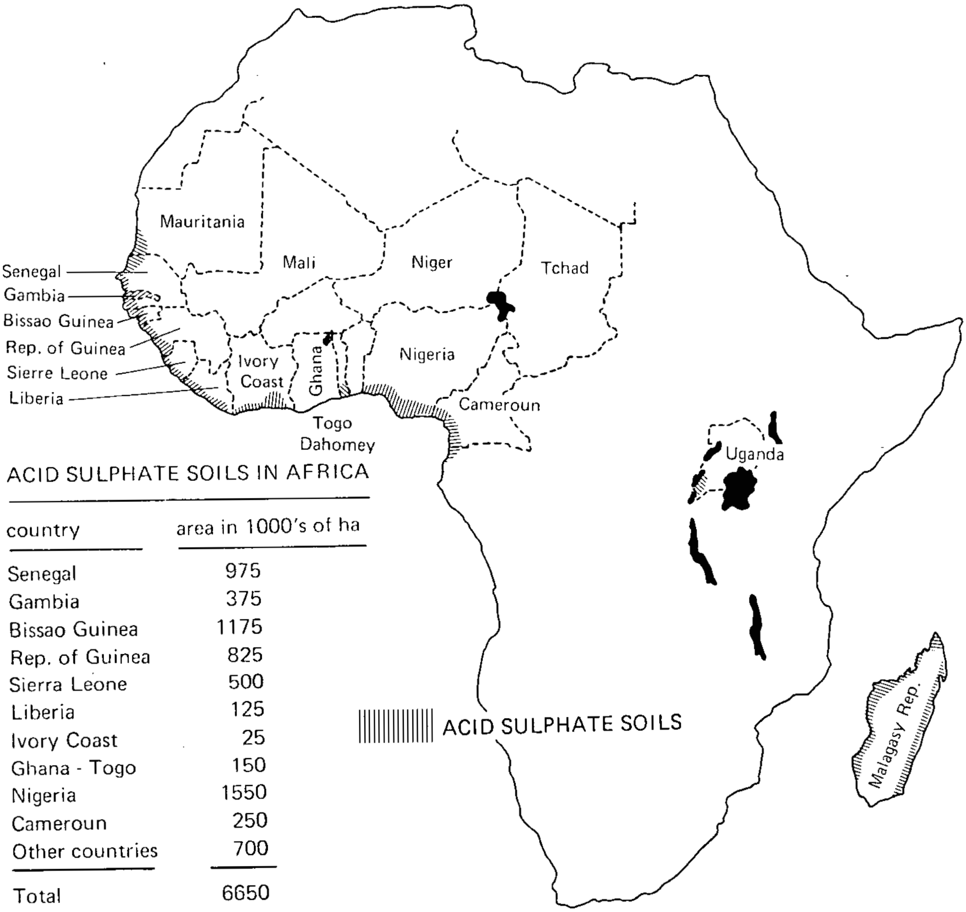
In the coastal plain of Senegal occur at least 600,000 ha of acid sulphate soils. In the Casamance area, in the South, these soils are used and reclaimed for rice production. Main constraints are the availability of fresh water, toxicities related to high salinity and acidity, and phosphorus deficiency. The topography facilitates control of water levels. In response to proposals of the organizing committee for the Second International Symposium on Acid Sulphate Soils, Bangkok 1981, a factorial field experiment with two rice cultivars, two levels of phosphorus and three levels of lime, was conducted in two sites with acid sulphate soils during the growing seasons of 1979 and 1980. The results were strongly influenced by drought and salinity especially during 1980. No effects of lime on rice yields were noticed. Triple superphosphate had an overall beneficial effect regardless of soil differences and varieties. No significant differences in grain yields between rice varieties were demonstrated. The modern short duration IR 1529 variety obviously suffered from salinity and its growing season was prolonged.

It is concluded that with sufficient fresh water and correction of phosphorus deficiency rice production is feasible on acid sulphate soils in Senegal.

In the south of Senegal the coastal plains consist of large flats, topographically well suited for controlling water levels for wet rice cultivation, but they are built up on fluvio-marine sediments, which are the parent material of acid sulphate soils. The acid sulphate soils taken in their widest sense, including potentially acid sulphate soils as well as actually acid and para acid sulphate soils, represent a considerable reserve of lands, which have not yet been completely exploited because the techniques and methods of their management are insufficiently developed.

Acid sulphate soils cover more than six million hectares in Africa (Figure 1). The majority of these soils occur along the west coast from Senegal to Cameroun. Their acreage in Senegal has been estimated to be 975,000 ha by Kawalec (1973) and 500,000 ha by Marius (1979).

One of the most remarkable characteristics of these soils is their very fast evolution determined principally by rapid transformation of sulphur, including the oxidation of pyrite and the liberation of sulfuric acid on initial drainage.



ACID SULPHATE SOILS IN AFRICA

country	area in 1000's of ha
Senegal	975
Gambia	375
Bissao Guinea	1175
Rep. of Guinea	825
Sierra Leone	500
Liberia	125
Ivory Coast	25
Ghana - Togo	150
Nigeria	1550
Cameroun	250
Other countries	700
Total	6650

Figure 1. Acid sulphate soils in Africa, according to Kawalec 1973

The main constraint for the productive management of acid sulphate soils, and many other soils of the Sudano-Sahelian region, is the inadequacy and the irregularity of the rains. The deficit during the last decade assumed a chronic character. Availability of good water and appropriate techniques that counteract adverse soil conditions are the basis for all management alternatives aimed at reclaiming and improving these soils for agriculture.

More specific restraints for the various acid sulphate soils in the Casamance in the South of Senegal, have been defined by the different research institutions working in the area.

For soils of the mangrove belts (*potentially acid sulphate soils*) these constraints are:

- salt excess. Levels of EC fluctuate around 100 mS/cm (Touré and Arial 1977);
- toxic products of sulfate reduction (H_2S). Values of log $\frac{B.S.R.*}{B.S.O.}$ of 4.5 have been found, well above the lower limit of the sulphate reduction toxicity for rice of log $\frac{B.S.R.}{B.S.O.} = 2$ (Jacq and Roger 1978) (*B.S.R.: number of sulphate-reducing bacterias per gram of dry soil; B.S.O.: number of sulphate oxidizing bacterias per gram of dry soil);
- potential acidity. On oxidation the pH of these soils may drop to 2;
- deficiency in phosphorus;
- low bearing capacity.

The soils of the 'tanne' areas, i.e. bare or herbaceous areas behind the mangrove forest belts, are the *modal acid sulphate soils*. Their specific constraints are:

- strong salinity (EC between 120 to 140 mS/cm);
- strong acidity (pH 3.0 to 4.5) of surface layers;
- multiple and inter-related toxicities ($SO_4^{=}$: 28,000 ppm; Fe^{2+}: 2000 ppm; Al^{3+}: 1200 ppm, according to Beye et al. 1970);
- deficiencies in phosphorus and nitrogen.

The deeply developed, 'older' acid sulphate soils (or *para acid sulphate soils*) although having the advantage of a superficial desalinization, still are very acid and their nutrient content is low.

Acidity and low fertility are the most constant features among the different acid sulphate soils. Several ways of reclamation and improvement, combining irrigation and drainage, organic and mineral enrichment have been attempted in the Casamance. Thus, it has been established that on empoldering unripe mangrove soils (potential acid sulphate soil) in the lower Casamance, the pH drops lower as the drainage is deeper (Beye 1972). The magnitude of this acidification varies with the origin of the organic matter enclosed in the parent material. When it is derived from roots of Rhizophora species the acidification is much stronger than for organic matter derived from Avicennia roots, owing to the higher pyrite

content of Rhizophora roots (Marius 1979).
Although high in organic matter, nitrogen response in these soils is low because of a distortion in its microbiological activity. In contrast, response to phosphorus is most pronounced, due to the marked phosphorus deficiency. For 'tanne soils' a highly significant response to phosphorus, as rock phosphate with a residual effect lasting four years, has been demonstrated (Beye 1973). On these 'tanne soils' mulching (applying 5 cm of straw at the end of the rainy season) gave good results. The pH increased and the electrical conductivity decreased by 50% in four years (Beye 1973). This simple desalinisation method proved very effective in restoring rice production in areas previously considered as unsuitable.

Liming of the acid sulphate soils has not given the expected results. The quantities of lime required are often uneconomic and apparently induce ionic imbalances in the soil solution. In the case of a strongly acidified young sulphate soil at Tobor (Casamance) 28 t of lime/ha were necessary to raise the pH to a level of 5.5 (Beye et al. 1975).
Results obtained elsewhere in tropical countries with the reclamation and the management of acid sulphate soils probably are of practical relevance for the Casamance. Their application, however, becomes problematical as the available documentation often lacks relevant description of local edaphic environment and soils.
To compare results and practical solutions for reclamation and plant growth on acid sulphate soils in different parts of the world, an international programme for field experiments was proposed by the committee preparing the second international symposium on acid sulphate soils. For wetland rice the proposal called for factorial field experiments with two rice cultivars, two levels of phosphorus and three levels of lime. The present investigations have been conducted and the results are presented within the scope of that programme.

3 Materials and methods

The experiments were set up on two sites:
- at Simbandi on a clayey 'para' acid sulphate soil (Tables 1, 3, 4);
- at Djibélor - P18 on a relatively shallow and light textured silty

clay (Tables 2, 3, 4).

To characterize the soils chemically, air-dried soil samples were placed into plastic pots provided with a gravity drainage system for soil solution analysis. Mean values of some electro-chemical and chemical parameters of the soil solution at 8 weeks of flooding are in Table 5.

A composite surface soil sample (0-20cm) was taken from each experimental site and analyzed for pH and lime requirements to bring the upper 20 cm of the soil to pH 4.5 and 5.5 (by incubating 0, 2, 4, 10, 20 and 40 meq of finely ground Ca (OH)2 per 100 gr of soil under moist conditions for a week and measuring the pH in water).

The trial was a 2 × 2 × 3 factorial experiment in randomized complete blocks, with 3 replicates.

- Factor 1: two rice cultivars, our traditional rice, the Blikissa or Etoual, and one modern short duration variety, IR 1529.
- Factor 2: two levels of phosphorus (0 and 50 kg P_2O_5/ha as triple superphosphate).
- Factor 3: three levels of lime (0; lime to pH 4.5, lime to pH 5.5). For the Djibélor soil (initial pH 4.5) the zero lime treatment was omitted.

All plots, except the control, received basal dressings of 100 kg N/ha as urea; and 50 kg K/ha as KCl.

Lime and fertilizers were applied about 2 weeks before transplanting and were incorporated by plowing and harrowing operations. Three to four week old seedlings were transplanted within one week after flooding. The only plant protection given was Furadan 3 G (Carbofuran) at a level of 24 kg/ha of the commercial product against stem borers.

The trials were conducted during the 1979 and 1980 rainy seasons.

Table 1. Soil profile description at the experimental site at Simbandi

LOCATION

Simbandi-Balante Valley, facing the village of Simbandi (60 km upstream from Ziguinchor), 100 m from the river bank.

VEGETATION

Philoxerus vermicularis on small dikes. Some tufts of Heliocharis mutata, Fimbrystilis dichotoma and Cyperus difformis.

PRECIPITATION

Annual mean: 1300 mm (from June to October).

SOIL SURFACE

Many cracks (5 to 10 cm deep) at the soil surface with blocks easily removable by hand. The surface soil is dry with a salt crust of 2 cm thickness.

PROFILE

0-17 cm	Clay, very dark grayish brown 10 YR 3/2 with some rust coloured mottles. Coarse prismatic structure, finer and falling apart in crumbs toward the lower part of the horizon. Very firm. Few fine roots. Gradual boundary to
17-74 cm	Clay, grayish brown 10 YR 5/2, moist, with yellow, red and rust coloured mottles. Fine prismatic structure, cracks filled with surface horizon material. Fine roots. Contains small ferruginous concretions. Clear boundary to
74-117 cm	Sandy clay, light gray 10 YR 6/1, moist, with black mottles. Massive with tubular pores. Presence of old fine roots channels in weakly indurated ferruginous pipes.

A boring reveals the presence of a black clay horizon (7.5 YR 2/0) with high organic matter content and some pockets of green matter at a depth of 160 cm.
The saline ground watertable is at a 117 cm depth.

Table 2. Soil profile description at the experimental site at Djibélor - P18

LOCATION

In the plots of the Rice Research Center of Djibélor (Lower Casamance) in the alluvial plain.

VEGETATION

Fuirena umbellata, Heliocharis fistulosa, Heliocharis mutata, Bacopa decumbens.

PRECIPITATION

Annual mean 1450 mm (from June to October).

PROFILE

0-25 cm	Silty clay, moist, dark brown 10 YR 3/3, with few black mottles and many rust coloured mottles along roots. Finely granular structure. Well provided with organic matter. Many fine roots. Clear boundary to
25-33 cm	Clayey sand, moist, gray, 7.5 YR 5/0; with rust coloured mottles along fine roots. Massive with fine pores. Many whitish fine roots. Gradual boundary to
33-110 cm	Loamy sand, moist, gray 7.5 YR 5/0, with mottles of jarosite (pale yellow) 5 Y 8/6 in the lower and rust coloured mottles in the upper part of the horizon. Some pockets of black clayey material. Massive with many channels of former mangrove roots. Few mangrove roots with jarosite inside. Few fine roots. Gradual boundary to
110 cm +	Sand and clay, wet, gray, 7.5 YR 5/0. Permanently reduced horizon. Massive. Many undisturbed mangrove roots. Roots seem to be those of Rhizophora.

The saline ground watertable is at 125 cm depth.

Table 3. Analytical characteristics of the soils*

	pH 1:2.5	pH KCl	EC mS/cm	C $^o/oo$	N $^o/oo$	P_2O_5 $^o/oo$	K me%	Texture Clay %	Texture Silt %	Texture Sand %
Simbandi										
0-17 cm	4.8	4.2	25.5	1.8	1.16	1.43	2.54	68	17	15
17-74 cm	4.3	3.7	29.0	1.4	0.28	1.40	5.00	49	38	13
Djibélor P18										
0-25 cm	5.2	4.4	21.2	2.4	1.40	0.46	1.23	18	15	67
25-33 cm	4.6	3.8	20.2	0.84	0.14	1.31	3.23	10	10	80

Table 4. Soluble salts of the ground water*

	pH	EC mS/cm	Eh mV	mmol/l $\frac{1}{2}Ca^{2+}$	$\frac{1}{2}Mg^{2+}$	Na^+	K^+	HCO_3^-	Cl^-	$\frac{1}{2}SO_4^=$
Simbandi	6.2	23.6	+ 40	17.8	43	89	24	6.48	202	59
Djibélor P18	3.9	27.7	+ 170	15.5	28	152	27	-	346	69

Table 5. Mean values of some parameters in soils after 8 weeks of flooding*

	pH	EC mS/cm	Eh mV	Fe ppm	NH_4^+ ppm	$SO_4^=$ ppm	P_2O_5 $^o/oo$	Mn ppm
Simbandi	5.8	6.7	+ 373	324	16	1152	1.8	1.7
Djibélor P18	5.7	8.2	+ 200	265	23	635	0.1	0.9

* Methods: C (Anne), N (Kjelldahl), P_2O_5 (nitric attack), K^+ and Na^+ (flame photometry), Texture (Robinson's pipette), Ca^{++} and Mg^{++} (complexometry), HCO_3^- (titrimetry H_2SO_4), Cl^- (argentimetry), $SO_4^=$ (turbidimetry by spectrophotometer), NH_4^+ (Keeny and Bremmer), F and Mn (Colorimetry by spectrophotometer)

4 Results and discussion

4.1 Simbandi

The annual precipitation at the experimental site was 911 mm in 1979 and 502 mm in 1980. Experimental results are in Table 6.

Table 6. Experimental results at Simbandi. Yields in t/ha

	Grain Yield		Straw Yield	
	1979	1980	1979	1980
pH < 4.5	0.6	2.0	2.2	1.9
	2.2*	1.2*	2.8*	1.2*
pH = 4.5	1.9	3.0	2.6	2.9
	1.9*	3.5*	2.5*	3.4*
pH = 5.5	0.5	3.7	2.4	3.5
	2.4*	3.2*	3.6*	3.1*
pH < 4.5 +	1.8	3.0	2.7	2.9
P_2O_5	3.1*	3.3*	6.2*	3.2*
pH = 4.5 +	2.4	2.9	3.6	2.8
P_2O_5	2.4*	2.6*	5.3*	2.5*
pH = 5.5 +	2.5	3.7	4.1	3.5
P_2O_5	2.1*	3.4*	6.4*	3.3*
Means	1.6	3.1	2.9	2.9
	2.4*	2.9*	4.5*	2.8*

* Local Variety Blikissa

In 1979, no significant differences for grain yields were noted between the two varieties. Phosphorus had a significant (LSD: 5%) positive effect independent of pH (Table 7).

Table 7. Mean grain yields of the 2 varieties (t/ha) at Simbandi in 1979

Phosphorus	pH < 4.5	pH = 4.5	pH = 5.5
0	1.4 a	1.9 ab	1.5 a
50 kg P_2O_5	2.5 b	2.4 b	2.3 b

(Yields followed by the same letter do not differ significantly at the 5% level)

In 1979 straw yield of the local variety (4.5 t/ha) was significantly higher than that of IR 1529 (2.9 t/ha), Table 6.
Statistical analysis does not show any significant differences between treatments nor varieties for the 1980 crop. The heterogeneity of the results stems primarily from salinity damage to transplanted seedlings. This year's irregular and deficient rainfall did not at any time reduce soil salinity and some plots had to be transplanted twice. Complementary irrigation has been necessary.

4.2 Djibélor

At this site the total precipitation in 1979 was 1.177 mm and only 671 mm in 1980. Table 8 gives the experimental results.

Table 8. Experimental results at Djibélor

	Grain Yield t/ha		Straw Yield t/ha	
	1979	1980	1979	1980
pH = 4.5	2.7	0.9	5.8	9.5
	2.8*	1.7*	7.7*	3.0*
pH = 5.5	3.0	0.8	6.5	2.0
	2.9*	1.8*	8.0*	2.9*
pH = 4.5 +	2.9	1.1	5.8	2.8
P_2O_5	2.9*	2.1*	7.0*	3.4*
pH = 5.5 +	2.9	1.1	5.6	2.7
P_2O_5	2.8*	2.3*	7.5*	3.6*
Means	2.9	1.0	5.9	2.5
	2.9*	2.0*	7.6*	3.2*

* The asterisk refers to the local variety Etoual

Rainfall during the 1980 season was particularly deficient with many periods of droughts that delayed the beginning of field trials. The transplanting was late and yields were far below those of 1979. No significant differences between any of the treatments were observed. The arithmetical mean differences seem to indicate that on the whole the local variety is better adapted to the prevailing soil conditions, and especially to soil salinity, than the IR 1529 variety. An effect of pH was not noticeable. A beneficial effect of phosphorus on yields, without being significant, has been observed only during the dry second year.

5 Conclusions

Lime had no clear effect on the yields of the two varieties of this field trial, conducted over two seasons at two sites with different soil conditions. This lack of response may be attributed to the general decrease of soil acidity to a same level, induced by continued flooding.

Phosphorus has had a significant positive effect on grain yields on Simbandi soil, irrespective of the pH during the first year. The action of phosphorus is on the whole beneficial.
Of the two varieties used in this trial, IR 1529 seems to be more sensitive to salinity than the local varieties which are salt tolerant but whose main weakness is their tendency to produce large amounts of straw. Under the prevailing conditions of salinity stress IR 1529 did not realize its potential. Its grain production was less and its growing season was extended beyond that of the local variety.
Availability of fresh water and correction of phosphorus deficiency are the main requirements for satisfactory rice production on the acid sulphate soils of Senegal.

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RICE CULTIVATION ON ACID SULPHATE SOILS IN THE VIETNAMESE MEKONG DELTA

Vo-Tong Xuan, Nguyen Kim Quang & Le Quang Tri
University of Cantho
Hau-giang, S.R. Vietnam

1 Summary

In the Mekong Delta of Vietnam an estimated 60% of the land is affected by acid sulphate soil conditions. By trial and error local rice farmers have developed various management systems that overcome or minimize the adverse soil conditions.
Two popular and successful practices applied for rainfed rice are described: (1) the intensive shallow drainage system, yielding up to 4 t/ha of paddy on shallow-developed and potential acid sulphate soils, and (2) the acid avoidance practice yielding up to 6 t/ha on well-developed acid sulphate soils.

2 Introduction

Although a complete and comprehensive inventory of the distribution of acid sulphate soils in the Vietnamese part of the Mekong Delta has not been realized yet, an estimated 2.6 million ha of potential and actual acid sulphate soils have been recognized in various areas in southern Vietnam (Soils Survey Division, Ministry of Agriculture, 1978, unpublished data). The well-developed acid sulphate soils are found on large areas in the Plain of Reeds, the Plain of Hatien, and on scattered spots throughout the Delta with a total area of about 870,000 ha. The potential acid sulphate soils in tidal marshes and underneath mangrove forests total to about 704,000 ha. Shallow-developed acid sulphate soils are found in empoldered backswamps subject to salt water intrusion with a total of about 1,015,000 ha. Another estimated area of 27,000 ha of potential acid sulphate soils can be found underneath 0.5-2.0 meters of peat soil found mostly in *Melaleuca*, *Avicenia* and *Rhizophora* forests in Min-hai province. Despite the fact that about 60 per cent of the total land areas of the Vietnamese Mekong Delta is affected with acid soils, the subsistent farmers have long been using part of that land quite satisfactorily. By trial and error, they have found various ways to overcome the acidity of their soils to produce food crops for subsistence. This paper describes some of the popular methods of management of acid sulphate soils by South Vietnamese farmers.

3 Rice cultivation on shallow-developed and potential acid sulphate soils

In the various districts of the former Ca-mau region, now belonging to Minh-hai province, where annual rainfalls reach 2,200 to 2,400 mm, a method of rice cultivation gaining increasing popularity is called 'intensive shallow drainage system'. Up to the main crop season of 1980, thousands of individual intensive shallow drainage systems have been installed on an estimated 90,000 ha of acid sulphate soils. This represents about 52 per cent of the rice land of Ca-mau region.

The drainage system comprises an intensive network of shallow ditches (Figure 1). As the ditches are excavated, the land between two ditches becomes a slightly raised bed on which rice is grown. Since land ownership is still by individual farmers, each farmer makes his own system. At present, therefore, sometimes the networks are not connected together by a common drainage canal. Thus, drained acid or saline acid water may run off the raised beds but remains stagnant in the ditches. Rice yields usually double in the first year after installment of the shallow drainage system, and from the second year on, a yield increase of two to four times is reported by most farmers.

Figure 1. Rice cultivation with intensive shallow drainage systems

It is not known exactly who came up first with the idea for such a system. According to our investigations, sometime in 1957 during a meeting attended by some 100 of the more successful traditional rice farmers in this region, one farmer reported that when he considered abandoning the land on which he had obtained almost no yields during the previous years, he constructed a seedbed to prepare seedlings for his last effort and he discovered that those seedlings left on the raised seedbed became the best rice plants he had ever seen. In the following year, he turned all his land into several raised beds, and got good yields. Another idea came from the observation that as farmers pulled their sampan boats through muddy fields to transport their newly harvested rice to threshing pads, several ditches were incidentally formed. During the following year's rice crop, they observed that rice plants along those ditches grew much better than those away from the ditches. From then on, ditches were excavated intentionally.

We made several investigations to identify soil types in these areas. Mostly the intensive shallow drainage system is practiced in empoldered areas with dikes running along waterways to prevent salt water overflow, and with gates made from hollow coconut trunks to permit simple regulations at high and low tides. We found that in almost all cases, the soils are typical young acid sulphate soils with jarosite present at 30 to 50 cm below the surface. The practice is being gradually extended to areas of newly cleared mangrove and *Melaleuca* forests where potential acid sulphate soils are found at 30 to 60 cm below a thick peaty topsoil of various depths.

3.1 Land and drainage system preparation

Excavations of ditches usually starts after harvesting the previous crop of rice, when the soil is just dry enough for earth work. The common land area unit used by Vietnamese farmers in the Mekong Delta is the '*công*' measuring 36 × 36 m^2 (1/7 ha). For new construction, one side of the field is divided into four strips of 9 × 36 m^2. Between each strip a ditch of about 1 m width and 0.3 to 0.6 m depth is excavated by hand. The more depressed the field is, the wider and deeper the ditches are. The excavated soil is spread evenly on the strip between the two ditches thus forming a moderately raised bed (see Figure 2). In this operation the soil is not broken into granular form, but deposited carefully as unaltered thin slices of spade-shaped soil. For two- and three-year old systems, repairing the ditches by dredging is carried out soon after harvesting the previous rice crop. The dredging is timed to allow the soil on the ridges to dry thoroughly.

Each shallow drainage ditch is open on one end to a larger and deeper drainage canal, while the other end is kept closed. Each adjacent farmer may have a separate main drainage canal, or several farmers may pool efforts to construct a main drainage canal running to a river. All together, the area looks like an immense checkboard. Experienced farmers observed that even if drained water could not be evacuated to the river, it still did not appreciably harm the growth of the rice plant on the ridges.

Figure 2. Excavation of ditches and formation of raised beds

3.2 Drainage control practices

The Ca-mau region receives a higher rainfall than other regions in the Mekong Delta. With the first heavy rains, normally in April, rainwater washes off the oxidized sulphidic soil material on the ridges and removes toxic substances such as aluminum and salts. These substances concentrate in the shallow ditches and in drainage canals. The outlet gates remain closed until the drained water reaches the level of the surface of the raised beds. With the next rains, the accumulated water is allowed to run through the canals and out to the river at low tides. The cycle is repeated two or three times before the entire region is naturally flooded, and drainage is no longer possible.

3.3 Planting

Saline- and acid-tolerant, medium duration rice varieties are utilized extensively. Some of the most popular varieties are: Than Nong Do, Trang Mot Buoi, Trang Hoa Binh, Nang Tet, Trang Lun, Trang Tep Thai lan, etc. At the beginning of the rainy season in April, seedbeds are prepared. On some raised beds first weeds are chopped off, then the topsoil is hand-tilled to a granular structure with clod size around 3 to 4 cm in diameter. Sowing takes place in early June. Twenty days after sowing, the final land preparation of the other raised beds begins. By this time, the whole area may be flooded to about 10 to 40 cm. Weeds are chopped off with a large scyth and gathered into the shallow ditches the drainage capacity of which is not needed for the time being. Forty-five to 60-day-old seedlings (about 60 to 100 cm tall) are transplanted on the cleared raised beds which are submerged under 10 to 40 cm of water. Transplanting is facilitated by driving a round wooden dagger into the soil to make a hole into which 3 to 4 seedlings are pushed. Farmers seldom use chemical fertilizers under such conditions. Thus the rice plant grows under totally rainfed conditions. The maximum water level reaches usually 0.5 to 0.8 meter (Figures 3 and 4).

After first installation of the intensive shallow drainage system, rice yields increase every year up to the fourth year. In the first year, grain yields jump to 1.5 to 2.0 t/ha compared to the previous undrained yields of 0.2 to 0.5 t/ha on similar land without ditches. The fourth year yields maybe as high as 4.0 t/ha, but after that yields tend to decline unless the drainage capacity is restored again e.g. by dredging the ditches. As an alternative many farmers prefer to excavate a very narrow (0.25 meter) ditch right in the middle of each raised bed, running along its length. Others may refill the old ditches and excavate new ones.

Our actual field determinations of grain yields during November-December 1980 harvests gave a range from 3.20 to 3.85 t/ha with the rice variety Trang Mot Buoi under natural conditions, without applying any fertilizer. The huge amounts of decaying weeds spread on the fields, may contribute positively to the soil fertility.

Figure 3. Rice on raised beds at heading stage

Figure 4. Rice on raised beds at ripening stage

4 Rice cultivation on well-developed acid sulphate soils

In depressed backswamps, normally deep water or floating rices are being cultivated, as in Hatien Plain, and part of the Plain of Reeds. Rice seeds traditionally were broadcasted in dry conditions before the onset of monsoon rains. Along the fringes of the Plain of Reeds in Long-an and Tien-giang provinces with the introduction of high yielding rice varieties with short growth duration (90 to 100 days), farmers turned to transplanting the short duration rice near the end of the rainy season. As soon as water in the field started receding, rice seedlings were prepared on raised beds. Simultaneously, the fields for transplantation were rotovated to incorporate weeds into the soil. Phosphate fertilizers were used extensively, as the most important input to maximize grain yields. Occasionally, one or two additional sampan pump irrigations with fresh water still available in the canals were necessary if drought occurred toward the ripening period of the rice plant. Rice yields often reached as high as 4.5 to 6.0 t/ha with high yielding rice varieties such as IR36, IR2307-247-2-2-3, and IR2823-399-5-6.

This system is called 'acidity avoidance practice'. The farmers avoid toxic substances dissolved by rain water during the early part of the rainy season, and transplant only when the soil has been leached, and toxic substances were diluted to a safe limit. Some farmers even planted a first crop of short duration rice very early at the beginning of the rainy season in an attempt to forestall development of adverse conditions. The time of seeding is crucial in this case, and it should be early in order to enable the plants to reach the ripening stage before the build-up of acid substances in the flooding water to toxic concentrations. Grain yields with precocious transplanting seldom surpassed 4.0 t/ha.

5 Conclusion

The farmers in the rainfed areas with acid sulphate soils in the Mekong Delta are gaining more and more experience to better manage their soils for food production. The practices such as intensive shallow drainage system and acid avoidance cultivation as described above are now adopted widely. Pending the realization of large scale irrigation schemes for efficient fresh water supply and production increase in acid sulphate areas, the popular methods now in use seem to be the most practical. They can serve as a basis for further agronomic studies aimed at more intensive and productive rice cropping on various acid sulphate soils under purely rainfed conditions.

EFFECT OF WATER MANAGEMENT ON FIELD PERFORMANCE OF OIL PALMS ON ACID SULPHATE SOILS IN PENINSULAR MALAYSIA

Toh Peng Yin and Poon Yew Chin
Harrisons & Crosfield (Malaysia) Sendirian Berhad
Kuala Lumpur, Malaysia

1 Summary

The yield performance of oil palms in fields with various acid sulphate soil conditions is examined in relation to changes in water management. In the severely and moderately acid areas, yields improved appreciably when after a period of deep drainage, the watertable was raised, with increases of 36.3% and 17.6% being recorded respectively in the first consecutive four year period after raising the watertable. These yield improvements were maintained thereafter.

Practical recommendations are given for maintaining a high watertable with provision for periodic flushing of the drains in oil palm plantations.

2 Introduction

In Peninsular Malaysia, it has been estimated that there are about 110,000 ha of acid sulphate soils (Kanapathy 1973). These soils are mostly interspersed amongst fertile marine alluvia along the west coast, where oil palm is an important perennial crop.

The adverse effects of acid sulphate soils on oil palm growth were first highlighted during the 1960's when in a series of investigations on amelioration of such soils, intensive drainage was carried out in an attempt to remove the source of their potential acidity, viz., pyrite, through oxidation and leaching of the resultant sulphates. This proved disastrous as yields in the field under investigation plunged from an average of 15.17 tonnes fresh fruit bunches (ffb) per ha in the years preceding the intensive drainage to 6.03 tonnes ffb/ha within four years. Subsequent examination showed that even after this period of intensive leaching, reserves of unoxidized pyrite remained very large and the soil was still very acid (Bloomfield et al. 1968).

The next phase of investigation involved inhibition of further pyrite oxidation by flooding the pyritic horizon. This treatment led to progressive improvements in palm condition in the following year and, three years after this treatment, yields reached 18.80 tonnes ffb/ha and remained at that level five years later (Poon and Bloomfield 1977).

Since means of resolving the acid sulphate problem were developed, cultivation of oil palms on these soils has expanded considerably. It is presently estimated that the acreage of oil palms grown on acid sulphate soils in Peninsular Malaysia amounts to about 40,000 ha (Paramananthan 1980).

Acid sulphate soils too often are being considered collectively, without taking into account existing variations in acid severity associated with depth of acidic layers. This may have led to misleading impressions on the general performance of oil palms on acid sulphate soils. It is therefore proposed to examine in greater detail, the yields of oil palms on acid sulphate soils in relation to these variations in severity.

3 Identification of acid sulphate soils and classification of fields with acid sulphate soil conditions

Acid sulphate soils in Peninsular Malaysia are characterized by an organic layer in the topsoil overlying a clay subsoil in which the acidic horizon occurs. Typically, pale yellow deposits of jarosite occur as large blotches on ped faces and around old root channels in this acidic horizon.

The criteria suggested by Coulter (1967) as standards for the identification of the acidic horizon, viz., air dried, soil pH less than 3.3 and water soluble sulphate content more than 0.1% have been found practicable for delineation of such soils (Hew and Toh 1973). There is however considerable variation in the depths at which the acidic horizon occurs in the soil, ranging from less than 30 cm to more than 120 cm from the soil surface. The growth and yield performance of oil palms have been observed to be associated with this variation.

Accordingly, the acid areas have been classified arbitrarily into three categories of acidity depending on the depth at which the acidic layer occurs:

Category of acidity	Depth of acidic layer (cm)
Severe	0 - 60
Moderate	60 - 90
Mild	90 - 120

Within individual fields, there can be a range of depths at which the acidity occurs. Therefore, for the present purpose, a field is classified into the respective category of acidity if more than 70% of the area falls into that category. This definition simplifies interpretation and presentation of data, as available yield data pertain only to entire fields.

The degree of acidity in the various fields that have been selected for the present study, has been determined from soil analyses performed on soil samples collected at an intensity of one point per 10 acres. At each sampling point, soil samples were collected at 15 cm intervals up to a depth of 120 cm. Analyses data accumulated over several years have been used.

4 Yield of oil palms on acid sulphate soils

The yield performance of oil palms in acid sulphate areas, classified into various categories of acidity, is examined in relation to changes in water management. Various periods have been considered, with the period 1964-1967 representing the period prior to the wide-scale introduction of the policy of maintaining a high watertable. Yield performance of palms after the raising of watertables is examined in consecutive periods of four years from 1968 to 1979.

The average yields per annum for four consecutive periods of four years each, commencing from 1964, for palms under the various categories of acidity are summarized in Table 1. Only the pre-1960 plantings have been included in this compilation so that areas selected have experienced a sufficiently long period of adverse growing conditions prior to the introduction of appropriate ameliorative measures. In addition, yield data have also been provided for comparable age palms growing on non-acid sulphate soil.

Table 1. Yields of pre-1960 oil palm plantings under various categories of acidity

		Yield (tonnes ffb/ha/year)			
Category of acidity	Area (ha)	1964-67	1968-71	1972-75	1976-79
Severe	273	11.44	15.59	17.52	18.06
Moderate	366	16.38	19.27	19.08	18.98
Mild	12	22.81	23.43	22.14	17.32
Non-acid sulphate	888	23.89	24.14	22.44	20.41

The policy to raise watertables was affected in the majority of the acid sulphate areas during 1967. It will be noted (Table 1) that this ameliorative measure resulted in substantial improvements in palm productivity in the severe and moderately severe acid areas.

There are insufficient areas of mild acidity in the same age group for a proper comparison. However, the yield trend in one field indicates that oil palm yields are not adversely affected when the acidity occurs at 90-120 cm. Raising the watertable in that area did not result in dramatic improvement in yield performance. The very satisfactory yields recorded during 1964-1967 in this mildly acid field may also be attributed to the fact that, in normal practice, the depth of internal field drains rarely exceeded 90 cm and the acidic layer was never subjected to very intense drainage.

The growth and productivity of the oil palm is greatly influenced by the soil moisture status and prolonged periods of dry weather can precipitate severe yield declines. Thus, irrespective of the soil acidity level, oil palms will respond to water management practices aimed at avoidance of moisture stress development.

The full impact of altering the watertable by drainage in acid sulphate soils becomes apparent from the yield trends in an area over which soils were completely acid sulphate (severe). Figure 1 illustrates the yield trends in such a 1952 planting (121 ha) during the period 1960-1979. Drains in the area under consideration were deepened in 1961/1962 to 120 cm and their frequency increased to one per 4 palm rows in an effort to leach out the oxidized sulphates.

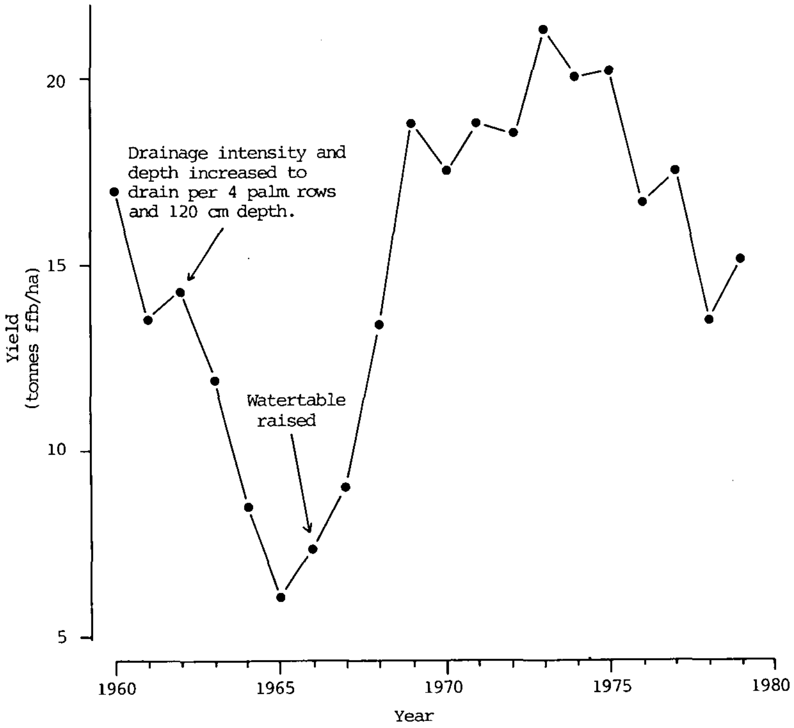

Figure 1. Effect of increased drainage and subsequent raising of watertable on yield of oil palms on severe acid sulphate soils

This intensified drainage caused a steep yield decline from 14.31 tonnes ffb/ha to 6.03 tonnes ffb/ha three years later (Poon and Bloomfield 1977). Raising of the watertable by strategic placement of water retention blocks along the drains produced highly economic yield responses. Though significant yield improvements were recorded in the areas where watertables were raised after a period of free drainage conditions, the yield levels in these areas did not reach those obtainable on non-acid sulphate soils.

Table 2 summarizes the yield performance of 1966-1973 oil palm plantings on moderately acid soils which have not been subjected to intensive free drainage since commencement of planting. Yields of similar age palms on non-acid sulphate soils are included for comparison.

Table 2. Yield comparison of 1966-1973 oil palm plantings on acid sulphate and non-acid sulphate soils

		Mean yield (tonnes ffb/ha)		
Category of acidity	Area (ha)	3-5 yr.	6-8 yr.	9-11 yr.
Moderate	1319	19.94	25.85	26.07
Non-acid sulphate	1051	21.45	28.19	25.75

It is apparent from Table 2 that yields of subsequent oil palm plantings established on acid sulphate soils with appropriate raised watertable policy from commencement of planting have been similar to those of plantings on non-acid sulphate soils. There are no comparative data for plantings on severely acid soils.

5 Current recommendations for water management of acid sulphate soils

The proper management of drainage and irrigation is crucial in relation to oil palm performance in hyperacidic subsoil conditions. The problem of drainage is two-fold. Free drainage conditions will result in the intensification of acidity while inadequate drainage will give rise to flooded conditions, both of which will adversely affect palm performance.

The appropriate drainage intensity within fields depends largely on soil characteristics such as permeability and water retention, which are dependent on soil texture and structure. Acid sulphate soils in Peninsular Malaysia are generally heavy textured and occur in low-lying situations. As such, they require the installation of an extensive drainage system prior to oil palm cultivation.

The drainage system on acid sulphate soils involves a network of field drains running parallel to palm rows which drain into collection drains.

The collection drains are in turn connected to the main drains which lead directly to the tide gate and the outlet drain beyond. This pattern of drainage is illustrated in Figure 2.

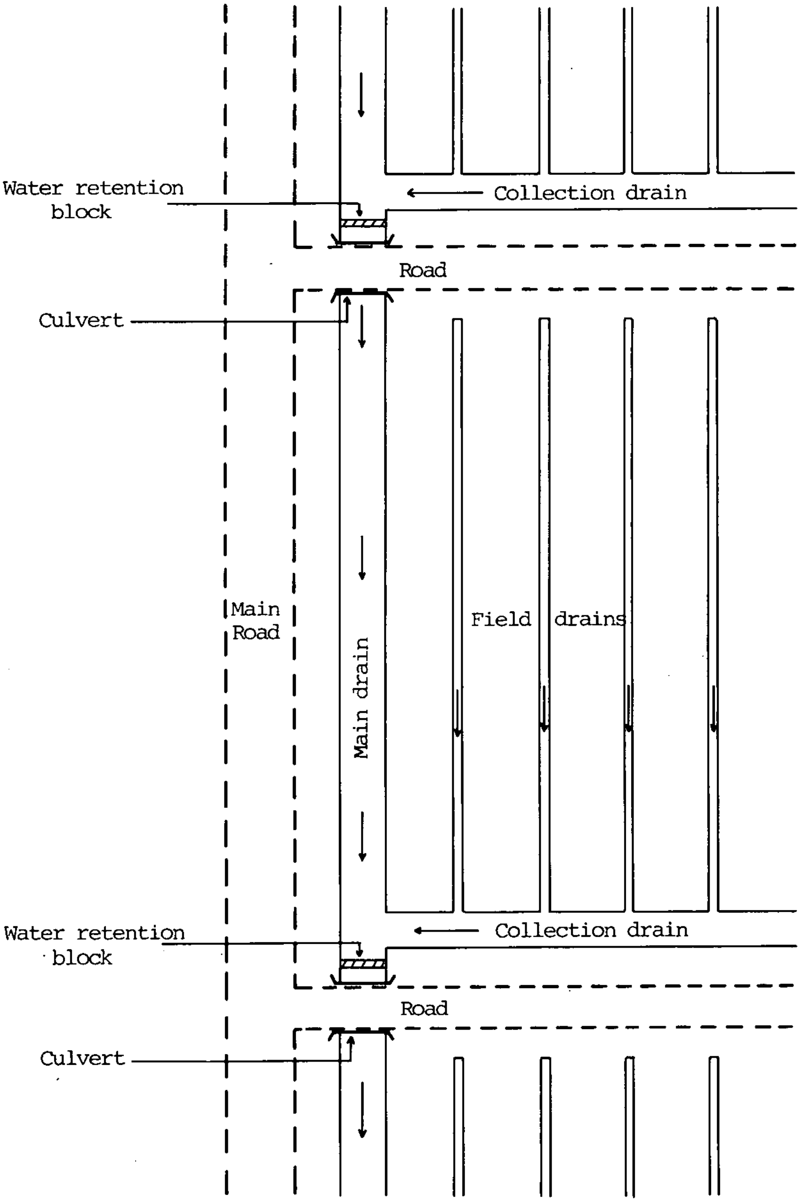

Figure 2. Schematic diagram of drainage system

Typical dimensions for the field, collection and main drains are given below:

Type of drain	Width (m) At top	 At bottom	Depth (m)
Field	1.00	0.45	0.75
Collection	2.00	0.60	1.50
Main	3.30	1.20	1.80-2.40

The field drains are spaced between 6 rows of palms or 47 m apart while the collection drains are located 396 m apart. The main drains are located 738 m apart. To obviate flooding, the drain dimensions must be varied according to the volume of water offtake necessary during wet weather conditions, as determined by observations in situ.

While the width or intensity of the field drains can be varied according to circumstances, the depth of these drains must not exceed 75 cm, otherwise there is a risk of accelerated oxidation of the pyritic layer during dry weather conditions.

The main requirements in the management of acid sulphate soils is that the watertable should be raised and maintained above the pyritic layer for as long as possible. To achieve this, the main drains must be blocked at various points along their length by weirs. These may be built by using soil bags, i.e. soil packed in used fertilizer bags, or by the construction of sluice gates. From experience, these water retention blocks are best constructed next to the culverts at a point close to where the collection drains meet the main drain. At this location the culvert face will assist in minimizing water leakages through the blocks. Normally the watertable in acid sulphate areas is maintained at about 60 cm from the soil surface.

With the location of the water retention blocks as described, it will usually be unnecessary to place any more blocks in the field drains. However, in situations where the slope of the land is uneven, it may be necessary to place soil bags at various points along the field drains to maintain the watertable.

In many situations, despite placement of water retention blocks, the watertable is not expected to remain at the required level throughout the year because of seasonal dry weather. In practice, the watertable will fluctuate, though ideally water should be visible in the field drains throughout the year. From observations, the watertable can be maintained at a reasonable level for up to a month into the dry season, but this will largely depend on soil texture and structure.

The fluctuating watertable does not completely prevent oxidation. During the rainy periods, acid accumulation in the ground water is decreased by regular precipitation and removal of acids through the drains. The problem becomes acute during prolonged dry spells when fresh water is not available and the acid concentration increases progressively owing to evapo-transpiration and accentuated oxidation of pyrite.

In practice, the problem of acidity build-up is minimized by periodic flushing of the drains during the wet season, which is achieved by opening up the sluice gates and soil blocks. Well before the end of the wet season, when rainfall is still virtually assured, the sluice gate and blocks are set in place. Fresh water is then allowed to build-up again to the required level, before the dry spell sets in. One to two flushings during the wet season are normally adequate.

6 Discussion

The profound influence of proper water management on the productivity of oil palms grown on acid sulphate soils may be associated with improvements in conditions suitable for root development. With a raised watertable, the secondary and tertiary roots are generally concentrated close to the watertable and primary roots that penetrate to greater depths during the drier periods produce upward-growing secondaries and tertiaries. When the watertable recedes during dry weather, roots are apparently able to proliferate through less toxic areas in the moist acid horizon to reach the watertable below. In contrast, in freely drained acid sulphate soils, few roots can penetrate the apparently less differentiated acid horizon to reach the watertable. Primary roots that happen to penetrate the acidic horizon produce very few secondaries and tertiaries and are usually stunted due to excessive soil acidity. Root spread is also much restricted and the bulk of roots are concentrated close to the bole of the palm. Consequently, oil palms grown in freely drained acid sulphate soils are unthrifty and frequently exhibit symptoms of moisture stress and multiple deficiencies.

Reservations had previously been expressed on the risk of incurring H_2S toxicity problems owing to anaerobic conditions brought about by maintaining a high watertable over prolonged periods. However, in field practice it is rarely possible to maintain a constant watertable and levels fluctuate throughout the year depending on rainfall distribution. Hence, no problems with H_2S toxicity have been encountered over the last fifteen years and it appears unlikely that such a problem will occur in the foreseeable future.

In addition to proper water management, a rational manuring programme must be implemented if palm yields are to be optimized. Bunch ash, derived from burning empty oil palm fruit bunches, is used almost exclusively as the source of potash in acid sulphate areas. Its highly alkaline reaction contributes to pH improvements in the topsoil. Studies have also shown that bunch ash improved soil moisture retention properties, this being associated with partial destruction of the crumb structure in the topsoil (Yeow et al. 1977).

7 Conclusion

There is a relationship between oil palm yields and the depth at which the acidic horizon occurs. Acidic horizons below 90 cm have virtually no effect on palm yields. On the other hand, where the acidic layers occur within 60 cm of the soil surface, yield levels will be reduced. Fortunately, such areas of severe acidity are usually discontinuous and reclamation of acid sulphate areas as a whole for oil palm cultivation is highly economic.

The recommended drainage pattern, with the location of water retention blocks at strategic points as described, has improved the yield performance of oil palms considerably over many years. It is now envisaged that there are relatively few problems with the growth of oil palms on acid sulphate soils provided that the pyritic horizon is not too shallow and the areas do not experience prolonged dry spells.

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PROBLEMS IN RECLAIMING AND MANAGING TIDAL LANDS OF SUMATRA AND KALIMANTAN, INDONESIA

L.J. van den Eelaart
Euroconsult
Arnhem, The Netherlands

1 Summary

Tidal lands of Indonesia are cultivated already on a large scale. Spontaneous or government-sponsored transmigration and reclamation proceed at a very fast rate at present. The soils of tidal lands reclaimed for rice cultivation in Indonesia are highly permeable and therefore have no or only a shallow water layer on the fields during the peak of the wet season. Yet they have high ground watertables throughout the year. Tidal irrigation is confined only to areas close to the rivers. Deep flooding can occur only where tidal action is weak or absent.

Continuous availability of water without flooding causes profuse growth of weeds, which is a major agronomic problem in tidal lands.

Potential acid sulfate soils occur over large areas, but the upper 30 cm is mostly free of potential acidity. In soils with potential acidity at shallow depth ground watertables should be kept high to prevent strong oxidation of pyrite. An important inherent limitation of the land is the occurrence of organic soils. They are unsuitable for rice when organic surface layers are thicker than 70 cm before reclamation. In these soils maintaining the field in a flooded condition is even more difficult than in clay soils, due to a still higher permeability. Moreover the organic soils are generally low in plant nutrients, they may give toxic organic compounds in stagnant surface water, while the surface soil may dry out irreversibly in the dry season.

Double cropping in tidal lands hardly exists so far. Irrigation in the dry season is limited by scarcity of good quality irrigation water.

Rainfed dry season rice may suffer from drought, despite high ground watertables. A short duration dryland crop, following the wet season rice cultivation suffers from insufficient drainage in most years. Stoplog structures in the canals to maintain high water levels in the drainage canals should help to keep fields flooded. Field bunds with clay cores built after removal of organic surface layers, would have the same effect and should further improve the productivity for rice. Yet some flushing of surface water should be allowed to prevent stagnant water conditions which apparently have an unfavourable effect on rice.

In South and Central Kalimantan experiments with a rainfed double rice cropping system using drought-resistant varieties seem promising. For the tidal lands project, sponsored by the World Bank (IBRD), a short duration dryland crop after rice is proposed. A gradual lowering of ground watertables over the years to improve conditions for the dryland crop is probably necessary. Preliminary observations in farmers fields indicate that such a dryland crop is possible even in potential acid sulphate soils. An additional positive effect of such a system is easier weed control.

A dense network of shallow field ditches with automatic flapgates to control water levels would provide the required dry-season water management. Excessive lowering of the ground watertable at the end of the dry season can be prevented by letting in tidal water through the flapgate structure. Upland tree crops can be grown well in tidal lands. By means of locally developed reclamation and planting techniques, coconut cultivation has become quite successful.

2 Introduction

The Indonesian government is opening up vast areas of tidal swamps for its transmigration program. This paper describes and discusses soils and reclamation techniques in existing tidal lands projects and provides proposals for improvements.

A number of tidal lands projects are sponsored by the World Bank (IBRD). The Directorate of Swamps, Tidal Swamps Reclamation Project (P4S) of the Ministry of Public Works has assigned Nedeco (Euroconsult) to supervise and assist the surveys and design for these projects which are carried out by IPB (Institut Pertanian Bogor), ITB (Institut Teknology Bandung) and UGM (Universitas Gajah Mada, Yogjakarta).

The principle of low-cost development for reclamation is applied in the most recent tidal lands projects, sponsored by the World Bank and is dealt with here. Other systems for rice growing exist, or are being developed, but will not be discussed here. In this regard it should be stressed that the viewpoints expressed in this paper do not necessarily reflect official viewpoints.

Tidal lands can be defined as coastal swamplands where water in wells and canals is subject to tidal fluctuations throughout the year. Further inland, water-levels in the rivers along swamps are so high that, at least during an appreciable part of the year, no daily tidal movements can be distinguished.

The majority of the soils in tidal lands are organic; most of the mineral soils are potentially acid at some depth.

Sizable areas have already been reclaimed, either by spontaneous settlers or by government sponsored transmigrants. The area now in use probably exceeds 500,000 ha (Collier 1979) out of a total of approximately 2×10^6 ha of tidal land in Sumatra and Kalimantan.

Conform present Government policies most of the tidal lands in the transmigration projects will be used for wetland rice. In the projects sponsored by the World Bank only soils with less than 50 cm organic surface layers after reclamation are considered suitable for rice. This is equal to maximally 70 cm peat in virgin conditions. As will be discussed later, thicker peat soils need costly measures for proper water management. Land covered by mangrove is preserved in view of its importance for marine life.

3 Environmental conditions in tidal lands

Under natural conditions tidal lands in Indonesia are covered by a dense fresh-water swamp forest of moderate logging quality. These forests can extend more than 100 km land inwards. Logging or shifting cultivation practices, combined with repeated fires have a detrimental effect on quality of wood and result in a dense forest of gelam (Meulaleuca leucadendron) with an undergrowth of a reed and grass-like vegetation. Mangrove forest occurs only in a 2-3 km wide belt, dominated by brackish water, along the coasts and in narrow strips along rivers and creeks. The climate is characterized by abundant rainfall moderately well distributed over the year. In most places monthly rainfall is below 100 mm only for about 2 months per year.

In the major tidal lands of Kalimantan and Sumatra the daily tidal fluctuations are predominantly diurnal (= one tidal cycle per day). Maximum tidal amplitudes are reached at springtide, minimum amplitudes at neaptide. The mean tidal range along Sumatra's east coast is about 1 m in the extreme south and north of the island and more than 4 m near the Strait of Malacca. In South and Central Kalimantan the mean tidal range is just over 2 m.

The mineral soils and the shallow peats are situated at about mean high tide level and in places up to several meters higher. Because the majority of tidal lands borders rivers having a mean tidal range of over 2 m throughout the year, drainage by gravity is not a problem, even after considerable subsidence due to reclamation.

A variety of soils is found in tidal lands, often in a complex pattern. The most common mineral soils are: Sulfaquents, Fluvaquents, Hydraquents and Tropaquents. Soils of the latter three Great Groups often have sulfidic materials within 1 m depth. Of these the Hydraquents are probably most widespread. The presence of potentially acid (sulfidic) materials is easily seen from the conspicuous pale yellow jarosite mottling and low field pH developed in gray clay dug up from ditches. Results from soil surveys, including analytical data on pyrite, show that indeed sulfidic material is ubiquitous at depths below 50 - 100 cm and occurs still closer to the surface in places (see profiles 1 and 2 and IPB soil survey reports).

Profile 1. Soil: Typic Sulfaquent, fine clayey, acid

No. Profile : 1435, Karang Agung Area
No. Mapping Unit : 9
Soil materials : Surface : Very fine clayey
Subsurface : Fine clayey
Drainage : Poorly drained
Topography : Level
Vegetation : *Melaleuca leucadendron*
Land use : Idle land
Observed water level : + 10 cm

Depth (cm)	Description and chemical data
0 - 20	Grayish brown (10 YR 5/2) clay; ripe; pH H_2O 4.1; C-org. 4.1%; pyrite 0.4%; CEC 32.4 me/100 g
20 - 80	Light brownish gray (10 YR 6/2) clay loam; half ripe; pH H_2O 3.0; C-org. 4.5%; pyrite 1.0%; CEC 31.9 me/100 g
80 - 120	Greenish gray (5 GY 5/1) clay; half ripe; pH H_2O 3.0; C-org. 5.1%; pyrite 1.2%; CEC 33.2 me/100 g

Profile 2. Soil: Haplic Hydraquent, very fine clayey, acid

No. Profile : 44, Mesuji Area
No. Mapping Unit : 11
Soil materials : Surface : Fibric materials
Subsurface : Very fine clayey
Drainage : Poorly drained
Topography : Level
Land use : Shrubs
Observed water level : 0 cm

Depth (cm)	Description and chemical data
0 - 20	Dark reddish brown (5 YR 3/2); fibric materials; pH H_2O 4.6; pyrite 0.2%; C-org. 37.74%; CEC 92.2 me/100 g
12 - 29	Dark grayish brown (10 YR 4/2) with dark gray (2.5 Y 3/0) clay loam; nearly ripe; pH H_2O 5.0; pyrite 0.15%; C-org. 9.64%; n-value 0.81; CEC 35.3 me/100 g
29 - 43	Light brownish gray (2.5 Y 6/2 + 10 YR 6/2) clay; nearly ripe; pH H_2O 4.8; C-org. 5.20%; n-value 0.71; CEC 36.8 me/100 g
43 - 95	Light gray to gray (5 Y 6/1) with greenish gray (5 BG 6/1) clay; half ripe; pH H_2O 5.2; pyrite 0.06%; C-org. 1.18%; n-value 1.3; CEC 33.7 me/100 g
95 - 120	Bluish gray (5 B 6/1) clay; unripe; pH H_2O 3.6; pyrite 1.56%; C-org. 1.92%; n-value 2.3; CEC 33.9 me/100 g

The organic soils are mainly Tropofibrists, Tropohemists, Troposaprists and Sulfihemists. Among the ripened soils, often mottled, the Tropaquepts are the most common. Up to now Sulfaquepts or Sulfic Tropaquepts have not been observed. The absence of sulfuric horizons with jarosite mottling in the profile, may be related in part to the continuously wet conditions due to well-distributed high rainfall. If this is true, Sulfaquents develop to Tropaquents or Tropaquepts, without an intermediate stage of Sulfaquepts or Sulfic Tropaquepts. The absence of a sulfuric horizon does not mean that there are no acidity problems in the tidal lands of Indonesia. But, favoured by the climate, the local cultivation and reclamation practices apparently keep the acidity at an acceptable level.

The nutrient status of the Entisols is quite good, partly because of relatively high contents of 2:1 clay minerals and organic matter. The CEC for mineral soils is mostly in the range of 20-40 me/100 gram soil (pH 7.0) for fine and very fine clays. This probably explains why with proper cultivation and water management, but without fertilizer or nutrient-rich irrigation water, rice yields of over 2 ton/ha have been obtained for about 40 years in tidal lands of South Kalimantan.

In thick organic soils the nutrient status is considerably less favourable and nutrient deficiencies are often a major constraint.

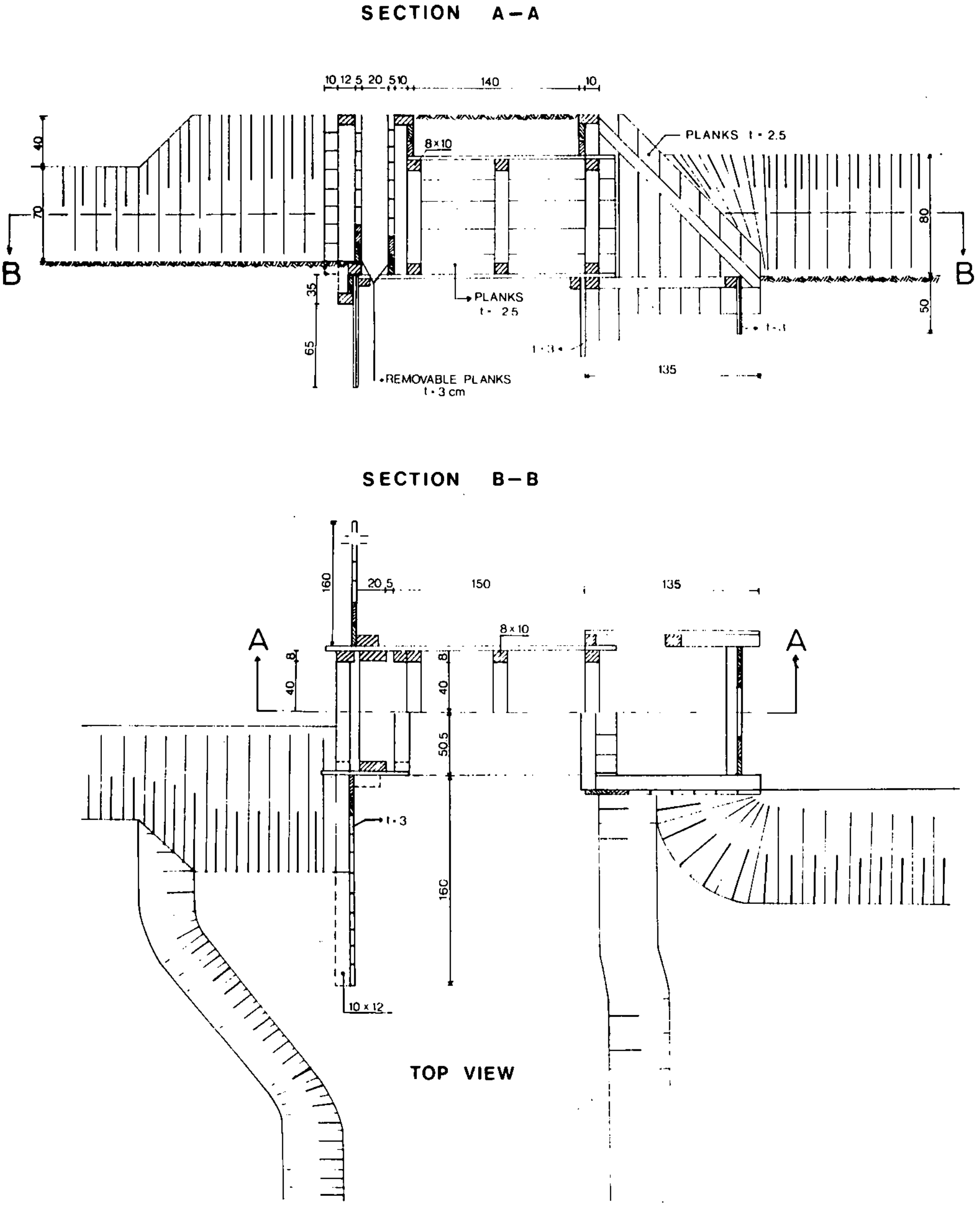
4 Soils and water management for rice-based cropping systems

4.1 Existing water management systems

Most of the reclaimed tidal lands have a so-called open system of water management: the drainage system is in open connection with the tidal rivers. In these conditions most tidal sawahs have a water regime similar to the phreatic regime, described by Moormann and Van Breemen (1978), characterized by high ground watertables throughout the year. Usually there is no or little surface water on the field. This is caused by percolation losses due to high permeability of the soils and by lack of tidal flooding. Tidal flooding is mainly restricted to areas adjacent to rivers and big canals. The percolation losses from the flooded fields are in some schemes in the order of 20-50 mm/day (the ponded water case, Luthin 1957).

In places, mostly confined to the homesteads of transmigrants, upland crops are grown on raised beds and wetland rice in ditches between the beds (sorjan system).

In older settlements in South Kalimantan stoplog structures (Figure 1) or seasonally constructed earthen or wooden dams are used.



Source: LAPI-ITB. 1980

Figure 1. Stoplog structure

4.2 Formulation of problems

4.2.1 Water retention in rice growing season

Wetland rice grows optimally if there is a surface water layer of about 10 cm on the field. The main advantages of the water layer are:

- a buffer for sufficient water supply during dry spells in the growing season. Rice is one of the least drought-resistant food crops.
- simplified weed control by wetland preparation and flooding. Only a limited number of weed species can grow and compete with rice under flooding.
- greater availability of plant nutrients, such as nitrogen, phosphorus and several minor elements (with the exception of zinc and copper). In acid soils the pH of the soil will increase on flooding by reduction.

The absence of a water layer in the tidal lands during the growing season causes a considerable yield depression, and the lack of surface water for rice is a major problem in tidal lands.

However, if measures are taken to keep ponded water on fields, there may arise some problems unless the surface water is refreshed regularly:

- In places that during the dry season have a low pH in the soil ($pH < 4.5$), on flooding the soil pH will increase by reduction, but at the same time ferrous iron will be mobilized to reach the soil surface and the overlying water, where oxidation of the ferrous iron brings about acidification (van Breemen 1975), which in stagnant surface water may affect rice growth.
- In peat soils as well as mineral soils with a humic surface stagnant water contains organic compounds toxic to rice (Ponnamperuma 1976).

4.2.2 High ground watertables

If tidal movement is allowed in canals, drainage as well as lateral tidal intrusion in the soil takes place. The net result is that watertables stay close to the soil surface. The phenomenon is most pronounced in relatively low-lying areas with a strong tidal movement in the adjacent canals.

Such permanently high ground watertables give rise to major problems.

The most important are:

- weed problems. In the dry season the sawahs are fallow for a long period. When farmers grow modern high-yielding varieties this period may last as much as eight months. High ground watertables, long fallow periods and the absence of flooding during the growth of rice promote abundant weed growth. This aggravates rat problems because the tall weeds in the sawahs provide excellent hiding places for rats.
- drainage problem for dryland crops. To facilitate a palawija crop (= dryland crop following rice) in the sawahs of the tidal lands, lower ground water levels are required for considerable periods of its growing season.

4.2.3 Acidity hazard

When the tidal recharge is small, e.g. due to wide drain spacing and little tidal movement, ground watertables may drop to 70 cm below surface during long dry spells and surface layers dry out considerably. This causes strong acidification in Sulfaquents. This problem is at present limited to relatively small areas. Preliminary observations indicate that for most tidal lands in Sumatra and Kalimantan an artificial lowering of ground watertables to 30 - 50 cm will not cause strong acidification; even not in Sulfaquents.

4.2.4 Organic surface layers

The organic surface layers are often highly detrimental to rice cultivation. The problem is widespread in tidal lands.

- Irreversible drying of the surface layer in half-decomposed and non-decomposed peat is a major problem. Planting in irreversibly dried peat will often be a complete failure because of insufficient water supply to the plant roots. Also in later stages of the crop, dry spells may cause considerable loss of yield.
- Prolonged flooding in peat soils may cause zinc and copper deficiencies (Ponnamperuma 1976).

- Pyritic layers often underly the organic layers in peat soils. After oxidation of the peat they will be close to the surface and strong acidification is possible.

4.2.5 Cropping systems and availability of water in the dry season

Lack of water in the dry season is a serious limitation for crops. Suitable cropping systems still have to be developed for large-scale application.

- Water balance calculations indicate that a rainfed dryland crop and a rainfed short duration second rice crop will suffer from drought if their growing season extends far into the dry season.
- Irrigated rice requires the availability of good quality irrigation water during dry spells. Development of large-scale irrigation is limited by salt intrusion during low rainfall periods. Construction of cheap storage reservoirs, e.g. in small tributaries, will be difficult, and proper locations for dams are rare.

In South Kalimantan certain local varieties are transplanted two to three times with the growing season extending into the dry season. Although farmers sometimes complain about a considerable risk of drought for this crop, it is apparently grown with success in large areas. It is not clear what causes the good results. Perhaps the crop receives somehow additional water, either by surface flow from adjoining higher areas or from tidal intrusion. Another explanation is that local rice varieties are adapted to a gradual decrease of soil moisture after the surface water has been drained off.

This transplanting system makes two rice crops a year possible, as will be explained in section 4.4).

4.3 Improved water management systems

Better water control on the sawahs is the primary requirement for an increase of food production in tidal lands. The present low level of water management explains failures to improve yields of rice and other crops. The raised bed system (sorjan system), introduced by the Javanese

transmigrants, provides a major improvement of water management; with better drainage for upland crops and reduced percolation losses for rice. However, the sorjan system has two important disadvantages. First much labour is required for construction of the beds, therefore farmers limit the system to homeyards and nearby sawahs. Second, during the construction of beds, potentially acid soil in the troughs is exposed to the atmosphere and acidifies with harmful effects on rice.
For the projects sponsored by the World Bank a less labour intensive system is proposed. It is discussed below.

4.3.1 *Maintaining water layers on sawahs*

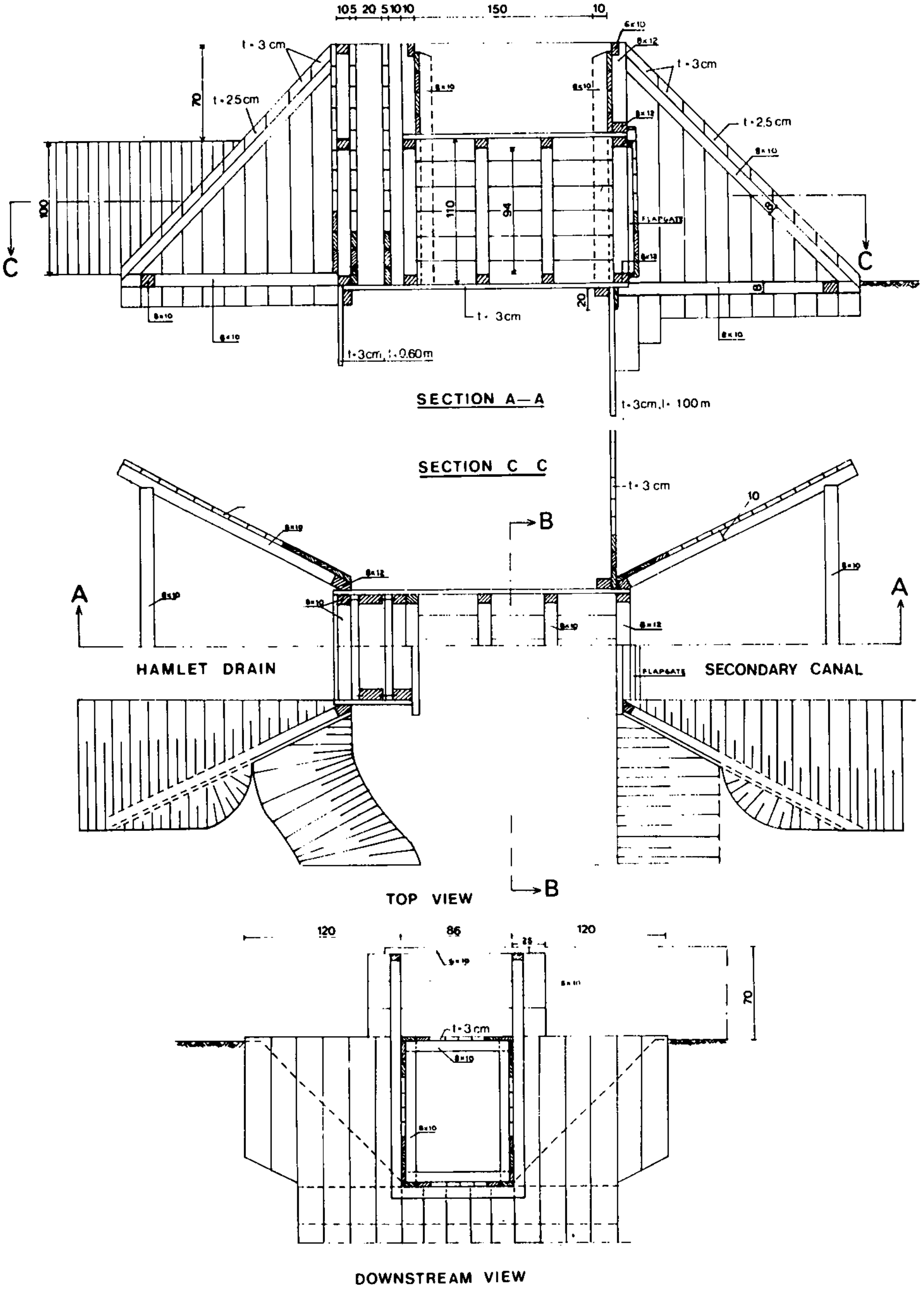
In general, rainfall is sufficient for one rice crop per year including some extra flushing of surface water, provided that percolation losses do not exceed 1 - 2 mm/day. The percolation losses can be reduced to this level by the following measures:

- Keeping adjacent water levels in the drainage canals of the sawahs high. This can be accomplished by the construction of stoplog structures (see Figure 1) in the tertiary or secondary canals. Water levels on the sawahs are regulated by means of the stoplogs. The location of such stoplog structures is determined by the local topography and the need for well-drained hamlet areas.
- Field bunds around sawahs will only work properly if any organic surface layers have been removed before construction of clay bunds. The costs to construct such bunds in thick peats are a major limiting factor of these soils for rice cropping.
- Large percolation losses are likely to occur at the boundary between sawahs and areas without surface water (fields under upland crops, homeyards, etc.). Although still in an experimental phase, those losses may be reduced by placing plastic sheets vertically until 1.5 m depth along boundaries. Alternatives to the plastic sheets may be a wide uncultivated strip, or deep ripping of the subsoil and the subsequent compaction of the soil material at boundaries.

4.3.2 *Control of ground watertables*

In the low-cost simple technology approach adopted in the transmigration projects, control of ground watertables can be obtained by digging of small field ditches and the construction of automatic flapgates ('pintu klep') by farmers. The ditches should be 30 - 90 cm deep, may have vertical side slopes and should be between 20 to 80 m apart. Flapgates in secondary or tertiary canals must always be combined with stoplog structures to control the water levels upstream of the flapgate structure (see Figure 2). Low dikes are required along watercourses with tidal movements.

In areas below highest tide levels and with strong tidal movements in canals, an artificial lowering of the ground water is obtained only by a flapgate in combination with low dikes. The tidal influence can be restored by the opening of the flapgate structures. In the presence of tidal influence many small field ditches will keep the ground water levels high in sawahs, even during long dry spells.



Source: LAPI-ITB. 1980

Figure 2. Flapgate structure

4.4 Improved cultivation techniques

To optimize the production in the low-cost simple technology approach a number of agronomic recommendations are suggested.

4.4.1 Water layer on sawah (wet season)

Before planting rice and at the end of the growing season, toxic compounds should be leached by subsurface drainage and surface flushing after a period of saturation and flooding. During the growing season water layers on the sawah should be maintained at a constant level of 10 cm by means of stoplog structures.

4.4.2 Artificial lowering of ground watertables

Controlled lowering of the ground watertable during part of the year has the following advantages:

- A palawija (dry) crop can be grown in sawahs.
- During fallow periods weeds can be burnt more easily, which facilitates both weed and rat control.
- Alternating periods with flooding and with a relatively deep watertable will alter the environmental conditions for weeds and should reduce the number of weeds that compete with rice. This is important if short duration rice crops are grown.
- Irreversibly dried peat is easily burned after lowering of ground watertables.
- In peat soils toxic organic compounds are oxidized and nitrogen, copper and zinc will become better available for plants.

Sudden exposure to air of underlying pyritic layers is a hazard and a gradual lowering of watertables is advisable. This is particularly true where peat has been burnt.

4.4.3 *Acidity control*

So far Sulfaquents were found only in land below high tide levels. Under these conditions tidal intrusion is relatively easy. Acid or saline water entering fields by tidal intrusion or tidal flooding probably has no or little effect on the following rice crop.

In Sulfaquents, watertables must be kept high in periods of extreme drought, and leaching of toxic compounds, including free acids, after oxidation periods is important.

4.4.4 *Weeding and puddling*

Weeds in tidal lands are mainly controlled by slashing them during land preparation. The weeds are often collected in heaps and later spread over the land.

In mineral soils puddling reduces percolation losses and controls weeds. At present only zero-tillage or light superficial tillage are carried out by farmers in tidal lands. Use of draft animals is difficult because of the soft soils and the many large tree remnants at shallow depth. Perhaps the high permeability of the surface layer is important for leaching of toxic compounds. Intensive puddling could lead to a strong decrease of this permeability. Long-term trials should be conducted to assess whether puddling offers advantages for tidal lands.

4.4.5 *Doubling cropping systems*

Double cropping of rainfed rice is possible if two crops can be grown within about 9 consecutive months. Locally in S-Kalimantan, the two-three times transplanted, traditional variety is preceeded by a modern short-duration, high yielding variety on a small part of individual farms. The availability of labour is a major constraint for this cropping system, especially between harvest of the first crop and transplanting of the second crop. Experiments are carried out with a less labour intensive double cropping system involving broadcast rainfed high yielding varieties. This method looks attractive and may be promising;

comparable experiments are carried out in the Philippines, but for different land systems (Morris and Zandstra 1979). However, high inputs for pest and weed control are required for this cropping system. At present a palawija crop after rice may have better prospects. This rotation would involve periodic lowering of the ground watertable, which would further facilitate pests and weed control. Moreover, the cropping system rice-palawija is less labour-intensive which makes it more favourable for tidal lands under the present conditions.

5 Reclamation and water management for upland tree crops

Extensive tracts of tidal lands are definitely unsuitable for rice due to the presence of deep peat. However, coconut can be grown successfully on soils with, in virgin conditions, 1.5 - 2.0 m of peat over clay. Experience in Malaysia shows that also oil-palm has a considerable potential in tidal lands. For mineral soils and shallow peats yields of both tree crops are in general 20-40% higher than in upland areas. But in peats of about 1.5 - 2 m thickness yields will be about the same as for upland areas, provided proper drainage is applied.

Successful reclamation methods for coconut in tidal lands of Indonesia are the raised bed system (Banjarese method, South and Central Kalimantan) and the drainage system (Buginese method used in Rian, Jambi and West Kalimantan). In the *raised bed system*, perpendicular to a main canal with a strong tidal movement, ditches are dug in open connection with the main canal. They are spaced 50 m apart and are up to 1 m deep. Coconut is planted in an 8 × 8 m grid on mounds. In the course of seven years the mounds are connected with each other, developing into a raised bed-trough system. In the first two or three years the coconut is intercropped with a (poor) rice crop during the wet season. This rice crop probably suffers from acidity in many cases. No adverse effects are noted for the coconut and after a few years also crops like coffee do well on the raised beds. The main disadvantages of the system are the laborious construction of the raised beds and the need for continued maintenance due to subsidence of the beds.

In the *Buginese drainage system*, the land is drained by preventing tidal intrusion, using flapgate structures and low dikes and by constructing a dense network of shallow drains. The flapgate structures are often of the culvert type (= polongan klep), made of wood. Watertables are gradually lowered by deepening the ditches. To control the water levels in the canals, stoplog structures are required. In the first years the watertables in the soils are kept at about 30-40 cm below surface, later at 60-70 cm depth. In clay soil, coconut is planted at very shallow depth, while some soil is added around the nut, forming a small mound. In peat coconut seedlings are planted in 40 to 60 cm deep holes and are covered by peat to compensate for future subsidence. From the first year of reclamation onwards, coconuts are interplanted with upland crops, including maize and bananas, even in Sulfaquents. In later years only the perennial crops prevail. In the first years shallow drainage apparently does not harm the crops. Presumably the higher nutrient status of the virgin soils compensates for adverse effects of drainage. This has been noted in Surinam too (Kamerling 1974).

The drainage system is far less labour-intensive than the Banjarese raised bed system, both initially and later during maintenance.

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VARIETAL REACTIONS OF RICE TO IRON TOXICITY ON AN ACID SULFATE SOIL

F.N. Ponnamperuma and J.L. Solivas
The International Rice Research Institute
Los Baños, Philippines

1 Summary

A total of 420 rices was screened on an acid sulfate soil in a farmer's field, Albay, Philippines, during three seasons. Forty-one were found to have tolerance for iron toxicity. Iron toxicity was severe in the wet season following the dry season apparently because of strong acidification following soil drying. But the tolerant rices generally fared better than the susceptible in both seasons. Yield trials confirmed the tolerance of the varieties identified as tolerant in mass screening tests. Tolerant rices gave grain yields of nearly 3 t/ha when iron toxicity was severe and over 6 t/ha when it was mild. Tolerant varieties may be a substitute for lime on moderately toxic acid sulfate soils.

2 Introduction

Iron toxicity is a widespread nutritional disorder of wetland rice associated with excess water-soluble iron (Ponnamperuma et al. 1955). It occurs on acid sulfate soils (Sulfaquepts) and strongly acid Oxisols, Ultisols, Hydraquents, Tropaquents, and Histosols (Ponnamperuma 1958, Howeler 1973, Tanaka and Yoshida 1975, Panabokke 1975, van Breemen and Moormann 1978).

Iron toxicity is characterized by the appearance of small brown spots on the lower leaves starting from the tips. Later the whole leaf turns brown, purple, yellow, or orange. Growth and tillering are depressed and the root system is coarse, scanty, and dark brown (Ponnamperuma et al. 1955, Tanaka and Yoshida 1975). Yield reduction may range from 10 to 90% depending on soil, variety, and growth stage of the appearance of symptoms (Gunawardena 1979, Virmani 1978).

In acid sulfate soils, iron toxicity is an important growth limiting factor (Nhung and Ponnamperuma 1966, Tanaka and Navasero 1966, Ponnamperuma et al. 1973, van Breemen and Pons 1978). Although iron toxicity can be alleviated by liming and drainage, varietal tolerance is a more simple and economical solution (Ponnamperuma 1974, Ikehashi and Ponnamperuma 1978) especially for the small farmers of South and Southeast Asia.

Several workers have shown that marked differences exist in rice varieties in their tolerance for excess iron (IRRI 1971, Ponnamperuma and Castro 1972, Gunawardena 1975 and 1979, Virmani 1978). With the initiation of the Genetic Evaluation and Utilization (GEU) Program (IRRI 1974), mass field screening for iron toxicity tolerance was begun. Mass screening was followed by yield trials of promising rices from greenhouse and field tests.

3 Materials and methods

The soil at the experimental site (a farmer's field at Malinao, Albay, Philippines) is a Sulfaquept developed in a recent sulfurous alluvial fan sediment of volcanic origin. Chemically and morphologically it is an acid sulfate soil (van Breemen 1978). The chemical characteristics are in Table 1. It was plowed wet and harrowed after broadcasting 50 kg N/ha and 25 kg P/ha.

Table 1. Some chemical characteristics of the soil at the experimental site, Malinao, Albay, Philippines

pH of dry soil (1:1 H_2O)	3.5
EC_e (mmho/cm)	1.0
CEC (meq/100 g)	9.5
Organic C (%)	1.23
Total N (%)	0.15
Active Fe (%)	2.50
Active Mn (%)	0.001
Ex. K^+ (meq/100 g)	0.17
Ex. SO_4^{2-} (%)	0.27
Available (Olsen) P (ppm)	7.0

3.1 Mass screening

The test materials for mass screening were drawn largely from the elite lines of the breeding program of the International Rice Research Institute. Three week-old seedlings raised on a normal seedbed were planted in three 3-m rows at a spacing of 20 cm × 20 cm. A randomized complete block design replicated three times was used. A resistant check and a susceptible check were included in the rices tested. The plots were irrigated with water from a nearby stream. The plants were scored for iron toxicity based on foliar symptoms and general appearance on the scale 1 to 9 (1 = nearly normal plant; 9 = nearly dead or dead plant). A score of 3 or less indicated tolerance; 6 or more indicated susceptibility.

3.2 Yield trials

Fifteen promising rices from screening tests were tested each season in replicated yield trials at the field screening site.

Three-week old seedlings raised on a normal wet seedbed were transplanted in 2 m × 3 m plots at a spacing of 20 cm × 20 cm. The treatments were replicated 3 times. In later tests the plot size was increased to 3 m ×

4 m, and the susceptible check was planted in two rows between plots throughout the field to monitor soil differences. Fifty kg N/ha as urea and 20 kg P/ha as ordinary superphosphate were broadcast and incorporated just before transplanting. The plants were scored at 4 and 8 weeks after transplanting for iron toxicity on the scale 1 to 9. Grain yield was measured at maturity.

4 Results and discussions

4.1 Mass screening

Table 2 summarizes the results of three seasons' mass screening. The scores at 4 weeks after transplanting were used for rating tolerance because the differences were more marked and the coefficient of variation of the scores was less than at 8 weeks after transplanting. Table 3 lists the names of the tolerant rices.

Table 2. Scoring results of field mass screening of rices for tolerance to iron toxicity in an acid sulfate soil, Malinao, Albay, Philippines. Figures show number of varieties rated on the scale 1 to 9 (1 = nearly normal growth, 9 = most plants nearly dead or dead).

Varieties tested	Season	1	2	3	4	5	6	7	8	9	Total
IRON[1] 1978	1979 Dry	0	0	36	166	57	2	1	0	0	262
1979 GEU[2] Elite	1979 Wet	0	0	0	5	15	33	23	9	0	85
1980 GEU Elite	1980 Dry	0	0	5	39	26	3	0	0	0	73
Total		0	0	41	210	98	38	24	9	0	420

[1] IRON: International Rice Observational Nursery

[2] GEU: Genetic Evaluation and Utilization

Problems encountered included soil heterogeneity and seasonal differences in expression of toxicity symptoms, but varietal differences were clearly discernible (Table 4). Seasonal differences are evident from the exclusion of IR36, the resistant check, as a tolerant rice in the 1979 wet season (Table 3), although during this season any rice that scored 4 or less was considered tolerant. The severity of iron toxicity in the 1979 wet season was probably due to the prolonged drying and acidification of the field during the dry months immediately preceding the wet season.

Table 3. Varieties/lines found tolerant of iron toxicity in field mass screening on an acid sulfate soil, Malinao, Albay, Philippines

1979 dry season	1979 wet season	1980 dry season
BPI R1-2	IR3838-1	IR36
IR36	IR5853-118-5 (IR52)	IR13240-10-1-3-2
IR4442-165-1-3-2	IR8192-200-3-3-1-1	IR13423-17-1-2-1
IR4568-225-3-2	IR9129-136-2-2-1-2	IR19743-46-2-3
IR4625-269-4-2	IR13419-113-1	IET 1444
IR9129-136-2	IET 1444	IR14632-246-2
B2149-PN-26-1-1		

Table 4. Analysis of variance for scores for iron toxicity at 4 weeks after transplanting in 3 seasons

	Mean squares		
Sources of	Season		
variation	1979 dry	1979 wet	1980 dry
Replication	9.319**	62.123**	2.26*
Variety	1.083**	2.709**	1.276**
Error	0.623	1.562	0.68
CV %	19.3	20.3	18.8

** Significant at the 1% level

* Significant at the 5% level

4.2 Grain yield

The 1979 dry season grain yields of 15 selected rices and iron toxicity scores are in Table 5. IR4683-54-2 gave the highest yield (4.5 t/ha) and the lowest score (2.5); IR26, the susceptible check, gave the lowest yield (1.7 t/ha) and the 2nd highest toxicity score (4.8). Apart from that, there was no correlation between symptoms at 4 weeks after transplanting and grain yield. Seven of the 15 rices yielded significantly more than IR36, the resistant check.

Table 5. Iron toxicity tolerance scores and grain yield of selected rices on an acid sulfate soil in Malinao, Albay, Philippines, 1979 dry season

Variety/line	Score at 4 WAT[1]	Grain yield (t/ha)
IR4683-54-2	2.5 d	4.5 a
IR2863-38-1	3.8 bcd	3.7 b
IR5863-163-1	4.3 abc	3.6 b
IR4432-52-6	4.8 ab	3.4 b
BHR 134-33	3.5 bcd	3.4 b
BHR 145-47	4.3 abc	3.3 bc
IR46	4.0 abc	3.2 bc
BHR 134-1	3.8 bcd	2.8 cd
BHR 134-25	4.3 abc	2.5 de
IR36 (resistant check)	3.3 bcd	2.5 de
BHR 134-43	5.3 a	2.3 de
BHR 134-5	4.5 abc	2.3 de
BHR 134-28	3.3 bcd	2.2 def
IR20	4.0 abc	2.1 ef
IR26 (susceptible check)	4.8 ab	1.7 f

[1] WAT: weeks after transplanting

Note:

In a column values followed by the same letter are not significantly different at the 5% level.

In the 1979 wet season iron toxicity was severe because of soil drying and acidification in the dry months preceding the wet season. The toxicity scores were high and the yields were low (Table 6).

Table 6. Iron toxicity tolerance scores and grain yield of selected rices on an acid sulfate soil in Malinao, Albay, Philippines, 1979 wet season

Variety/line	Score at 4 WAT[1]	Grain yield (t/ha)
IR4422-480-2	5.0 bc	2.7 a
B2149-PN-26	5.2 bc	2.6 a
IR46	4.5 c	2.6 a
IR4625-269-4-2	4.7 bc	2.5 a
IR45	4.5 c	2.4 ab
IR4683-54-2	5.0 bc	2.4 ab
BPI R1-2	6.5 ab	2.2 ab
IR44	5.2 bc	2.1 abc
IR4442-165-1	6.5 ab	2.1 abc
IR5254-3-5	6.0 abc	1.8 bc
IR1552	6.5 ab	1.8 bc
IR9129-136-2	5.5 abc	1.6 cd
IR5201-127-2	5.0 bc	1.0 d
IR42	6.0 abc	-
IR26	7.2 a	-

[1] WAT: weeks after transplanting

Note:

In a column values followed by the same letter are not significantly different at the 5% level.

But IR4422-480-2, IR4683-54-2 and IR46, which were among the top yielders in the dry season experiment, were among the best in the wet season as well. IR26, the susceptible check and IR42 suffered severely from iron toxicity and had their maturity delayed so long that they could not be harvested with the rest. During the 1980 dry season iron toxicity was not severe (due apparently to the soil being wet during the months before planting) and toxicity scores were low and the yield was high (Table 7). IR4683-54-2 which had given low scores and high yields in the two earlier tests was the highest yielder with 6.7 t/ha. IR46 also showed its tolerance for excess iron both in the score and in yield.

Table 7. Iron toxicity tolerance scores and grain yield of 15 selected rices on an acid sulfate soil, Malinao, Albay, Philippines, 1980 dry season

Variety/line	Score at 4 WAT[1]	Grain yield (t/ha)
IR4683-54-2	3.0 c	6.7 a
IR46	4.0 abc	6.4 ab
IR44	4.0 abc	6.3 abc
IR50	5.0 abc	6.2 abc
IR13149-43-2	5.0 abc	6.0 abc
IR13419-113-1	4.0 abc	6.0 abc
IR42	5.3 ab	5.9 abc
IR9129-136-2	3.0 c	5.7 abcd
IR48	5.7 a	5.6 abcd
IR52	5.0 abc	5.4 bcde
IR36	3.7 abc	5.2 cde
IR4422-480-2	4.7 abc	4.6 def
IR3839-1	4.3 abc	4.6 def
IET 1444	4.3 abc	4.4 ef
IR13168-143-1	3.3 bc	3.8 f

[1] WAT: weeks after transplanting

Note:

In a column, values followed by the same letter are not significantly different at the 5% level.

5 Conclusions

Marked varietal differences exist in the tolerance of rice varieties for excess iron. The visual score according to foliar symptoms and general appearance separates tolerant from the susceptible in mass screening tests but is not a good index of tolerance as measured by grain yield within varieties having a similar degree of tolerance.

There were marked seasonal differences in the performance of rices on the acid sulfate soil. The differences appeared to be associated with the water regime before planting. Tolerant rices gave nearly 3 t/ha of grain when iron toxicity was severe and over 6 t/ha when it was mild. Costly amendments such as liming may be avoided by using tolerant varieties.

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WATER, SOIL AND RICE IN AN ACID SULFATE SOIL OF THAILAND

Hidenori Wada, Faculty of Agriculture, University of Tokyo, Japan
Jongruk Chunchareonsook, Supamard Panichsakpatana, Paiboon Prabuddham, Tasnee Attanandana
Department of Soil Science, Kasetsart University
Bangkok, Thailand
and Chakrapong Chermsiri, Agricultural Chemistry Division, Ministry of Agriculture and Cooperatives, Thailand

1 Summary

Four long-term experimental plots at the Rangsit Rice Experimental Station (Rangsit series) were selected as the sites of investigation. Vertical flow of water and leaching loss of water-soluble substances should be minimum in this soil during most periods of submergence since internal drainage of the soil is extremely poor and the ground water-table is high. Flood water became acidified and enriched with SO_4^{2-}, Cl^-, Na^+, Mg^{2+}, from the soil, indicating that substances accumulated in the submerged soil tend to diffuse upward and to be transferred to the flood water. At the soil-water interface a very thin and acid oxidized layer is formed that might partly inhibit nitrification-denitrification processes in the topsoil. The vertical profile of Fe^{2+} and NH_4^+ in the Apg horizon support the supposition of upward diffusion of these substances. Removal of NH_4^+ in flood water run-off is proposed as one of the main processes of N-loss from the acid sulfate soil. N_2-fixing activity was low in the early stage, became very high at the flowering stage and low again at harvesting time. The decrease in the N_2-fixing activity in the later period may have been caused by a decrease in the population of active microorganisms. Nitrogen absorbed by rice plants is found to be nearly equal to the amount of 'utilizable N in soil' which can be calculated from the NH_4^+ content in the soil.

2 Introduction

Several features of water, soil and rice in an acid sulfate soil of Thailand will be dealt with in this paper. This is actually only a part of the results so far obtained by the cooperative research between Thailand and Japan on the nitrogen cycle in paddy fields which started in 1979 and will continue till 1981. Many reports have been published about different segments of the N-cycle in paddy soil such as mineralization, immobilization, nitrification, denitrification, N_2 fixation, fertilization, leaching of nitrogenous compounds, absorption by plants etc. (IRRI 1979). An integral study of the N-cycle, measuring all of these items at the same time for a specific paddy field is required to appraise the economic efficiency of N-input in paddy production. This information is very important in the light of diminishing natural resources and increasing pollution of our environment. In this cooperative research, not only nitrogen in various forms were measured but also other factors which might be useful for characterizing the paddy fields were studied.

3 Materials and methods

Soil. Four long-term experimental plots at the Rangsit Rice Experimental Station were selected as the experimental sites. The soil at this station is classified as the Rangsit series, a well developed acid sulfate soil (Sulfic Tropaquept) (Van Breemen and Pons 1977). It has jarosite mottles between depths of 50 and 150 cm below the soil surface. The four plots are as follows: a non-fertilized plot (Plot 1), a manured plot (Plot 5), a fertilized plot (Plot 6) and a fertilized and manured plot (Plot 10) (Table 1).

Table 1. Plots and fertilization at Rangsit Rice Experimental Station

Plot No.	N	P_2O_5 kg/ha	K_2O	Rice Straw Compost ton/ha
1	0	0	0	0
5	0	0	0	12
6	50	25	25	0
10	50	25	25	12

In each plot 3 treatments were set up a few days after transplanting (Figure 1).

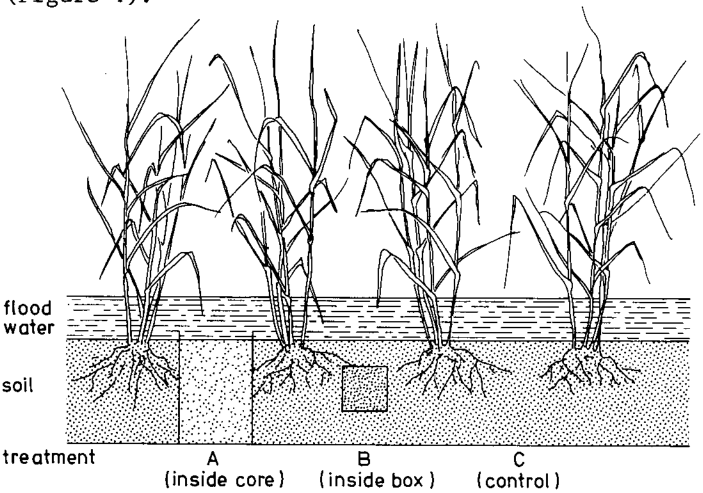

Figure 1. Treatment set up in paddy fields

Treatment A: A core made of stainless steel (diameter 25 cm height 20 cm) was pushed into the Apg horizon to protect the soil inside the core from invasion of rice roots. The upper part of the core was kept below the level of flood water and just above the surface of the soil so as to allow free exchange of flood water between inside and outside the core. Treatment B: A similar core of the same type was inserted into the Apg horizon, its upper rim being kept above the level of flood water. After removing the flood water from inside of the core the soil inside the core was well mixed and about 400 g of it was placed in a plastic box and tightly enclosed. Then the plastic box was buried in the soil inside the core and the core was removed from the Apg horizon.

Treatment C: Adjacent soil planted with 4 rice hills was considered to be a control for A-soil and B-soil and called C-soil. Before transplanting A-soil and B-soil do not exist and only C-soil is available for investigation (pH :4.4, organic C: 1.84%, organic N: 0.14%, CEC: 3.75 me, active Fe: 0.9%).

Undisturbed soil samples (0-10 cm) were collected at the various stages of rice growth with a 200 ml core sampler (10 cm high) from A-soil and C-soil. The plastic box containing B-soil was also collected at the same time. These soil samples were stored in an ice box and brought back to the laboratory.

The undisturbed soil samples from A and C were divided into 3 parts: the upper part (0-2 cm), the middle part (2-5 cm), and the lower part (5-10 cm). Each part of the undisturbed soil samples and the B-soil were analyzed for moisture content, pH, Fe^{2+} (extracted with pH 2.8 acetate buffer solution and measured colorimetrically (Kumada and Asami 1958), NH_4^+ (extracted with a 10% KCl solution and determined by distillation method) and acetylene reduction activity (Matsuguchi et al. 1978).

Water. Holes with a diameter of about 10 cm were dug to between 50 cm and 1 m depth in a paddy field adjacent to the 4 plots and plastic pipes were pushed into the holes to collect ground water and also to measure the level of ground water. The opening on the top of the plastic pipe was covered with a plastic cap.

The surface water of the 4 plots, irrigation water and canal water were collected using plastic bottles and ground water was sampled at 10 and 40 cm below the soil surface with a long plastic tube attached to a syringe. Immediately after sampling pH, EC, temperature and turbidity of the water were measured by using a water checker (U7, Toa electronic Co.). An aliquot of each water sample was brought back to the laboratory and analyzed for several chemical elements.

Rice plants. Rice plants (tops and roots) with average tiller number and height were collected from each plot and dry weight and nitrogen content were measured. In addition roots of the rice plants with rhizosphere soil were analyzed for acetylene reduction activity using a gas chromatograph (Shimadzu Co.).

Time of sampling. Water, soil and rice plants were collected several times during the period of flooding and/or rice growth; a few days before transplanting, a few days after transplanting, during the panicle initiation stage, during the flowering stage and at harvesting time.

4 Results and discussion

4.1 Water (Table 2)

The ground watertable was found to be maintained at about 7 cm below the soil surface. The height of the ground watertable and the extremely poor internal drainage of Rangsit soil may have completely inhibited the downward movement of water and water-soluble substances from flood water through the Apg horizon to the subsurface horizons during most periods of submergence.

Table 2. Water analysis at Rangsit Experiment Station (panicle initiation stage, 1980)

Sample	pH	Temp (°C)	DO (ppm)	EC mS/cm	Turbidity (ppm)	$\frac{1}{2}Ca^{2+}$	$\frac{1}{2}Mg^{2+}$	K^+	Na^+	$\frac{1}{2}Fe^{2+}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	HCO_3^-	SiO (ppm)
									mmol/l					
Flood water														
Plot no. 1	4.1	34.3	9.2	0.9	1.5	1.13	1.50	0.46	3.10	0.14	5.31	2.48	0	6.5
5	4.6	34.7	6.9	1.9	56.0	0.69	0.73	0.23	2.17	0.02	3.13	1.83	0	6.0
6	4.2	39.1	7.3	0.9	37.5	1.13	1.40	0.28	2.88	0	5.0	2.35	0	6.0
10	4.7	40.7	5.1	1.1	138.0	0.63	0.06	0.18	2.17	0.003	2.5	1.83	0	6.0
Ground water														
in 50 cm pipe														
at: 10 cm	3.1	34.1	3.4	0.95	3.5	3.75	8.33	1.70	11.52	0.09	18.75	10.17	0	52.5
40 cm	3.4	33.5	-	1.2	9.0									
in 100 cm pipe														
at: 10 cm	2.7	34.4	4.0	2.0	1.5	3.5	8.33	2.31	14.59	0.36	21.9	11.99	0	7.0
40 cm	2.7	33.6	4.0	2.0	1.5									
Irrigation water	5.0	35.0	-	1.1	5.0	1.00	1.07	0.54	2.17	0.007	4.40	1.70	0.11	2.0
Canal water	6.1	37.8	3.0	1.2	49.0	0.50	0.57	0.45	0.85	0.029	0.81	0.47	0.88	14.0

Analytical methods:

pH, Temp., DO, EC, - water checker

Ca^{2+}, Mg^{2+}, Na^+, K^+ - atomic absorption spectrophotometer

Fe^{2+}, SiO_2 - colorimetry

SO_4^{2-} - turbidimetry

Cl^-, HCO_3^- - titration

In general the concentration of SO_4^{2-}, Cl^-, Na^+, Mg^{2+} and acidity was highest in the deep ground water and successively lower in shallow ground water, flood water, irrigation water and canal water. The high acidity of the ground water, increasing with depth, is obviously caused by the oxidation of pyrite and the hydrolysis of jarosite in deeply situated layers or horizons. The acidification of the flood water by forming H_2SO_4 at the surface of the submerged acid sulfate soils was studied by Van Breemen (1976). In the context of these latter studies the concentration gradients observed in the present investigation can be said to indicate that several water-soluble substances accumulated in the submerged acid sulfate soils were diffused upward and, as such or after being converted to other forms, transferred to the flood water. The contents of the above mentioned ions (SO_4^{2-}, Cl^-, Na^+, Mg^{2+}, H^+) in the flood water decreased with time. This means that they did not accumulate in the flood water but were slowly removed throughout the period of submergence, probably by the slow lateral movement of flood water. This process was suggested by Van Breemen (1976).

4.2 Soil

4.2.1 pH

The pH of the soil was low in the upper part of the soil column and, at any time, increased gradually with depth. This result is in accordance with the formation of strong acid at the soil surface as suggested by Van Breemen (1976). The profile of pH in the soil also suggests that the pH of the soil surface was very low since the oxidized layer was always very thin (1-2 mm) and some of the protons formed in the oxidized layer diffused downward and acidified the middle part of the soil.
Soil pH did not increase rapidly with time as in most (non-acid sulfate) flooded soils. The slow rate of soil reduction and of removal of acid substances by run-off water may be the main reasons for this sluggish increase in soil pH.

4.2.2 Fe^{2+} (Figure 2)

In the B-soil, the concentration of Fe^{2+} was higher in the manured plots (5 & 10) than in the non-manured plots (1 & 6). Organic substances derived from manure may have enhanced the reduction of ferric iron. In the A- and C-soil the Fe^{2+} content was low in the upper part of the soil and increased gradually with depth. This result can be explained by upward diffusion of ferrous iron in the Apg horizon and the oxidation of it at the soil surface. If this idea is valid the upward diffusion of ferrous iron should have been accelerated by the gradual increase in soil pH with depth because the proportion of mobile ferrous iron in the soil solution to ferrous iron adsorbed at the cation exchange site becomes high when the soil pH is low. The larger Fe^{2+} content of B-soil compared to that of A-soil (or C-soil) indicates that fairly large amounts of Fe^{2+} were lost from the reduced soil. Part of the Fe^{2+} diffused to the soil surface is not oxidized since Fe^{2+} was detected in the flood water.

The Fe^{2+} content in the soil was rather high before transplanting and increased only slightly afterwards. Because the Fe^{2+} content was probably much lower just before flooding, this fact suggests that the reduction rate of the submerged soil was much faster before transplanting than after transplanting. During a short period after submergence, the soil contains fairly large amounts of decomposable organic substances (ploughed-under plant debris, soil organic substances made decomposable by air-drying in dry season, etc.) and a high population of active microorganisms (aerobic and facultative anaerobic microorganisms) which can utilize these organic substances, causing a rather quick soil reduction. After this flush of decomposition, the reduction process is slowed down either by the decreased availability of decomposable organic substances or by a thinned population of active microorganisms.

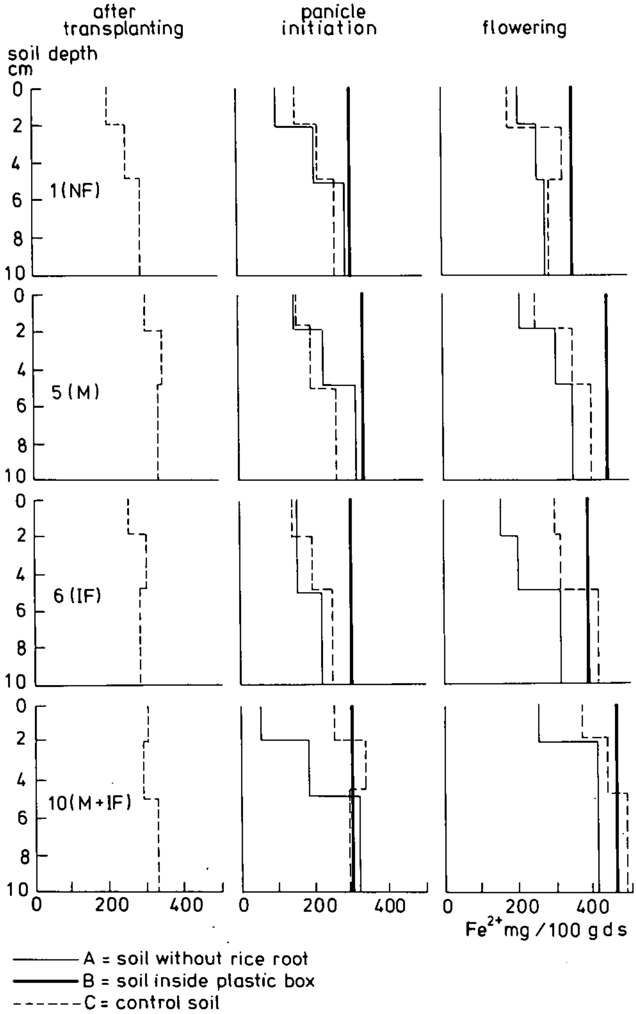

Figure 2. Ferrous content in Apg horizon at Rangsit Rice Experiment Station (1980)

Plot No.:

1 (NF) = no fertilizer

5 (M) = manure

6 (IF) = inorganic fertilizer

10 (M+IF) = manure + inorganic fertilizer

4.2.3 NH_4^+ (Figure 3)

The NH_4^+ content of B-soil was highest in plot 10, and successively lower in plots 6, 5 and 1. This is obviously a consequence of manuring and fertilization. The profiles of the NH_4^+ content of A-soil and C-soil were similar to those of Fe^{2+} during the flooding period after transplanting. Most of the arguments made for upward diffusion of Fe^{2+} can be applied to NH_4^+ except that NH_4^+ is more weakly held by soil particles and more easily diffused than Fe^{2+}. Comparison of the NH_4^+ contents between B-soil and A-soil indicates a larger relative loss of NH_4^+ from the soil than of Fe^{2+}.

The upward diffusion of NH_4^+ inside the reduced part of the soil and the loss of the NH_4^+ at the oxidized layer through the nitrification-denitrification process has been well established for non-acid sulfate soils by laboratory experiments (Uehara 1980) and recognized in the paddy field with extremely poor drainage in Japan (Uehara 1980). In the acid sulfate soils one would expect inhibited nitrification-denitrification because, as mentioned above, the thin oxidized layer was very acid. The transfer of NH_4^+ from soil to flood water and the removal of NH_4^+ by run-off water in the same way as with other cations such as Na^+ and Mg^{2+}, may cause larger losses.

NH_4^+ was concentrated in the upper part of the soil a few days after transplanting. At the time of transplanting nitrogenous fertilizer was broadcast, and the NH_4^+ in the upper part of the soil should have been mainly derived from chemical fertilizers.

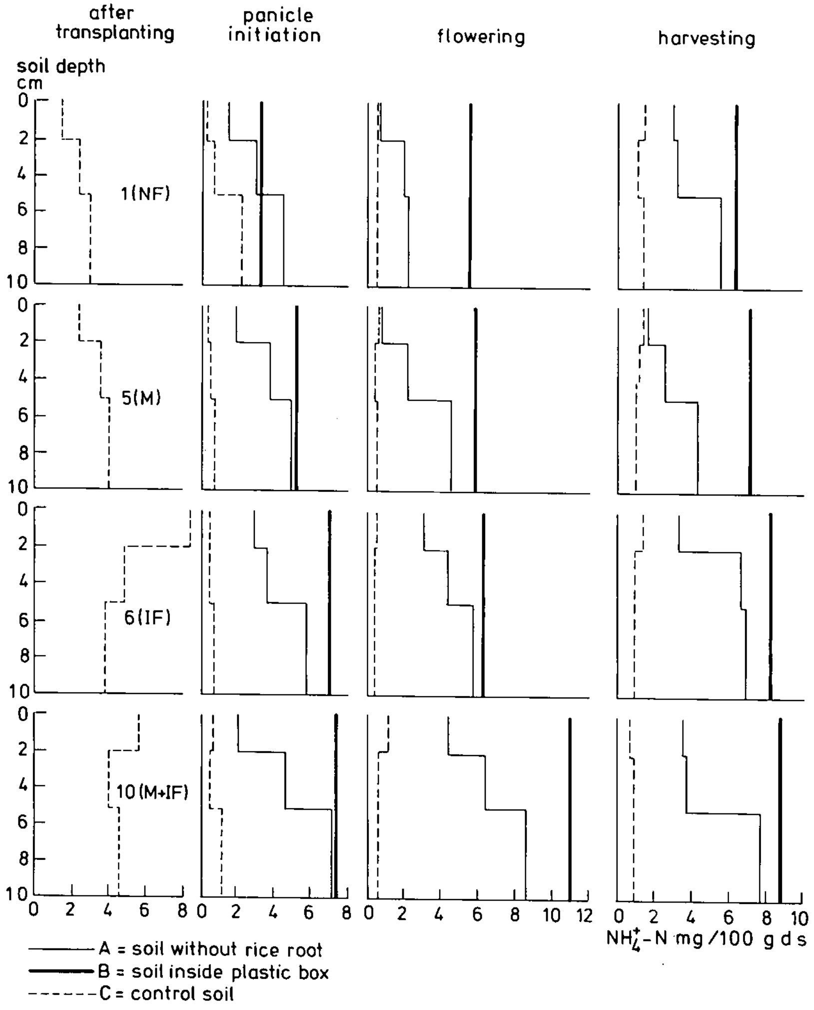

Figure 3. Ammonium-nitrogen content in Apg horizon at Rangsit Rice Experimental Station (1980)

Plot No.:

1 (NF) = no fertilizer

5 (M) = manure

6 (IF) = inorganic fertilizer

10 (M+IF) = manure + inorganic fertilizer

4.3 N_2 fixation (Figure 4)

Acetylene reduction activity (ARA) is regarded as a reliable index to the N_2-fixing activity. The ARA in flood water was very low compared to that in the soil. The activity in the upper part of the soil was not significantly higher than that in the lower part of soil. These results suggest that heterotrophs played a more important role in N_2 fixation than the photoautotrophs.

The ARA of C-soil was always higher than that of A-soil and B-soil and rice roots in the rhizosphere soil showed a very high ARA as compared with the soil itself. Accordingly rice roots can be said to be one of the favourable sites for N_2 fixers and can contribute to the increase of N_2 fixation in the Rangsit soil.

Acetylene reduction activity was highest in plot 5 and successively lower in plots 10, 6 and 1. Organic substances derived from manure and debris of the rice plants (the growth of the rice plants was better in plot 6 than in plot 1) may have been utilized by the N_2 fixing bacteria as carbon sources.

Primary roots had a higher ARA than secondary roots. Partially decomposed cells of old rice roots may have been better substrates for the N_2 fixing bacteria than the exudate from young rice roots.

These results are similar to those obtained in Japan (Panichsakpatana 1978). However there were several differences between the ARA in the Rangsit soil and in Japanese paddy soils. The maximum ARA in the Rangsit soil was much higher than that in Japanese soil and change with time of the ARA in the Rangsit soil differed from that in the Japanese soils. In the Rangsit soil, the ARA of A-, B-soils as well as C-soil increased rapidly from the panicle initiation stage to the flowering stage and drastically decreased afterwards. It is rather difficult at present to explain completely this time course of the ARA. However the lowered population of active microorganisms in the later period of submergence, discussed above, may be responsible for the drastic decrease in the ARA in this period.

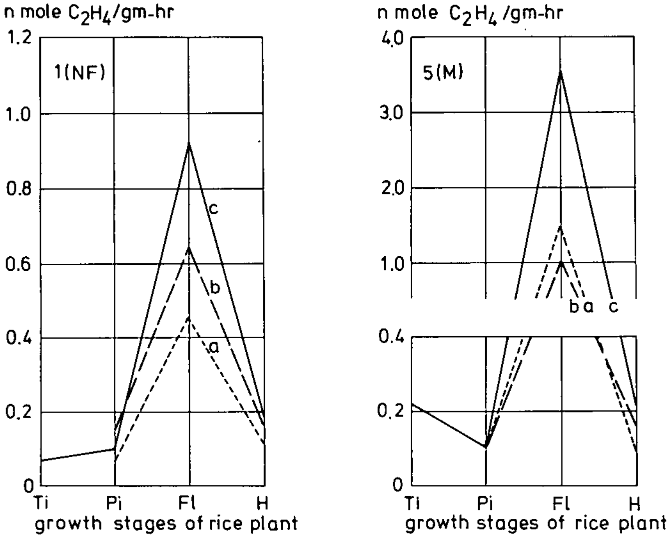

Figure 4. N_2-fixing activity of soils indicated by Acetylene Reduction Activity (ARA) in two paddy fields (plot 1: not fertilized and plot 5: manured) at Transplantation (Ti), Primordia initiation (Pi), Flowering (Fl) and Maturing (H) stages of a rice crop grown during wet season 1979 in acid sulphate soils (Rangsit Series) at Rangsit Experimental Station. Triple soil samples collected (a: within metal frame between 4 rice hills, b: in buried plastic box, c: between 4 rice hills).

4.4 Rice plants (Table 3)

Fertilization and manuring clearly increased growth (height, tiller number and dry matter) with plots giving increased yields in the order 1<5<6<10.

Table 3. Relationship between 'utilizable' NH_4-N and total plant N absorption

Fertilizer treatment plot nr.	Utilizable[a] NH_4-N (ppm)	Observed plant N		Predicted plant N	
		(mg/hill)	(kg/ha)[b]	(mg/hill)[c]	(kg/ha)[d]
A. *Primordia initiation stage*					
1	11.1	77.77	12.4	70.17	11.1
5	20.1	89.37	14.3	123.12	19.6
6	20.1	116.95	18.7	123.12	19.6
10	33.3	163.95	26.2	200.79	32.0
B. *Flowering stage*					
1	19.9	125.90	20.1	121.94	19.4
5	19.3	142.19	22.8	118.41	18.8
6	26.6	178.72	26.6	161.37	25.7
10	35.6	199.95	32.0	214.32	34.2
C. *Maturing stage*					
1	26.5	152.11	24.3	160.78	25.6
5	25.7	183.12	29.3	165.07	24.8
6	35.4	209.44	33.5	213.14	34.0
10	47.3	306.86	49.1	283.16	45.2

a = (NH_4-N in A-soil) - (NH_4-N in C-soil) = utilizable NH_4-N

$$b = \frac{\text{mg N/hill} \times 160.000 \text{ hills/ha}}{1,000,000} = \text{kg/ha of plant N}$$

$$\left.\begin{array}{l} c = 4.8588 + 5.8837 \times (a) = \text{mg/plant of plant N} \\ d = 0.6444 + 0.9418 \times (a) = \text{kg/ha of plant N} \end{array}\right\} \quad r = 0.94^{**}$$

The difference in the total amount NH_4^+-N in the soil between A-soil and C-soil was approximately equal to the amount of the nitrogen absorbed by the rice plants at all times of measurement and also very closely intercorrelated. Accordingly it can be said that one of the main controlling factors for growth and yield of the rice plants was the amount of 'utilizable nitrogen' and this value was estimated by the above mentioned calculation.

5 Conclusion

In conclusion, transformation and transfer of substances in the acid sulfate soil during the period of submergence can be schematically shown in Figure 5.

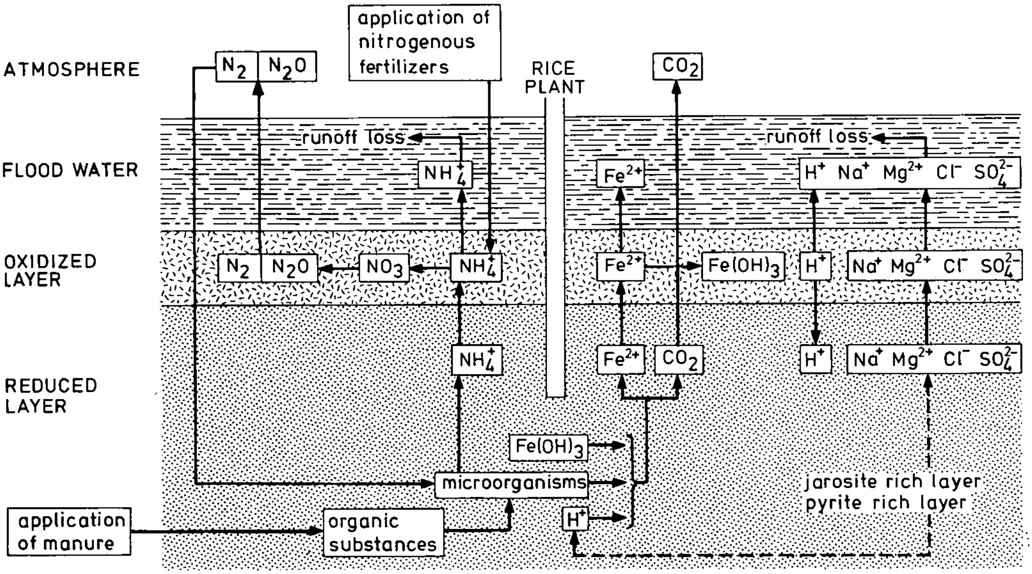

Figure 5. Compartment model of nitrogen transformation in acid sulfate soil during rice growing season

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RAPID RECLAMATION OF BRACKISH WATER FISHPONDS IN ACID SULFATE SOILS

R. Brinkman
International Rice Research Institute
Manila, Philippines
V.P. Singh
Brackish Water Aquaculture Centre
Leganes, Iloilo, Philippines

1 Summary

The reclamation of acid sulfate soils for agriculture is generally considered to be a slow process. The productivity of brackish water fishponds in these soils also remains poor for 5 to 15 years after construction or deepening. This is due to the very slow growth or inactivity of the algae on which the fish feed, and to the intermittent fish kills by extremely acid water which leaches from the dikes during rains after dry periods. However, the water management possibilities inherent in the operation of brackish water fishponds in tidal areas with a dry season enable the operators to reclaim both the pond bottoms and the surrounding dikes in one dry season, without a need for expensive chemical amendments.

The procedure involves thorough drying and dry cultivation of the pond bottom until it cracks to a depth of about 10 cm, followed by repeated inundation with saline or brackish water. The water is renewed every few days until its pH remains above 5. This cycle of thorough drying and repeated flushing is restarted one to several times, until the pH of the first inundation water after drying remains above about 5. Most of the acid is thus removed by diffusion into the standing water rather than by leaching to the subsoil.

The surrounding dikes are reclaimed at the same time. First, low paddy bunds are built along the edges of the flat crests of the dikes or a small ditch is dug along the center. Cross bunds are constructed wherever the elevation of the dike changes. Saline or brackish water is then

pumped into the enclosed shallow basins or ditches on top of the dikes in the same periods in which the pond bottoms are flushed. The dikes are allowed to dry out again at the same time as the pond bottoms.
With this procedure, brackish water fishponds in acid sulfate soils were made productive within one dry season after construction or deepening. Milkfish (Chanos chanos) harvests were about 0.4 to 0.5 t/ha every 4 months, the same as from well managed brackish water fishponds in non-acid marine clays, and there were no fish kills after rain in the treated ponds.

2 Introduction

The extent of acid sulfate soils in the Philippines is variously reported, but appears to be less than about half a million ha. Until about a decade ago, much of this area was mangrove forest. Smaller areas were used for one poor crop of paddy rice per year and for fishponds. In recent years, the area of fishponds has increased rapidly at the expense of the mangroves and the former paddy fields. Fishponds now appear to be the most important kind of land use in the coastal acid sulfate areas of the Philippines (Figure 1).

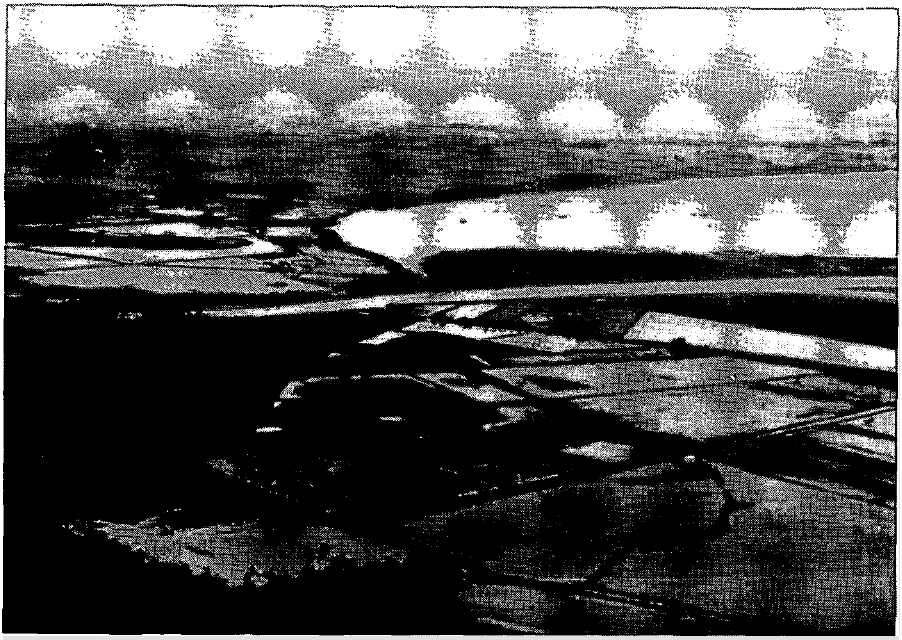

Figure 1. Aerial view of a brackish water fishpond area NE of Iloilo, Panay Island, Philippines

Brackish water fishponds are of two main kinds. Shallow ponds, with about 0.3 m water depth, produce milkfish (*Chanos chanos*, Pilipino: bangus), mainly for local consumption. Deep ponds, about 1 m, produce prawns (*Microbrachium* or *Penaeus monodon*) which is mainly exported to Japan.

Particularly in the first 5 to 10 years after construction or deeper excavation of fishponds in acid sulfate soils there are major problems precluding economic operation or even production. Growth of algae is inhibited or restricted by the low pH and the very low phosphate concentration of the pond water. The growth rate and the condition of the fish are impaired by the low pH and the unfavourable ionic composition of the pond water, the periodic presence of finely dispersed ferric hydroxide and the poor supply of algal feed. Moreover, there are sudden fish kills during rains after extended dry periods, owing to extremely acid water seeping into the ponds from the surrounding dikes. After about a decade, these problems gradually recede but fish production remains low, of the order of 0.6 t/ha per year. This should be compared with an average 1.5 or, with recommended management and fertilizer levels, up to 2.5 t/ha per year in areas with non-acid coastal clays.

The much more profitable prawns die in the first years and fail to grow satisfactorily even after many years in the acid sulfate areas, since they require a higher pH than milkfish.

Traditional, small fish farmers dig very shallow ponds to minimize the problems and limit capital costs. They survive and learn to live with the problems, but do not rise above poverty within a decade, and slowly even after that period. Larger farmers whose holdings are mainly financed externally, as well as companies developing extensive areas for fishponds, tend to abandon their efforts on this land and sell out after a few years of failure, whereupon a next victim repeats the process.

A rapid and low-cost reclamation method of fishponds in acid sulfate soils should be of great economic importance for the Philippines and other countries with extensive acid sulfate areas near the coast.

The next sections summarize normal fishpond operations, processes taking place in the fishpond soil and the resulting problems faced by the fish farmers, earlier reclamation efforts and requirements for permanent reclamation. The last five sections of the paper describe a general work plan and a sequence of activities that has been successful in reclaiming previously improductive acid sulfate fishponds within one dry season.

Figure 2 illustrates the different growth rates of fish in acid sulfate fishponds without and with reclamation.

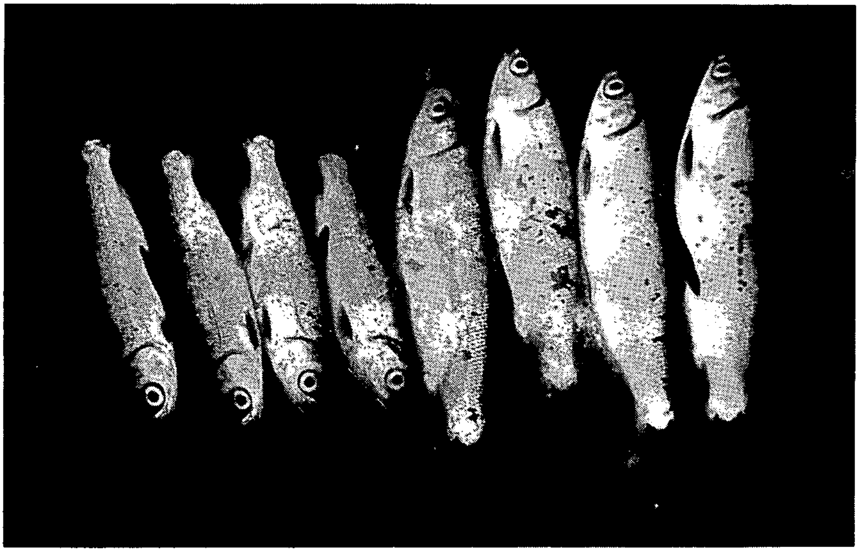

Figure 2. Milkfish from unreclaimed and reclaimed acid sulfate fishponds, 90 days after stocking (120 days old)

3 Construction and normal use of brackish water fishponds

Ponds are constructed by excavating a layer of soil from the area of the proposed pond, generally about a hectare in size, and building a surrounding dike with the excavated material. A sluice gate is built, using brick or concrete and wood, to connect the pond with an adjacent saline or brackish tidal river or canal. The pond bottom slopes down very slightly toward a shallow central channel ending at the sluice. The tidal fluctuation of the water level in the canal or river allows filling or draining of the pond twice a day. If there is fish in the pond, the water can be changed after insertion of a screen in the sluice opening. Before the start of each fish crop, the surface of the pond bottom is dried to a depth of several centimeters in order to destroy predators, disease carriers and parasites of the fish, such as certain snails. Then, 2 or more tons of chicken manure per ha are spread on the bottom to provide nitrogen and phosphate for the growth of green (and some blue-green) algae. After the pond is filled, an initial amount of 16-20-0 fertilizer is broadcast at a rate of 50 kg/ha. The seawater and the soil of the pond bottom supply sufficient potassium and minor elements. Algae start to grow, generally without inoculation, and soon form a thick mat that sinks to the bottom. Fingerlings raised from brood in a separate small pond are then stocked to graze the algae. Every 2 weeks, fertilizer at a rate of 8 kg N and 10 kg P_2O_5 per ha is broadcast (or placed to dissolve on a semi-submerged platform) as a top-dressing for continued algal growth. After 3 to 5 months, depending on the feed supply and the growth rate of the fish, the pond is harvested by draining the water and collecting the fish near the sluice, or traditionally, but less efficiently, by dragnet.

Prawns are produced in similar but deeper ponds. These are fed a protein diet mainly derived from operation of the fishponds: undersize fish, culled predator fish and filleting waste, supplemented by agricultural by-products (e.g., leaves of legumes), and by slaughtering waste if available.

4 Processes taking place in the pond soil during drying and after filling the ponds

The pond soil, initially reduced, contains the usual marine salts and considerable amounts of exchangeable ferrous iron. Upon oxidation, ferric hydroxide is formed and the soil may become partly aluminum-saturated. The pH drops from near-neutral to lower values. In acid sulfate soils, pyrite oxidation produces jarosite and iron hydroxide as well as sulfuric acid which attacks the clay minerals. The pH drops to very low values. The soil becomes largely aluminum-saturated; some free acid remains; aluminum salts are formed.

After inundation, the pond soil becomes reduced again. Acid is consumed by reduction of ferric hydroxide to ferrous ions. Part of the free acid and the aluminum salts and, somewhat later, large amounts of ferrous salts diffuse from the soil into the pond water. This process appears to be speeded up by the salts in the saline or brackish water.

Rain falling on previously dry dikes leaches further quantities of acid and aluminum salts as well as ferrous salts into the pond water, both from the surface and from the interior of the dikes. In the course of a few days, the ferrous iron is oxidized, producing more acid and finely distributed ferric hydroxide which remains suspended in the pond water for several days. If powdered lime is used to reduce the acidity of the water, ferric hydroxide is formed more rapidly.

Any phosphate that might have been present in the water is quickly trapped by the large amounts of aluminum salts or by free aluminum in the surface soil.

5 Problems faced by fishpond operators in acid sulfate areas

The main problems arising after construction or deeper excavation of fishponds in acid sulfate soils comprise the insufficient growth of algae, the poor condition and consequent slow growth of the fish, the hazard of sudden fish kills during rain after dry periods and, even if these are solved, the very low efficiency of phosphate fertilizers as normally applied.

The growth of the algae is inhibited or retarded by the low pH of the water, the high aluminum and the low phosphate concentrations. The low pH and the high aluminum concentrations may kill or, in less severe cases, weaken the fish so that they are an easy prey for diseases and parasites. The sudden influx of acid and aluminum salts from the dikes during rains after a dry period causes an ionic imbalance in the fish. That stress is commonly lethal to a large proportion of the population. Finely divided ferric hydroxide subsequently appears in the water and clogs the gills of the survivors, killing another contingent and weakening the remainder.

A lesser problem is the erosion of the dikes during heavy rains owing to the lack of a good vegetation cover on the acid, toxic soil for the first 5 to 10 years.

6 Earlier reclamation efforts

Farmers in one area on northwestern Panay Island, Philippines, have developed an effective, albeit very slow, reclamation method. Very large, wide, broad dikes are first constructed. Their level crest is ploughed repeatedly. Rains between ploughings remove some of the free acid that has developed in the oxidized, ploughed layer. Gradually, the surface material is brought back into the pond to form a 'safe' pond bottom with little or no free acid. The whole process takes 5 to 10 years and eventually creates moderately productive ponds.

Other reclamation methods that have been tried include:

- liming the pond bottom, which generally requires very large lime applications and does not eliminate the hazard of acid leaching from the dikes;
- heavily liming the crest and the sloping sides of the dikes, which seems to minimize the acid hazard from the first but not from subsequent rains;
- liming the junction of dike and pond bottom as well as facing the lower slope of the dike with limestone, both of which are apparently ineffective.

7 Requirements for permanent reclamation and use

Methods of permanent reclamation and use should prevent diffusion of acids, aluminum salts and large amounts of ferrous salts from the pond bottom into the pond water, prevent leaching of the same compounds from the dikes and minimize the rate of phosphate fixation by aluminum compounds in the pond soil.

The upper 5-10 cm of the pond bottom is regularly oxidized between successive production seasons. Therefore, the pyrite from this layer and a few centimeters below needs to be oxidized and the acids formed by the oxidation should be removed or neutralized. Deeper horizons remain continuously reduced in this land use, and need not be reclaimed.

In contrast to the pond bottom, a large part of the dike body dries out between production seasons and the upper part remains oxidized even during fish or prawn production, at least in dry periods. Therefore, the acid from as much as possible of the dike material should be removed before regular use of the ponds.

Neutralization of the first 10 cm pond bottom and of the whole dike body would generally require prohibitive amounts of lime. Moreover, it would be impractical to incorporate the lime throughout the dike. Removal of the acids is therefore indicated.

Methods to minimize phosphate fixation should be part of the regular management, since regardless of the reclamation method, much active aluminum remains in the pond soil.

8 General work plan; materials and equipment required

The procedure involves a precisely planned sequence of filling, draining and drying the ponds, cultivation by tooth harrow and finally broadcasting a small amount of lime without incorporating this in the pond soil. In the same period, the top of the surrounding dikes should be made into a series of long, narrow paddies by small levees along their edges, and seawater pumped (or carried) into these.

A pH meter or a roll or strips of pH indicator paper should be available. A tooth harrow and a draft animal are needed for cultivating the pond bottom. A small diesel-powered pump, mounted in a small boat or on a raft of bamboo or oil drums makes it possible to rapidly inundate the tops of the dikes. About one ton of powdered agricultural lime per hectare is also required.

The whole work plan can be completed in about 2½ to 3 months. All the work should be done in the dry season. Treatment of the pond bottom and of the dikes should proceed at the same time, as described below. During the first heavy rains after the pond is again in operation, some further work should be done, as described in the last section.

9 Treatment of the pond bottom

In the early part of the dry season, the pond has to be prepared for removal of the acid. This is done by drying the pond thoroughly. Small drains should be dug to let all remaining patches of standing water run dry. After one week's drying, the pond bottom should be tilled by tooth harrow in two directions. It should again be harrowed after thorough drying (when cracks in the soil are about 10 cm deep), so that the surface layer is broken into small pieces, but not into a powder. If there is no rain, the total drying period will probably take 2 to 3 weeks. Now, the acid in the dry layer is ready to be removed. Brackish or salt water is brought in to fill the pond. The pH of the water is measured immediately after filling and every few hours thereafter. The pH is expected to drop rapidly from that of seawater (7-9) to lower than 4, often about 3.

At the first opportunity after the pH has become constant, the pond should be drained and the drainage water should go to the sea, not into any other pond. This treatment removes part of the acid.

The pond is refilled and the pH checked again. The water should be drained as soon as possible after it has a constant pH. The refilling and draining process should be continued as long as the constant pH remains below about 5. This may take from less than a week (4-6 refills) to about two weeks. When the water remains at a higher pH, the pond bottom is drained and thoroughly dried again as described above.

After thorough drying, the pond bottom is cultivated and again refilled as described above. This time, the pH probably will not drop as low as in the first series of filling and draining.

When the pH remains above 5 in the seawater brought into the dry pond (after 1-3 drying cycles), the pond is drained and 500 kg agricultural lime per ha (not calcium oxide or hydroxide) is broadcast, well-distributed over the bottom. The lime should not be incorporated into the soil. The pond is then ready for the start of normal operations, if the dikes have also been treated.

10 Treatment of the dikes

At the same time when the acids are removed from the pond bottom, the acids in and on the dikes should also be removed. Because the dikes are normally dry, the acid can be washed out without first drying as is needed for the pond bottom.

Small levees, similar to the levees between wetland rice fields, should be constructed on the top of the dikes along both sides, and the surface between them should be levelled carefully. At the same time, any holes in the top surface should be filled and compacted. If the dike material is very loose and erodible, for example owing to high organic matter contents, a small ditch can be constructed along the centre of the level dike crest. This would have somewhat broader levees.

To avoid excessive amounts of earth movement, this bunding and levelling, or ditching, can be done separately for each section of dike, depending on its elevation, with cross bunds between sections. This work should be completed by the time the pond bottom has dried out and is ready for first filling.

Specifications for dikes to be newly constructed in acid sulfate areas should include levelling of the dike tops and construction of levees or ditching to avoid delay in reclamation.

At that time, seawater or brackish water (not acid drainage water) should be pumped or brought up into the levelled paddies on top of the dikes, enough to keep them flooded to more than 10 cm depth. At first it will be necessary to check the whole top surface and the length of the small levees and stop any visible leaks. Acid water will soon seep out toward the pond or the canal. Pumping of seawater from the intake canal (not acid drainage water) should be continued as necessary to keep all the tops of the dikes flooded.

When the pond bottom is ready to be dried thoroughly again, the top of the dikes should be allowed to dry out. If there is still some water standing after 2 days, this should be drained to the canal if possible, otherwise through the pond. When the pond bottom has thoroughly dried and has been cultivated, the top of the dikes should be flooded again during the next series of filling and draining the pond. When the pH of the water in the pond remains 5 or above, the standing water on the top of the dike should be removed.

The next work should be done while the tops of the dikes are moist. On dikes between two ponds, both levees are removed and the soil material brought towards the centre. The top of the dikes should be smooth and slightly sloping from the centre to both sides, without loose soil material. On dikes along a canal, only the levee along the side of the canal should be removed and the material brought toward the other levee. The top of these dikes should be smooth and slightly sloping towards the canal.

Then, 1 kg agricultural lime per 10 meters is broadcast on the slope of the dike along each pond, and 1 kg per 20 meters on the dike tops.

Weeds will start to cover the dikes, protecting them against erosion by rain, or grass can be planted to speed up the revegetation. Alternatively, pineapples can be planted on the dikes to provide more cash income. This was successfully practised in one location (Figure 3).

Figure 3. Pineapples growing on a long established dike of a brackish water fishpond in an acid sulfate area

11 Management measures

To decrease the rate of phosphate fixation during the growing season, silica-rich materials that bind some of the aluminum in the pond soil may be broadcast over the pond bottom. Readily available, cheap silica sources include partly decomposed rice hulls. Then, the usual amount of chicken manure is distributed over the pond bottom and the pond is filled. A few days later, initial amounts of N and P_2O_5 fertilizer are broadcast in the pond water. In normal, non-acid fishponds, the recommended amounts of phosphate are broadcast once every 2 or 3 weeks. In acid sulfate fishponds, however, the phosphate should be divided into portions broadcast every 2 days, or weekly portions should be placed in jute bags just submerged on floating platforms, 2 per ha, to dissolve slowly. By either one of these methods the phosphate concentration in the pond water can be kept high enough for good growth of algae, without excessive losses by fixation on the material of the pond bottom.

After sufficient growth of algae, the pond can be stocked. The regular, recommended fertilizer dosage should be continued but the phosphate should be applied as described above.

12 Prevention of fish kills during rains

Although much acid has been removed from the dikes, there may still be a danger of acid water seeping from the dikes into the ponds during heavy rains. As soon as heavy rain starts, the pH of the pond water along the dikes should be checked. Checking should be continued for several hours. If the pH drops below 5, agricultural lime should be broadcast immediately into the pond water along the dikes. About 1 kg of powdered agricultural lime should be used per ten meters in each pond along each dike. This is about 1 bag (50 kg) of lime for the four sides of a one-hectare pond.

When this is done, the pH should be measured again after a day. If it is still lower than about 5, the lime application should be repeated.

Because the pH meter should be used outside during heavy rain, a large, strong, clean see-through plastic bag should be kept with the meter. Before going out, the meter should be placed in the bag. The meter can then be read and operated through the plastic from outside. The cable of the meter should come out downward from the bag. This way, the meter can be kept dry.

It is advisable to practise the pH measurement and broadcasting the right amounts of lime along a short section of dike well before the first heavy rains to get acquainted with this procedure.

Once acid comes out of the dikes during rain, it is too late to start practising and also too late to go and buy a stock of agricultural lime. Therefore, a stock of at least 200 kg (4 bags) agricultural lime should be kept for each hectare of fishpond that has shown problems before.

KINETICS OF ACIDIFICATION DURING INUNDATION OF PREVIOUSLY DRIED ACID SULFATE SOIL MATERIAL: IMPLICATIONS FOR THE MANAGEMENT OF BRACKISH WATER FISHPONDS

V.P. Singh
Brackish Water Aquaculture Centre
Leganes, Iloilo, Philippines

1 Summary

Experiments to simulate conditions in acid sulfate and non-acid sulfate (but P-deficient) fishponds on coastal clays were conducted in fiberglass tanks with 35 cm soil material and 30 cm supernatant brackish water. After three weeks of initial inundation, the composition of supernatant and leachate was determined weekly for thirty weeks. Fertilizer treatments included nitrogen and phosphate application in the supernatant and an unfertilized control.

Algal growth was very poor in the supernatant of the acid sulfate soil and good over the neutral soil, both in the unfertilized and fertilized treatments.

Over the acid sulfate soil the pH of the supernatant decreased gradually from 4 to 3, with a temporary recovery on replacing the inundation water at week 18. Aluminum concentrations rose and fell twice from 0-3 mg/l minima at weeks 0 and 18 to maxima between 14 and 26 mg/l at weeks 10 and 28; sulfate rose from an initial 2000 mg/l to levels fluctuating between 4300 and 6200 mg/l, without decreasing on replacement of inundation water. Iron concentrations rose from virtually zero to between 7 and 10 mg/l at week 18, then suddenly to maxima of 20-25 mg/l after replacement of supernatant, followed by strong fluctuations with extremes of 0.5 and 34 mg/l.

Over the neutral soils, the pH of the supernatant remained high, above 7, with a temporary increase at week 18 on replacing the inundation water. Aluminum concentrations remained below 0.2 mg/l throughout;

sulfate rose from an initial 3050 mg/l to levels fluctuating between 3400 and 4000 mg/l. Iron concentrations rose from 0.2 to 2 mg/l at weeks 6 and 7 and then decreased gradually to about 0.1 mg/l.

The pH of the leachate of the acid sulfate soil rose from less than 4 to about 5.5; aluminum slowly decreased from about 40 to less than 2 mg/l; sulfate fluctuated between 7200 and 8500 mg/l throughout. Iron concentrations gradually rose from 1000 to about 3500 mg/l, with a sharp decrease at week 22.

In the leachate of the neutral soils, the pH remained between 6 and 7; aluminum concentrations were between 0.1 and 1.0 mg/l; sulfate rose from 2100 to 4700 mg/l at week 20. Iron concentrations rose from about 5 to 100 mg/l at week 5 and then remained at this level.

Nitrogen and phosphate fertilization did not appreciably influence these trends both for acid sulfate and neutral soil. Positive effect of fertilization on acid sulphate fishponds can be expected only after reclamation of the soil. Fertilizers should be applied frequently and in small dosis, also in fishponds with neutral soil.

2 Introduction

The soil is an important factor in fishpond productivity mainly because of its ability to adsorb and release the plant nutrients needed for algal growth, the natural food of the fish. The soil is the main and, perhaps, the only economical source of dike building materials. The quality of overlying water is strongly affected by the nature of the pond bottom soil. This influence of the soil on pond conditions is very clear in the case of acid sulfate soils.

Experience in the Philippines (IFP 1974), Indonesia, Malaysia, and Costa Rica has shown that fishponds with acid sulfate soil conditions often have a very low productivity and occasionally suffer acute fish kills. The direct causes include deficiency of essential nutrients such as phosphorus, poor development of algae, acidity and toxic amounts of iron and aluminum species in the water.

The pond mud is known to absorb phosphate thus making phosphate fertilization inefficient (Watts 1969). Acidity, including iron and aluminum species, is thought to be released mainly by the exposed acid sulfate soil material of dikes and also by pond bottoms on exposure after drainage. Preventing run-off from dikes, keeping pond bottoms flooded and in reduced condition, and liming of the pond bottom, have been recommended for alleviating the adverse acidic condition.

Experience with flooding of acid sulfate soil for rice and fish production has shown, however, that prolonged inundation of these soils does not necessarily prevent the acidification of the overlying water. The processes involved and the dynamics of the soil components causing changes in pH upon flooding and drainage have been studied and explained, a.o. by Ponnamperuma (1964), Ponnamperuma et al. (1967, 1969, 1973), Van Breemen (1976) and Singh (1980).

Once atmospheric oxygen has penetrated into a pyritic substratum, oxidation of pyrite is not stopped instantaneously again on flooding and restoring reduced conditions, because oxidative capacity stored in ferric iron maintains further oxidation of pyrite and production of soluble ferrous iron and sulfate (Van Breemen 1976). Non-pyritic acid sulfate soil also generates ferrous sulfate upon flooding. A part of this ferrous sulfate reaches the soil surface and the overlying water where it forms ferric hydroxide and sulfuric acid. Thus, the overlying water keeps acidifying although the acidity of the underlying soil may be decreasing due to chemical reduction caused by flooding.

In order to test this explanation for fishpond conditions and to assess the possibilities of reclaiming ponds with acid sulfate bottom muds, experiments were conducted to monitor the changes in bottom mud (through the analysis of leachate) and in the overlying water. For these experiments, acid sulfate soil and non-acid sulfate soil were placed in tanks and inundated with brackish water. Various fertilizer treatments were applied and the supernatant and the soil leachate were analyzed over a period of thirty weeks.

3 Materials and procedures

The studies were conducted in 65 litre fiberglass tanks, 40 cm diameter, with 35 cm depth of mixed soil material. A 30 cm deep layer of brackish surface water was maintained by adding brackish water to compensate for losses by evaporation and sampling. After three weeks of initial inundation, 200 ml supernatant and 200 ml leachate were collected weekly from each tank over an 18 week period. Then, all of the supernatant was removed by leaching and replaced by new brackish water. The replacement of supernatant involved an exposure of the soil to atmospheric influences for about 2-3 hours. Weekly observations were continued for another 12 weeks.

Soil materials used were the upper 35 cm of an acid sulfate clay (Table 1) and of a neutral but phosphate deficient clay (Table 1) for comparison. The soil material was taken from the soil profile by spade, brought to the experiment location in open containers, and thoroughly mixed after 20 days of drying in field-moist conditions. The tanks were each filled with about 30 kg of soil mixture by packing to a uniform depth and brackish water (Table 1) was added for the initial inundation.

Table 1. Some chemical characteristics of acid sulfate and non-acid sulfate soils and brackish water used for inundation

Characteristics	Acid sulfate soils	Non-acid sulfate soils	Brackish water
pH	3.5	7.2	7.8
Aluminum (ppm)	230	trace	trace
Iron (ppm)	110	25	trace
Sulfate (ppm)	1500	550	2300-4200[1]
Phosphorus (ppm)	14	10	-

[1] The sulfate content of brackish water increased with time during the dry season

Nitrogen (urea) and phosphate (single superphosphate), both at the rate of 100 kg/ha were applied twice. The applications were made at 0 and 5 weeks after first inundation by broadcasting on the water surface. The tanks were located in a building with a clear plastic roof and open windows on all sides. Day temperatures were around 27 to 30°C. The weather was mainly sunny as the experiment was conducted in the dry season. Sampling of the supernatant was done by siphoning; of the leachate by tapping through a filter. Water samples were kept in glass containers and analyzed within 8-10 hours. Analytical methods were as follows: pH by glass electrode, aluminum, iron, ammonia, nitrate, nitrite and phosphate by colorimetry; and sulfate by turbidimetry (APHA 1971, Black 1965, Dewis and Freitas 1970, Jean 1971, and Solonzano 1969).

4 Results and discussion

Main analytical results are presented in Figures 1-6 as a function of weeks passed since first inundation (Week 0). Data series that closely followed the same pattern of changes at the same level are represented only by one example. Tables 2 and 3 list the range over the whole period expressed by minima and maxima for each variable.

The focus of the discussion is on the variations with time of the properties of supernatants and leachates. These comprise variables associated with acidity (pH, aluminum, iron, sulfate) and with nutrition of plankton (phosphate, ammonium, nitrate and nitrite).

As the replacement of supernatant at week 18 appeared to have an important impact on most of the acidity-associated properties, the periods of weeks 0 to 18 and 18 to 30 must be distinguished in the discussion. They are referred to as periods I and II, respectively. 'Soil' refers to the soil material in the tanks unless explicitly indicated otherwise. The acid sulfate soil material is referred to as 'acid soil', the other soil material involved is named 'neutral' or 'non-acid soil'.

Table 2. Summary of supernatant compositions over acid sulfate and neutral soils inundated by brackish water

Chemical properties	Acid sulfate soil	Neutral soil
Unfertilized		
Salinity (ppt)	26 - 45	24 - 41
pH	2.9 - 4.1	6.6 - 7.9
Iron (mg/l)	0.43 - 21.00	0.03 - 0.30
Aluminum "	1.95 - 23.60	0.00 - 0.27
Ammonium "	0.00 - 8.70	0.00 - 0.44
Nitrate "	0.00 - 1.99	0.00 - 1.33
Nitrite "	0.00 - 0.05	0.00 - 1.40
Phosphate "	0.00 - 0.00	0.00 - 0.02
Sulfate "	2726 - 6220	2293 - 4132
Fertilized with nitrogen at 0 and 5 weeks; 100 kg/ha i.e. 30 mg/l supernatant		
Salinity (ppt)	26 - 42	26 - 37
pH	2.9 - 4.4	7.2 - 8.0
Iron (mg/l)	0.21 - 30.00	0.12 - 0.35
Aluminum "	0.29 - 26.10	0.00 - 0.22
Ammonium "	12.76 - 61.28	0.08 - 41.90
Nitrate "	0.00 - 1.64	0.00 - 11.31
Nitrite "	0.00 - 0.00	0.00 - 18.50
Phosphate "	0.00 - 0.00	0.00 - 0.06
Sulfate "	2583 - 6598	2504 - 4811
Fertilized with phosphorus at 0 and 5 weeks; 100 kg/ha i.e. 30 mg/l supernatant.		
Salinity (ppt)	27 - 42	26 - 38
pH	2.7 - 5.0	7.2 - 7.9
Iron (mg/l)	0.08 - 34.00	0.10 - 0.44
Aluminum "	0.00 - 26.00	0.00 - 0.21
Ammonium "	1.20 - 6.68	0.10 - 1.95
Nitrate "	0.00 - 2.37	0.00 - 1.91
Nitrite "	0.00 - 0.05	0.00 - 0.16
Phosphate "	15.02 - 0.00	17.09 - 0.00
Sulfate "	2704 - 5829	2476 - 4769

Table 3. Summary of leachate compositions from acid sulfate and neutral soils inundated by brackish water

Chemical properties		Acid sulfate soil	Neutral soil
Unfertilized			
Salinity (ppt)		27 - 40	22 - 33
pH		3.7 - 5.6	6.1 - 7.0
Iron	(mg/l)	990 - 2920	13.9 - 202
Aluminum	"	49.40 - 1.33	0.08 - 0.50
Ammonium	"	42.44 - 2.38	15.10 - 1.40
Nitrate	"	0.32 - 7.20	0.00 - 1.68
Nitrite	"	0.00 - 0.00	0.03 - 0.12
Phosphate	"	0.03 - 0.15	0.00 - 0.06
Sulfate	"	8196 - 6411	2257 - 4760
Fertilized with nitrogen at 0 and 5 weeks; 100 kg/ha i.e. 30 mg/l leachate			
Salinity (ppt)		23 - 39	19 - 31
pH		3.6 - 5.5	6.0 - 7.1
Iron	(mg/l)	820 - 4000	9.5 - 1185
Aluminum	"	35.10 - 1.30	0.05 - 1.20
Ammonium	"	50.00 - 28.00	37.50 - 1.96
Nitrate	"	0.20 - 6.85	0.00 - 1.50
Nitrite	"	0.00 - 0.02	0.03 - 0.68
Phosphate	"	0.03 - 0.22	0.02 - 0.06
Sulfate	"	6599 - 9447	2215 - 5398
Fertilized with phosphorus at 0 and 5 weeks; 100 kg P_2O_5/ha i.e. 30 mg/l leachate			
Salinity (ppt)		28 - 39	22 - 31
pH		3.6 - 5.6	6.0 - 7.1
Iron	(mg/l)	933 - 3100	12.7 - 1100
Aluminum	"	40.30 - 1.49	0.00 - 0.89
Ammonium	"	45.00 - 0.80	23.30 - 4.16
Nitrate	"	0.26 - 7.83	0.11 - 1.27
Nitrite	"	0.00 - 0.01	0.02 - 0.04
Phosphate	"	0.03 - 0.17	0.00 - 0.52
Sulfate	"	7108 - 9037	2149 - 5235

4.1 pH

The pH changes in supernatants and leachates for acid sulfate and neutral soils are summarized in Figure 1. At week 1, the leachate of the acid soil had a pH of 3.6 against 7.0 of the neutral mud, reflecting the initial difference in acidity between the two soil materials. The pH of the supernatant over the neutral soil at week 1 was 7.6, practically that of normal brackish water. One week after inundation, the pH of the supernatant over the acid soil had already dropped to 4.0. This initial drop might be explained by diffusion of acidity from the soil to the overlying water. However, while the leachate and the supernatant of the acid soil reached the same pH of 3.9 before week 2, thereafter the supernatant kept acidifying up to week 18, whereas the solution pH in the reduced soil increased up to 5.8 at week 10. From week 10 to the end of the inundation period the pH of the leachate gradually dropped again to 5.0, remaining a constant 2.5 units higher than in the supernatant. The contrast in the pH development in supernatant and leachate for the acid sulfate soil rules out simple diffusion as a cause of acidification of the supernatant. In fact, the acidification of the supernatant seems to hamper a further rise in pH of the reduced soil after a difference of 2.5 units is reached.

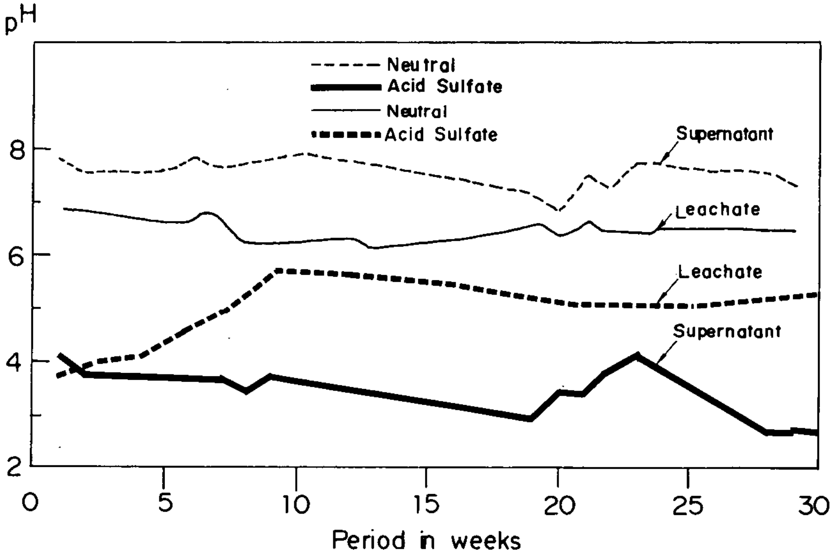

Figure 1. pH of supernatant and leachate

The dynamics of pH in the neutral soil followed a pattern that is the reverse of that for the acid sulfate soil, at least for the first 10 weeks after inundation. During this period the leachate of the neutral mud tended to acidify from pH 7 to 6, whereas the pH in the supernatant remained virtually constant or even rose slightly from pH 7.5 at week 2 to pH 7.8 at week 10. At week 10, the pH of the leachates of acid and neutral soils were very similar, (5.8 and 6.0) in contrast to the supernatants, which had pH 3.5 and 7.8, respectively. The large difference in acidity of the supernatants of the acid sulfate and neutral soils fluctuated only temporarily on replacement of the supernatant. In fact, the acidification of the supernatant over the acid soil appears to have been more intensive after the replacement than on initial flooding. The pH of the leachates of both soils fluctuated much less on replacement, as would be expected. The acidification of the supernatant of the acid soil from pH 4 to 3 between weeks 23 and 28, hence 5 to 10 weeks after replacing was not associated with an appreciable rise in pH of the soil solution (leachate), which over this period only changed from 5.0 to 5.2. The acidification of the supernatant, therefore, is related to the temporarily oxidized state of the acid sulfate mud rather than to continued deacidification of reduced mud.

This would be in accordance with the explanation for the acidification of overlying water on acid sulfate paddy soils in Thailand, given by Van Breemen (1976). According to this explanation, the reduction of flooded acid sulfate soil results in the formation of soluble ferrous sulfate, which through diffusion reaches the surface of the reduced soil. On contact with the supernatant, the ferrous sulfate is oxidized and produces a ferric hydroxide precipitate and soluble sulfuric acid. So, potential acidity in the form of ferrous sulfate is transported through the reduced acid sulfate mud and produces actual acidity in the surface water. The precipitation of ferric hydroxide at the soil-water interface acts in this model as a valve securing the one-way direction of the movement.

The process dominating pH dynamics in flooded neutral soils is the reduction of ferric to ferrous iron by organic matter, producing ferrous bicarbonate, which is oxidized to ferric hydroxide and CO_2 near the soil-water interface. The contrasting patterns of pH dynamics between acid and neutral soils can thus be satisfactorily explained.

The very low pH values (well below 5) observed in the supernatant of the acid sulfate soils are reported to be toxic to pond biota, both owing to direct and indirect effects of acid. These include damage by iron and aluminum species to fish and the unavailability of phosphate to the algae under these conditions.

As another interesting observation should be noted that it took only about 3-4 weeks for the pH of leachate to stabilize in the case of neutral soils; for acid sulfate soils this took 9 weeks. This clearly indicates that the reduction process was much slower in acid sulfate soils, hence it would take much longer for acid sulfate soils before their solution pH could be increased by flooding.

4.2 Aluminum, iron and sulfate

Figures 2 and 3 show the concentrations of aluminum, iron and sulfate in supernatant and leachate as a function of time. Aluminum and iron are the main toxic elements in fishponds with acid sulfate soil conditions. In the supernatant of the neutral soil, aluminum and iron concentrations remained well below toxic limits.

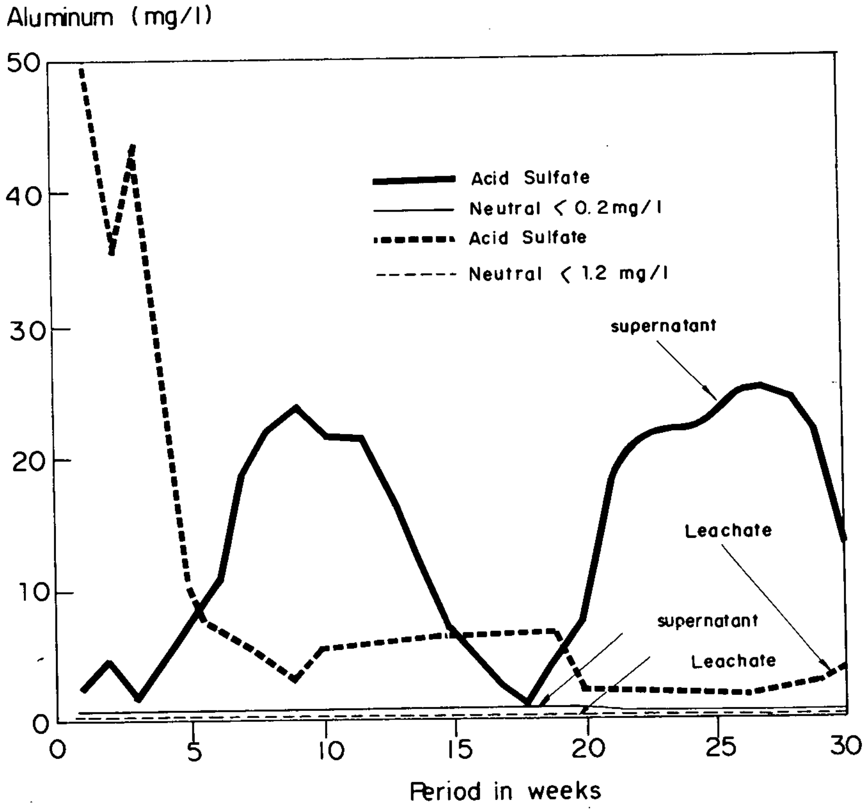

Figure 2. Aluminum concentrations in supernatant and leachate

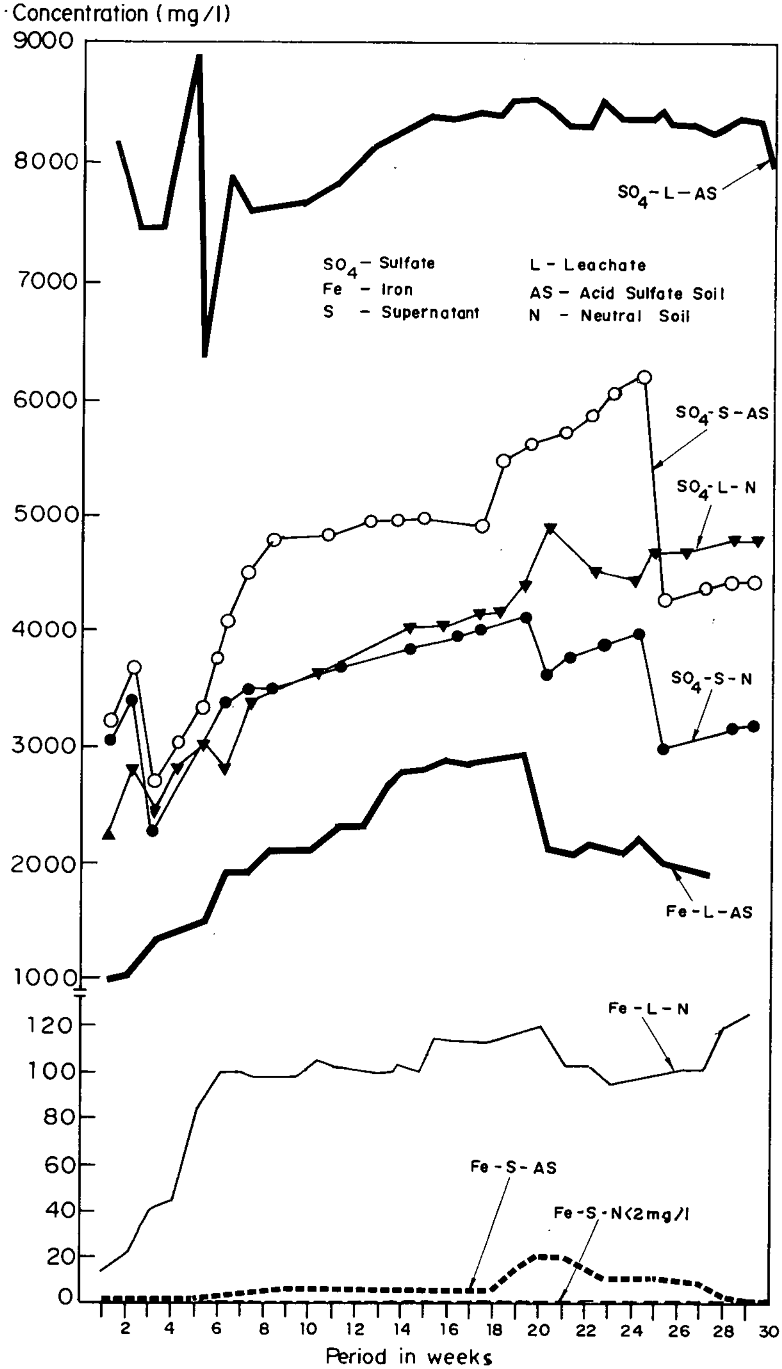

Figure 3. Iron and sulfate concentrations in supernatant and leachate

For the acid sulfate soil, dissolved aluminum in the supernatant fluctuated between 2 and 25 mg/l. Minima occurred at the start of each inundation period and peak concentrations 8 to 9 weeks later. Dissolved iron in the supernatant fluctuated between 0 and 20 mg/l. Iron concentrations rose very slowly from near zero at week 1 to 7-10 mg/l at the end of the first inundation period. On replacing the water, the concentration of iron rose to a peak of 20 mg/l after 3 weeks and then decreased to near zero in 8 weeks. The reason for the relatively low (but still toxic) iron concentrations in the first period, compared with the higher concentrations after week 18 is not clear.

In the leachate of the acid sulfate soil, the aluminum concentration was highest (50 mg/l) at the start and gradually decreased, remaining about 2 mg/l from week 20 onwards. In the leachate of the neutral soils, it remained below 1.2 mg/l throughout. Iron concentrations in the leachate of the neutral soils were between 10 and 120 mg/l, low in the beginning and increasing with time of flooding. A similar trend was observed for the acid sulfate soils where the iron concentration in the leachate increased from about 1000 to 3000 mg/l in 18 weeks. This decreased sharply after the second inundation but still remained above 2000 mg/l. The iron concentration in the leachate from acid sulfate soils thus was about ten times higher than from neutral soils throughout the periods.

The main decrease of aluminum in the soil solution coincided with a pH rise from 3.6 to above 5 and a more gradual rise in iron content from 1000 to 2000 mg/l. The former two were presumably caused by the alkalinity produced during iron reduction.

Sulfate contents of supernatants of acid and neutral soils were initially the same, about 3000 mg/l. The leachate of the neutral soil initially contained 2000 mg/l of sulfate, that of the acid soil much more (8000 mg/l). After some irregular fluctuations, the acid sulfate leachate reached a lower level of 6500 mg/l of sulfate at week 5. At that time, the leachate of the neutral soil and the supernatants of both soils all contained about 3000 mg/l. In all four examples, the sulfate level rose towards the end of the first inundation period, but most sharply in the acid sulfate supernatant. Replacement of the supernatant did not result in major, systematic changes in sulfate concentrations.

The drop in sulfate content in the supernatants of both acid and neutral soils at week 24-25 is due to a relatively large addition of new brackish water, without major impact on either pH, Al or iron content in supernatant or leachate. Apart from this irregularity, sulfate concentrations in the supernatant and the leachate of the neutral soil were very similar. In the acid soil, sulfate was much higher in the leachate (8000 mg/l) than in the supernatant, where it increased with time from 3000 to about 6000 mg/l. This indicates a relatively strong movement of sulfate from the acid soil to the supernatant. The general increasing trend with time may be associated with evaporation.

4.3 Nitrogen

The influence of urea fertilization (100 kg/ha) at weeks 0 and 5 on the development of ammonium, nitrate and nitrite contents is graphically represented in Figures 4 and 5. The graphs show conspicuous ammonium peaks in the supernatants of both soils within 2 to 3 weeks after fertilization. For the acid sulfate supernatant, the ammonium concentration reached 25 mg/l at week 2, dropped to 17 mg/l at week 3. It rose again after the second urea application to a peak of about 60 mg/l at week 8 and decreased gradually to about 25 mg/l at the end of the first inundation period (week 18). After replacement with new brackish water, the concentration of ammonium rose to 35 mg/l, then gradually decreased to 30 mg/l. There was less than about 1 mg/l of nitrate and essentially no nitrite at any time. In these acid conditions, there was virtually no uptake of N by algae and a low rate of removal from the supernatant to the air or the soil.

In the neutral supernatant, the ammonium peaks developed equally quickly after urea application, but ammonium concentration reached a lower level than over the acid sulfate soil after both applications and decreased much more rapidly. From week 15 onwards, it remained virtually zero. Comparison of nitrate and nitrite concentrations in the supernatant shows that over the neutral soil, the ammonium peaks are followed shortly by nitrate and nitrite peaks of 10 and 20 mg/l respectively, which declined to practically zero before the end of the first inundation period.

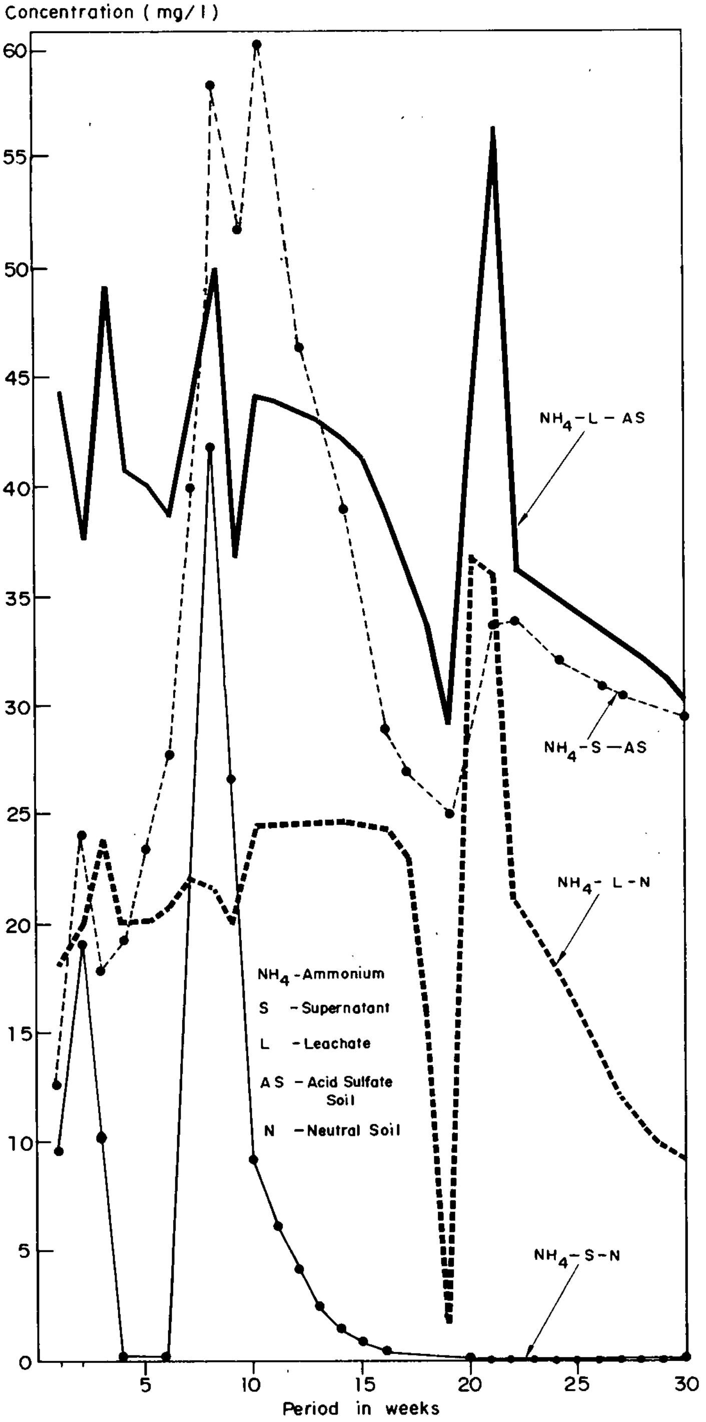

Figure 4. Ammonium concentrations in supernatant and leachate

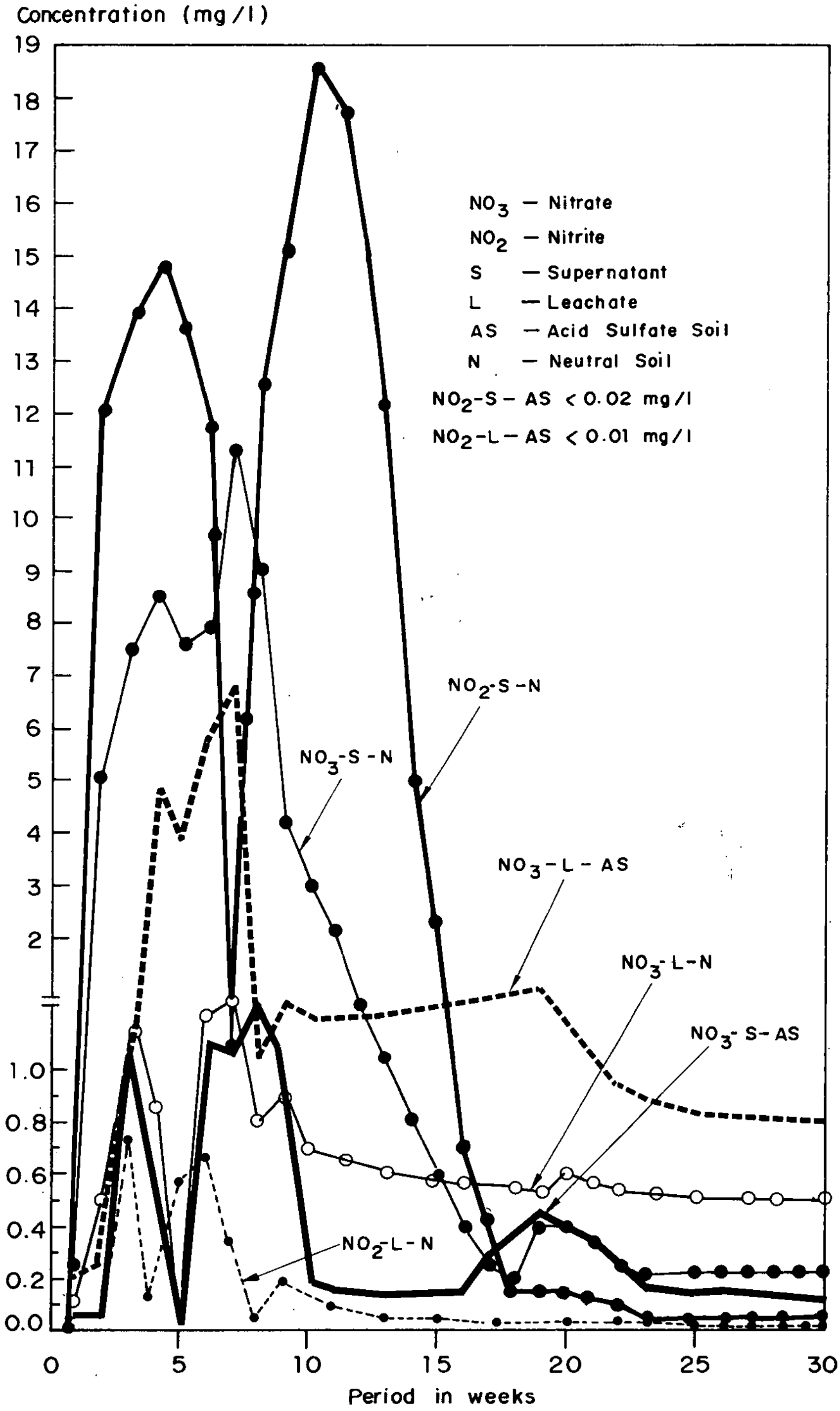

Figure 5. Nitrate and nitrite concentrations in supernatant and leachate

In the leachate of the neutral soil, the ammonium content was hardly affected by the fertilization; only minor and brief peaks of nitrite (0.7 mg/l) and nitrate (1.5 mg/l) were observed. This indicates that most of the urea-nitrogen added to the neutral supernatant becomes quickly available as ammonium, which was removed nearly as quickly: partly taken up by phytoplankton, partly lost by nitrification/denitrification, and perhaps by ammonia volatilization.
The leachate of the acid sulfate soil contained similar ammonium concentrations, and similarly low nitrate and nitrite concentrations, as the acid supernatants. Apparently, after an initial cation exchange, saturating part of the soil's exchange sites with ammonium, the concentrations of ammonium in the supernatant, the soil solution and on the exchange sites of the soil were in equilibrium with each other after the second urea application.

4.4 Phosphate

Figure 6 represents the changes in soluble phosphate in supernatants and leachates after superphosphate applications at the rate of 100 kg/ha at weeks 0 and 5.

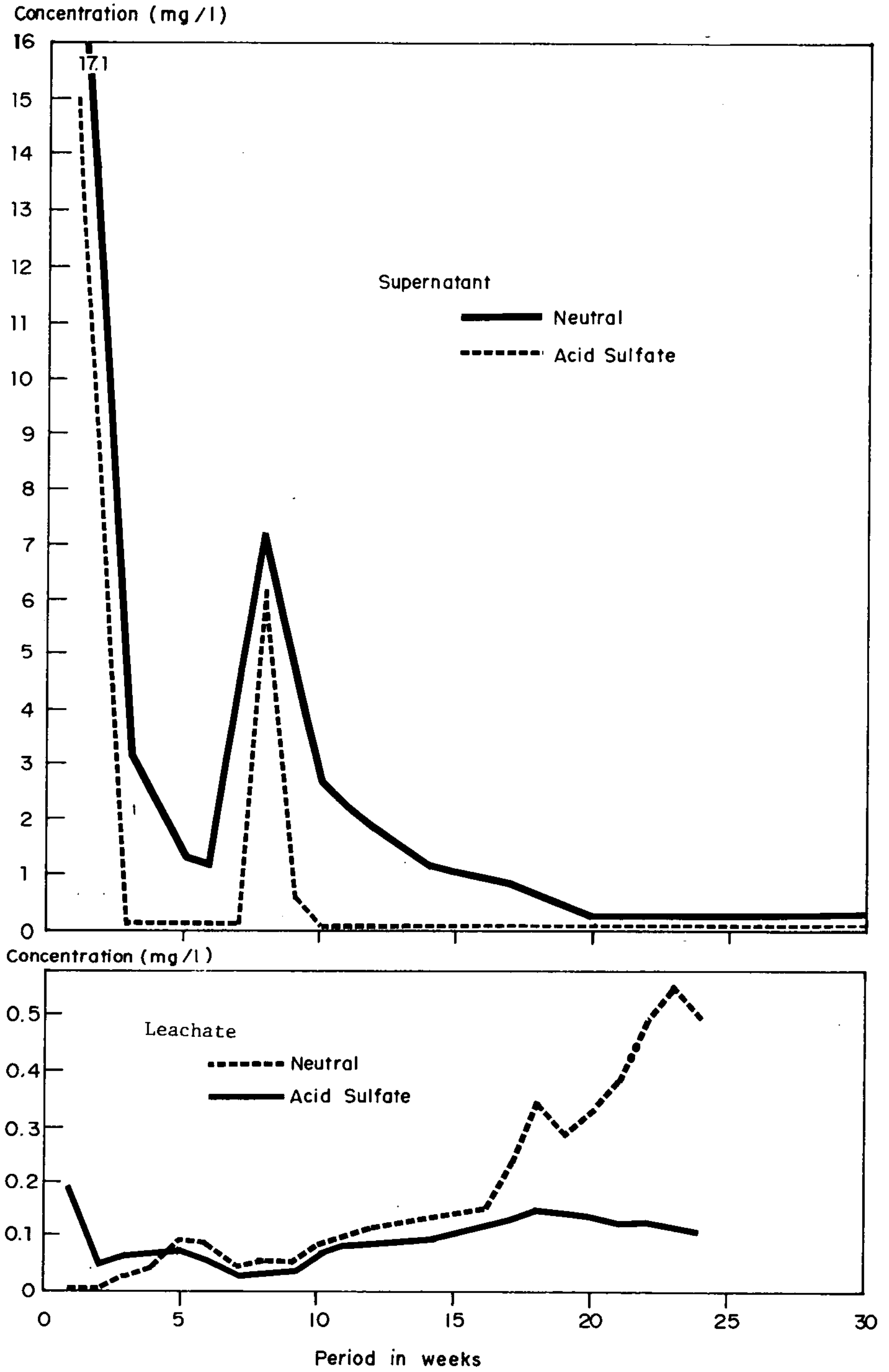

Figure 6. Phosphate (PO_4) concentrations in supernatant and leachate

In the supernatants of both soils, soluble phosphate rose to maxima within one week after application, and dropped sharply again within the next two weeks. In the acid supernatants, concentrations were almost zero within 2 weeks, whereas they remained above 1 mg/l for several weeks in the neutral supernatant. The peaks in the supernatant of week 1 reached 17.1 and 15.0 mg/l and those of week 8 reached 7.3 and 6.3 mg/l of phosphate, the higher values being reached for the neutral soil. The very rapid rise in dissolved phosphate after fertilization was confirmed by a parallel experiment with daily observations. The relatively low level of the second peaks cannot be explained by the application rate, which was the same both times. The pH of the acid supernatant during the first peak was 5.1 against 3.6 at the second peak. This acidification was associated with rises in soluble aluminum and iron from near zero to 9 and 4.5 mg/l respectively. Chemical immobilization of soluble phosphate should indeed be more intensive under the more acidic conditions at week 7, and, in the near absence of biological activity, is thought to be responsible for the lower second peak as well as for the very rapid depletion of soluble phosphate. The balance between dissolution and immobilization would be reached more quickly for the more acid supernatant and result in a relatively low peak level. No such explanation holds for the neutral supernatant, which had a pH between 7 and 8 both at weeks 1 and 8. Here the decrease in soluble phosphate must be ascribed mainly to biological uptake and turnover. The gradual decrease of phosphate in the neutral supernatant after the second application corroborates this assumption.

A biotic equilibrium was not reached, however. At the end of the first inundation period the soluble phosphate had reached a level of 0.7 mg/l and kept declining. Most of this amount appeared in the leachate of the neutral mud on replacement of the brackish water, which involved drainage by leaching of the first supernatant.

For the acid mud no transfer of soluble phosphate from supernatant to leachate is indicated by the observational data: essentially all must have been immobilized in the soil.

5 Implications for the management of brackish water fishponds

The quantities of iron and aluminum in pond water under acid sulfate conditions are high and are probably beyond the toxic limit to fishes and algae.

Repeated drying, leaching and flushing of acid sulfate soils may be effective in reclaiming these soils and should help in removing the high concentrations of elements such as iron, aluminum and sulfates. A reclamation procedure for acid sulfate fishponds is presented in another paper of this symposium (Brinkman and Singh 1981).

These soils should be kept inundated for as long as possible to maintain a high soil pH. If the ponds have to be drained and dried, as needed in most cases to eliminate predators and unwanted species of fish, the pond bottom should be thoroughly flushed before a new fish culture is started.

Application of nitrogen fertilizer in acid sulfate fishponds without prior reclamation appears to be useless. The very high nitrate and nitrite concentrations found after urea application in the supernatant of the neutral soil indicates that on such soils, losses by nitrification-denitrification from large doses of urea are considerable. The same order of losses should be expected from large single doses in reclaimed acid sulfate fishponds. In both cases, smaller urea application rates at short intervals should minimize these losses and increase nitrogen fertilizer utilization.

Phosphate appears to be strongly fixed in acid sulfate soils. Therefore, it should be applied in small doses at frequent intervals, perhaps every week, in acid sulfate ponds. A slow-release P-fertilizer may be a better source than superphosphate. Alternatively, phosphate could be placed on a semi-submerged platform or in a semi-submerged bag, from which it diffuses slowly into the pond water. This reduces the direct contact with the pond soil and improves the phosphate economy.

Acknowledgement

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MANAGEMENT OF ACID SULFATE SOILS FOR BRACKISH WATER FISHPONDS: EXPERIENCE IN THE PHILIPPINES

V.P. Singh
Brackish Water Aquaculture Center (BAC),
U.P. College of Fisheries
Leganes, Iloilo, Philippines

1 Summary

The productivity of fishponds in acid sulfate areas is influenced by their state of reclamation, the treatment of the pond bottom between fish crops, the time and mode of fertilizer applications, fish stocking rates and timing.

In acid sulfate areas, pH values of air-dry soil in water below 5 are correlated with deficient levels of available P and below 4.5, with potentially hazardous concentrations of aluminum. Very strongly acid pond soils remain the same for more than a month after inundation. When small amounts (0.5 t/ha) of lime are distributed on the surface before inundation, the pH rises rapidly owing to soil reduction. Growth of algae was best in supernatant of partly reclaimed acid sulfate soil limed on the surface with 0.5 t/ha of agricultural lime when nitrogen and phosphate fertilizers were applied in frequent, small doses and in 2:1 to 4:1 N:P_2O_5 ratio. Regardless of the rate of P_2O_5 application, its effect lasted less than 2 weeks.

Large lime applications by themselves are not effective in reclaiming acid sulfate fishponds. Moderate applications work well in combination with reclamation by the tillage and flushing method described by Brinkman and Singh (this symposium).

Acid sulfate soils or potential acid sulfate soils cover over 10 million hectares of land in the tropics. Nearly 5 million ha occur in South and Southeast Asia (Van Breemen and Pons, 1978). Less than 2 million hectares of these are cultivated. In addition to the areas already identified there are several large areas not yet examined that are presumed to be affected by acid sulfate soil conditions. Their extent in The Philippines, however, is not yet fully established (Early et al. 1979, Singh and Camacho 1980). Tang (1976) estimated that at least 60% of the fishponds in The Philippines are affected by acid sulfate conditions. My own survey showed that there are about 15 to 20 thousand hectares of acid sulfate soils in Panay Island alone, which are either uncultivated or used for brackish water aquaculture. It seems reasonable to recognize the possibility that low production of milk fish in The Philippines (600 kg/ha per year slightly over 2 crops/year) is attributable at least in part to the inhibitory influence of acid sulfate soils.

Two other papers in this symposium deal with mechanisms of acid formation in pond water (Singh 1981) and with a rapid reclamation method, eliminating most of the acidity and related hazards to fish (Brinkman and Singh 1981).

Even after reclamation, some hazards and problems remain. Special management methods are needed to circumvent these problems. In wet land rice as well as in fish culture, on reclaimed acid sulfate soils, available phosphate needs to be raised above deficiency levels; potential acidity in the subsoil should be kept immobilized; soluble iron (II) and aluminum concentrations need to be kept low. Fish cultivation is preferred over rice where the land is saline and tidal fluctuation can be used for water control.

Management methods appropriate for fishponds in reclaimed acid sulfate soils were developed at the Brackish Water Aquaculture Center (BAC), U.P. College of Fisheries, Leganes, Iloilo. Management aspects discussed in this paper include pond treatment between fish crops, time and mode of fertilizer applications, rates and timing of fish stocking.

Nutrient elements required by the algae are partly derived from the pond soil; this also influences the availability of added nutrients. The soil is the main, and normally only, source of dike building materials. The soil in fishponds also serves as a substrate for the bottom dwelling microorganisms, which are food for fish. The quality of the overlying water is affected by the nature of the pond bottom. This influence of the soil on pond conditions can be clearly seen in the case of acid sulfate soils.

Despite the high acidity and associated effects, acid sulfate soils have characteristics favorable for fish cultivation. Their topographic and hydrologic setting is often suitable for establishing fish cultivation. They are normally well supplied with plant nutrients except for P. Furthermore, though these soils generally are under salt-water influence, this salinity is not a problem because most brackish water pond biota are adapted to these salinity levels.

The most common problems associated with fishponds in acid sulfate soil material are the slow growth of fish and of the food organisms, as well as intermittent fish mortality. These problems can be attributed to several causes: low pH (Nikolsky 1963, Beamish 1972, IFP 1974), toxicity of aluminum, iron (Nikolsky 1963) and manganese (Karpevich and Shurin 1973); and phosphate deficiency owing to the high phosphate-fixing capacity of the soil (Hesse 1963, Watts 1965). Although occasional acute fish kills occur in these ponds, the chronic and sublethal effects that inhibit pond biota probably are more detrimental in the long run. If properly reclaimed and managed, fishponds in these soils can contribute to food production and this resource can be utilized to the fullest extent.

3 Properties of acid sulfate soils, BAC, Leganes, Iloilo

Before reclamation, the acid sulfate fishpond soils studied at BAC, Leganes, have a (dry) pH between 3.4 and 3.6 throughout to 0.5 m in depth (Table 1). Our past experience shows that this low pH range is injurious to fish, since fish kills were frequently observed when the pH of the water dropped below 5. The wet soil pH values show an increasing trend with depth, owing to reduction. Total potential acidity is in the range of 700-950 mmol H/kg soil. Acetate-soluble sulfate ranges from about 4300 to 5600 mg/kg. Ammonium acetate-extractable iron ranges from

200-300 mg/kg. Exchangeable aluminum ranges from 105 to 180 mg/kg (Table 1).

Table 1. Chemical properties[1] of some acid sulfate soils before reclamation. BAC, Leganes, Iloilo 1979

Profile depth (cm)	pH Wet	pH Dry	Potential acidity mmol H/kg	mg/kg Acetate soluble sulfate	mg/kg Available Fe	mg/kg Exchangeable Al	mg/kg Available P
0-15	3.6	3.4	700	4310	200	105	3.6
15-30	4.4	3.6	610	4320	250	81	4.4
30-45	4.4	3.4	870	5060	216	112	2.6
45-60	5.7	3.5	830	5010	318	168	1.6
60-75	6.3	3.5	950	5590	327	180	4.0

[1] Except for potential acidity all analytical methods according to Black 1973; potential acidity was measured by H_2O_2 oxidation followed by titration with NaOH; means of 50-100 samples taken randomly over 30 ha of newly built fishponds

There is little information on the toxicity limits of aluminum and iron for fish; Nikolsky (1963) stated that they are about 0.5 and 0.2 mg/l, respectively. Such concentrations develop rapidly in the supernatant of these soils (Singh 1981).

The soil is low in available P, from 1.6 to 4.0 mg/kg (Table 1). This can be explained by the presence of high amounts of exchangeable aluminum and available iron. Although little is known about the optimum phosphate content in soils for aquaculture, a minimum of 1 to 3 mg orthophosphate per liter pond water is reported to be necessary for good algae production (PCARR 1976). Phosphate concentration in the supernatant of these soils approach zero level and on fertilization rapidly drop to 0.0 mg/l (Singh 1981).

X-ray diffraction studies showed that the soil clay is monomineralic (more than 90%) smectite with some aluminum interlayering. The iron oxides present in the soil were X-ray amorphous.

A large series of samples from different depths was taken in an area of older, established ponds in BAC that had been subjected to different periods and methods of management. Values of potential acidity, exchangeable Al, available Fe and P were grouped in 0.5 unit pH intervals (dry pH, i.e. pH of air-dried soil in water, 1:1 W:V), to show their interrelationships. There were 50 or more samples in each pH interval: the means are shown in Figure 1. The results which are in agreement with the findings of other workers, e.g. Ponnamperuma (1977), demonstrate that dry pH values below 5 indicate deficient levels of P; below 4.5, possibly hazardous levels of Al.

It should be noted that these data refer to dry soil, and are not directly applicable to the conditions of the soil after about a week's inundation.

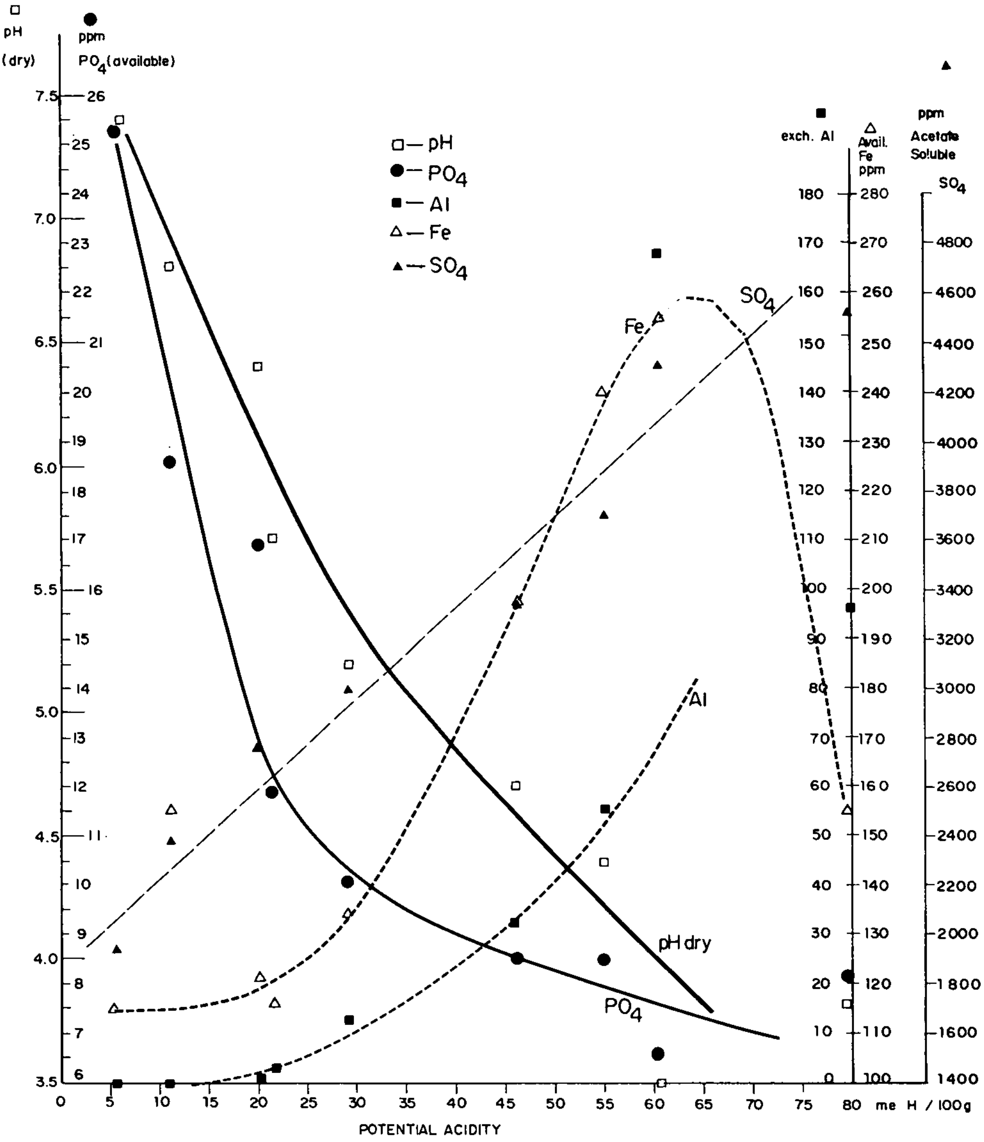

Figure 1. Available phosphate and iron, acetate-soluble sulfate, exchangeable aluminum and potential acidity as functions of pH in oxidized soils from brackish water fishponds at BAC, Leganes, Iloilo. Data are means of 50-54 samples, grouped by 0.5 pH unit ranges. The low available Fe at the lowest pH and highest exchange acidity is probably due to removal of Fe^{2+} by leaching and diffusion to the supernatant: this group of samples consisted mainly of surface material.

4 Kinetics of pH upon submergence of acid sulfate fishpond soils

pH changes with time after inundation with brackish water were estimated in a number of recently built ponds at Leganes. Initial pH ranged from 3.1 in the surface soil to 3.4 at 0.2 m depth (Table 2). After 4 weeks inundation, the pH showed virtually no change, presumably owing to a very low microbial activity in these extremely acid conditions. The ponds were then drained and 400 kg of powdered agricultural lime per ha was distributed on the wet surface without incorporation. The ponds were then submerged again within about 6 hours. After another 4 weeks of inundation, the soil pH had risen by 1.5 to 2 units at all depths measured (0-0.2 m). It thus appears that very small lime applications, far too low to neutralize an appreciable volume of soil, are in fact sufficient to start the microbial reduction process which then can continue and extend into adjacent (deeper) soil material.

Table 2. Kinetics of pH in an acid sulfate soil submerged for 4 weeks. BAC, Leganes, Iloilo 1979[1]

Depth (cm)	pH[2]		After liming[3] the surface and another 4 week's submergence
	Initial	After 4 weeks submergence	
0- 5	3.1	3.2	4.6
5-10	3.3	3.2	4.7
10-15	3.4	3.5	5.2
15-20	3.4	3.5	5.3

[1] Means of data on 50 individual small ponds, all treated the same way

[2] By immersion into wet soil

[3] Application of 400 kg powdered lime per ha on the surface; not incorporated

Other work, not reported here, indicates that such lightly limed, reduced pond bottoms do not release toxic quantities of Al or Fe into the overlying water, but that the soil material still strongly fixes phosphates.

5 Effect of nitrogen and phosphate application on primary productivity in acid sulfate fishponds

Partly reclaimed acid sulfate soil material from BAC, Leganes was placed in aquaria, applied with chicken manure at a rate of 2000 kg/ha and flooded for 4 weeks before application of fertilizer. Eight combination treatments of different amounts of N and P_2O_5 were applied every two weeks (Table 3). Phosphate concentrations in overlying water and primary productivity, as reflected by dissolved oxygen concentration, were monitored weekly for 6 weeks beginning one week after first application of fertilizer.

Table 3. Mean[1] dissolved oxygen and PO_4-P concentration (g/m^3) for different nitrogen - phosphorous combination treatments.
BAC, Leganes, Iloilo 1979

Treatment (kg/ha)[2]	Oxygen[3]		P
1. 0 N + 0 P_2O_5	3.01	c	0.01
2. 0 N + 30 P_2O_5	3.32	b	0.43
3. 30 N + 30 P_2O_5	3.70	b	0.43
4. 30 N + 60 P_2O_5	3.25	b	0.39
5. 30 N + 120 P_2O_5	3.50	b	6.38
6. 30 N + 0 P_2O_5	2.40	c	0.05
7. 60 N + 30 P_2O_5	4.29	a	0.03
8. 120 N + 30 P_2O_5	4.82	a	0.25

[1] Means of three replicates, average over 5 observations in 2 months beginning 6 days after first application of fertilizers

[2] Total rate over one season (2 months); one-third applied every 2 weeks

[3] Means in a column followed by the same letter are not significantly different by DMRT (0.05)

The treatment with 120 kg N and 30 kg P_2O_5 per ha resulted in highest algae growth which was not significantly different from the treatment with 60 kg N plus 30 kg P_2O_5 (Table 3). These two treatments produced significantly more algae than any other. The lowest dissolved oxygen concentrations, 3 and 2.5 g O_2/m^3, were recorded in the treatments without or with only 30 kg N/ha, respectively. The highest mean dissolved oxygen (4.8 O_2/m^3) was recorded for the treatment of 120 kg N/ha plus 30 kg P_2O_5/ha. These data are in agreement with the findings of Swingle and Smith (1939) and Feldman and Suchwiji (1961) as cited by Wolny (1966).

The application of nitrogen or phosphorus alone was no better than the control (Table 3). This supports the earlier findings of Singh et al. (1976) who indicated that if both nitrogen and phosphorus are limiting in a soil, hardly any benefit can be drawn from the application of only one of these nutrients. Applications beyond 30 kg P_2O_5/ha did not increase growth. Other work as well as the data in Table 3 indicate that an optimal ratio between N and P_2O_5 applications lies between 2:1 and 4:1.

The lowest phosphate concentration in the water (0.01 g/m^3) was recorded for the control treatment; the highest concentration (6.38 g/m^3) for the high P_2O_5 treatment. Intermediate phosphate concentrations were found in the other treatments. Clearly the phosphate concentrations in water is strongly affected by the amount of phosphate added.

Phosphate concentrations were near zero within about 2 weeks of application, presumably because of algal uptake and conversion into iron- and aluminum phosphate. Repeated, small applications of N and phosphate fertilizers may be necessary for a high and sustained growth rate of algae throughout the culture period.

As has been found elsewhere for wetland rice, acid sulfate soils used for fishponds rapidly fix applied phosphate even after reclamation. The remedies for these uses are different, however. In rice, a single basal application is given, the amount adjusted to compensate for fixation. In fishponds, this approach does not work. Even with big applications, the P concentration in the pond water approaches zero, inhibiting further primary production, within about 10 days. Therefore, weekly phosphate applications are needed, or a system by which phosphate is released to the pond water over a period of about a month from a semi-submerged heap or bag of superphosphate.

6 A combination of tillage, flushing and liming

Earlier experiences indicate that flushing, liming and proper fertilization can improve acid sulfate soils. Some of our ponds, which had received different amounts of lime and chicken manure (Table 4) and produced low to moderate fish yields, were tilled once to speed up oxidation and then subjected to repeated tidal flushing by brackish water and rain water to remove acids. Subsequently, the ponds received the same lime and chicken manure applications as before. High doses of chicken manure were effective only after flushing. Lime applications as high as 8 t/ha did not improve production before flushing; after that, low-lime, treatment gave some improvement. Higher applications had a negative effect, presumably owing to excessive reduction. At the start, zero-lime treatments yielded less, but a year later, after several more drying and flushing cycles, these treatments yielded comparable to those treated with lime.

Table 4. Total fish production (kg/ha per crop) in ponds, earlier provided with various levels of lime and chicken manure before and after one tilling and repeated flushing

Lime (t/ha)	Chicken manure (t/ha)	Production before tilling and flushing	Production after tilling and flushing	Production increase
0	2	366	419	53
4	2	478	555	77
8	2	403	566	163
4	8	689	930	241
8	8	412	805	393

After Camacho (1977)

In a study now underway at Carles, Iloilo, the pond bottom was tilled twice to speed up oxidation, subsequently flushed and washed several times with sea water. Here, the soil increased in (dry) pH from 3.7 to 6.2. Also, the dikes of the pond were leached once by pumping sea water, to remove free acids. After application of 3 t of chicken manure, 48 kg N and 60 kg P_2O_5 per ha pond bottom, algae grew well. The fish yield from this partly reclaimed pond was 350 kg/ha in the first season and 450 kg/ha in the following season compared with less than 100 kg/ha from the unreclaimed pond.

7 Waste materials as amendments

Filter press mud from sugar mills has been used by some fishpond operators to replace part of the agricultural lime. Although reports on this material appear satisfactory, at least in one experiment it caused an intense black coloration in the pond water, presumably by dissolved organic matter which inhibited growth of algae. After two months of application, when the overlying water was drained and replaced by fresh brackish water, the algae started growing well. If the material is to be used, it would probably be best to directly apply it to the soil surface and cover it with chicken manure. Renewal of the pond water may be necessary to obtain a supernatant sufficiently clear for algae growth.

Ash of rice hulls has been recommended for use in fishponds. This presumably could decrease phosphate fixation in the pond soil if the material would remain on the bottom. However, it tends to drift throughout the pond even when the water moves slightly by wind action on the surface. This drastically decreases the amount of light available for growth of algae.

8 Conclusions

Large-scale liming to reclaim fishponds without tillage and flushing of the pond bottom is not effective in increasing fish yields.
Low rates of liming in combination with tillage and flushing, as well as flushing the dikes (Brinkman and Singh, this symposium) rapidly raises fish yields. Even without liming, satisfactory fish yields have been obtained after one season of tilling and flushing.
Even after partial or full reclamation, regular application of 500 kg/ha of powdered lime on the pond bottom before the first inundation speeds up reduction and lowers peak concentrations of toxins that may be

released into the pond water.
With regular fertilizer applications to the pond water, a 3:1 ratio between N and P_2O_5 appears to be about optimal.
Whether acid sulfate pond soils are reclaimed or not, they rapidly fix applied phosphate. This should therefore be made available by slow release or in frequent, small doses.

9 Some recommended management practices

Based on the observations from farmers fields, interviews, research results from the Brackish Water Aquaculture Center, and cumulative experience, the following management practices can be recommended.
The development of fishponds in mangrove areas should be done with caution. Prior to any development work, a detailed soil survey is advised. Once an area has been identified as having actual or potential acid sulfate soil conditions, a decision must be made whether to develop it or not. Once an acid sulfate area has been developed into fishponds, the acids present in the surface layers of the soil should either be removed or neutralized to improve the pond conditions and fish harvest.

When the pond is dried between harvests to kill predators, only the standing water should be drained and the soil surface dried out; a network of drains should not be dug in the pond bottom.
Only small quantities of lime, of the order of half a ton per ha or less, should be applied and not incorporated, to speed up soil reduction after the first inundation. This should be followed by the application of organic manure, preferably chicken manure, of the order of 2 to 5 t/ha depending on the organic matter content of the pond soil.
If no growth of algae is observed within a week of pond preparation the water should be inoculated with algae collected from normal fishponds.
The first dose of inorganic fertilizer should be applied after the pond bottom has been sealed by swelling after inundation: in practice about a week after inundation, to minimize fertilizer loss into the soil.
Regular, small doses of phosphate should be applied every week or a larger amount should be placed in a bag semi-submerged in the pond, to minimize fixation on soil constituents while maintaining adequate

concentrations in the pond water.

Even after reclamation acid sulfate ponds should be stocked with older, heavier fingerlings than usual for non-acid ponds (e.g. 5 g rather than 1-2 g). Stocking should be done after the development of a solid mat of algae, not after a certain number of days.

The water quality of the pond, especially the pH, should be monitored regularly and if it becomes acidic (below tolerable limit) a small quantity of finely ground agricultural lime should be broadcast in the pond water. Alternatively, when pond water becomes turbid and acidic, it should be replaced by new brackish water, just before fertilizer application. The pond water should not be drained for at least 4-5 days after fertilizer or lime application.

The fish culture should start by growing milk fish or other hardy fish in the first year after reclamation; then, some prawns should be stocked with the fish on an experimental basis before embarking on the potentially more profitable prawn monoculture after several years.

Acknowledgement

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PHOSPHATE DYNAMICS IN AN ACID SULFATE SOIL UNDER FLOODED CONDITION STUDIED BY A TRACER TECHNIQUE

A.K. Alva and S. Larsen
Royal Veterinary and Agricultural University
Copenhagen, Denmark

1 Summary

Tracer techniques are efficient for studying P dynamics in flooded acid sulfate soil planted to rice. This study deals with changes in labile P in an acid sulfate soil from the Central Plain of Thailand. Available P was estimated at different times during the rice growing period by determining isotopic dilution of P absorbed by plants (L-value) and also by isotopic exchange in the soil (E-value). The influence of varying levels of applied N, P and K on labile P and the recovery of applied P were examined in a growth chamber.

During the growing period L-values for rice increased the first 80 days after transplanting and subsequently decreased towards crop maturity, as a result of crop-induced P mobilization followed by immobilization. The influence of rice cropping on labile P was appreciable 50 days after transplanting. ΔL-values and recovery of applied P, at a uniform rate of P application, increased with increasing N and K enrichment. At a given level of N and K accompanied by a low P application the recovery of applied P remained constant during the major part of the growing period, while at high application of P recovery decreased over the growing period. The influences of mineral nutrition on P dynamics are discussed. E-values were considerably higher than the L-values at the crop maturity stage. The possible causes for this discrepancy are discussed.

2 Introduction

A considerable portion of paddy soils in the Central Plain of Thailand consists of acid sulfate soils. These are poorly drained acid clays developed from brackish water deposits and typically have a low productivity due to their strongly acidic reaction. Phosphorus deficiency is one of the most important growth limiting factors for rice in these soils. P dynamics are extremely complicated in acid sulfate soils particularly under flooded conditions.

Radio-chemical methods and the anion resin exchange method are suitable for studying plant available P in soil because they bring about minimal changes in the chemistry of the soil. Alva et al. (1980) found a modified resin exchange method (developed by Sibbesen 1977) very useful in studying the P dynamics in flooded soils and for explaining the lack of response of lowland rice to P fertilization. Radio-chemical methods have been developed to determine the labile P fractions by measuring either isotopic exchange in the soil, i.e., estimation of the E-value (McAuliffe et al. 1948, Wiklander 1950, Russel et al. 1954), or isotopic dilution, i.e., estimation of the L-value (Larsen 1952). These values are measures for the quantities of soil phosphate that are exchanged with added labeled phosphate (E-value) or that dilute added labeled phosphate through uptake and absorption by plants (L-value). As a measure of plant available soil phosphate the L-value has considerable theoretical advantage over the E-value in that it reflects not only the conditions that confront the plant when grown in the soil but also any effect the plant has on P dynamics in the soil (Fried 1964).

In this study the L-value technique (Larsen 1951) was applied to monitor P dynamics in flooded acid sulfate soil planted to rice at different levels of N, P and K. E-values were determined after harvesting.

3 Materials and methods

3.1 Soil material

The soil used for the experiment was the topsoil (0-30 cm) of a Sulfic Tropaquept sampled at Klong Luang Rice Experiment Station in the Central Plain of Thailand. The soil was collected from a dry paddy field after harvesting. Prior to sampling, rice had been grown in that field under submerged conditions. The dry soil was shipped to the Soil Fertility Laboratory at the Royal Veterinary and Agricultural University, Denmark. In Table 1 some physico-chemical properties are given of a typical Sulfic Tropaquept in the same area (according to Satoru 1973 and Charoen 1974).

Table 1. Some properties of the topsoil sampled for use in the growth chamber experiment

Texture analysis (%)	
coarse sand	1.3
fine sand	3.2
silt	43.7
clay	51.8
pH (1:2.5 soil:water)	4.2
Total carbon (%)	1.41
CEC mmol/100 g soil	25.8
Base saturation (%)	62.6
Resin-extractable P mg P/100 g soil	0.198
Fe_2O_3 (%)	4.4
Al_2O_3 (%)	23.9

3.2 Growth chamber experiment

The soil was air-dried, ground and sieved through a 5 mm sieve. Three mCi carrier-free $H_3{}^{32}PO_4$ was mixed with 10 g of fine sand. This ^{32}P-sand was mixed with 30 kg of soil in a rotary mechanical mixer (giving 0.1 mCi ^{32}P/kg soil). $CaCO_3$ was added at the rate of 3 g per kg soil. Portions of 8 kg of ^{32}P-treated soil were placed into plastic pots (30 cm diameter and 30 cm height) and varying levels of N, P and K were applied as urea, superphosphate and KCl (Table 3) and thoroughly mixed with soil. Excess water was applied and the soil was puddled within the pots. Thirty-day old rice seedlings of the variety RD-1 were transplanted into the pots at the rate of six hills per pot and two seedlings per hill. After the establishment of the seedlings five cm standing water was maintained until plant maturity. During the maximum tillering stage and panicle initiation stage the pots were drained for a period of three days. The changes in climatic conditions in the growth chamber during subsequent growth stages are shown in Table 2.

Table 2. Climatic factors regulation in the growth chamber during different growth stages

Climatic factors	Basic vegetative stage	Photoperiod sensitive phase to panicle emergence	Panicle emergence to maturity
Temperature (^{o}C day/night)	28/22	32/26	28/22
Photoperiod (hours per day)	12	10	12
Light intensity (K lux)	14	19	17
Dew point temperature (^{o}C)	20	20	20

3.3 Plant sampling and estimation of L-values

The aerial parts of the plants were harvested at 30, 40, 50, 80 and 150 (plant maturity stage) days after transplanting, washed in deionized distilled water and dried at 80^{o}C for 48 hours. The dry matter was dry-ashed and collected in 0.2 N HNO_3. Ten ml extract was transferred to clean counting vials and activity of ^{32}P was counted by means of a liquid scintillation counter. The activity in the standard (1 mCi ^{32}P in 1 ml 0.01 N HCl) was counted simultaneously as a measure of activity applied per pot. Background counts were obtained on 10 ml 100 µmol P/ liter solution and subtracted from the sample counts. The P concentration was determined colorimetrically (Yoshida et al. 1971) by using a Technicon Auto Analyser.

L-values were calculated according to the following relationship (Larsen 1969):

$$L = \frac{\text{activity applied per pot (cpm/g soil)}}{\text{activity in the plant (cpm/g dry matter)}} \times \begin{array}{c}\text{Conc. of P in plant}\\ (\mu\text{mol P/g dry matter})\end{array}$$

3.4 Estimation of E-values

After the plants were harvested at maturity, a 5 g soil sample from each pot was transferred into a milk sample bottle. 90 ml 0.01 M $CaCl_2$ was added and the suspension was shaken for half an hour in an end-over-end shaker. Next 10 ml of 5 μM KH_2PO_4 labeled with carrier-free $H_3{}^{32}PO_4$ was added (activity applied = 1 μCi/g soil), and further shaken for 18 hours. The suspension was filtered. A bottle without soil was used as blank. The activity of ^{32}P in the filtrate and the blank and the concentration of P in the filtrate were determined. Correction for color quenching was done by using an external standard. E-values were calculated from the following relationship:

$$E = \frac{\text{activity of } {}^{32}\text{P added (cpm/g soil)}}{\text{activity of } {}^{32}\text{P in the filtrate (cpm/g soil)}} \times \begin{array}{l}\text{Conc. of P in}\\ \text{the filtrate}\\ (\mu\text{mol P/g soil})\end{array}$$

4 Results

Dry matter weights, L-values at various times during the growing period, and E-values after the final harvest are shown in Table 3. Increasing N and P application depressed dry matter yield during the former half of the growing period and increased it during the latter period. In terms of grain yield the response to N application exceeded that to P application. K application had little or no effect on dry matter production and on grain yield. L-values at various samplings increased with increasing N levels up to 1.25 g N/pot. E-values increased for every increment in N levels. With increasing P levels L-values increased at all sampling occasions, whereas E-values increased markedly only for the first increment (0.28 g P/pot). There was no clear effect of K application on the L- and E-values. Over the growing period L-values in most of the treatments changed only slightly up to 50 days, increased between 50 and 80 days and decreased thereafter.

Table 4 presents the recovery of applied P at various times during the growing period and for each of the N, P and K application. The recovery was calculated as the difference in L-value (ΔL) between the respective treatments and the standard zero P application (treatment 5 of Table 3, i.e., 1.25 g N, 0 P and 1.04 g K per pot with 8 kg of soil). The influence of different P levels only (0.28 g and 0.56 g P/pot) is indicated by ΔL_{1P} and ΔL_{2P}. The influence of a single increment of P (0.56 g P/pot) under varying N levels are indicated by ΔL_{1N}, ΔL_{2N} and ΔL_{3N} and the effects of varying K levels in ΔL_{1K} and ΔL_{2K}. With increasing N and K levels, but uniform P increment, percentage recovery of applied P increased. At uniform N and K levels but increasing level of P the recovery of applied P increased up to 40 days after transplanting and subsequently decreased. However, at the crop maturity stage P recovery was higher at highest rate of P application.

Table 3. Dry matter weight (DM, in g/hill) and L- and E-values (µg P/g soil) at varying levels of applied N, P and K

		Days after transplanting												
										150*				
		30		40		50		80		Straw		Grain		
	NPK (g/pot)	DM	L-value	DM	L-value	DM	L-value	DM	L-value	DM	L-value	DM	L-value	E-value**
1	0.00:0.56:1.04	1.2	62	2.3	67	3.0	69	11.6	89	12.5	76	6.9	66	333
2	0.62 -"-	0.8	75	1.6	85	2.2	84	14.7	113	21.3	84	13.1	78	402
3	1.25 -"-	0.8	108	1.5	103	1.8	95	12.2	116	33.0	84	20.8	84	441
4	1.88 -"-	0.7	95	1.0	97	1.9	98	14.8	113	34.8	69	22.7	83	485
5	1.25:0.00:1.04	0.9	36	1.6	43	1.8	48	14.7	56	24.4	33	14.1	35	194
6	" 0.28 "	0.5	69	1.7	75	2.3	83	9.5	83	29.1	31	19.0	47	500
7	" 0.56 "	0.6	114	1.0	113	3.6	93	7.8	90	27.9	72	21.6	100	448
8	1.25:0.56:0.00	0.9	84	1.4	82	3.0	80	11.8	119	24.0	61	15.1	86	537
9	-"- 0.52	1.0	114	1.7	109	4.2	106	8.2	115	28.6	98	18.5	85	410
10	-"- 1.04	1.0	111	1.0	106	1.3	93	14.5	125	22.6	89	17.2	100	512

* Plant maturity

** E-values after final harvest

Table 4. ΔL-values* (µg P/g soil) and recovery of applied P as influenced by varying levels of N, P and K enrichment (numbers in parenthesis indicate recovery of applied P in %)

	Days after transplanting					
					150**	
ΔL	30	40	50	80	Straw	Grain
ΔL_{1N}	26	25	21	33	43	31
	(37)	(34)	(30)	(47)	(61)	(44)
ΔL_{2N}	39	42	36	57	51	43
	(56)	(60)	(51)	(81)	(73)	(61)
ΔL_{3N}	59	54	50	57	36	48
	(84)	(77)	(71)	(81)	(52)	(69)
ΔL_{1P}	33	32	35	27		12
	(94)	(91)	(100)	(77)		(34)
ΔL_{2P}	78	70	45	34	39	65
	(111)	(100)	(64)	(49)	(56)	(93)
ΔL_{1K}	48	39	32	63	28	53
	(69)	(56)	(46)	(90)	(40)	(73)
ΔL_{2K}	78	66	58	59	65	50
	(112)	(94)	(83)	(84)	(93)	(71)

* $\Delta L_{1N} = (L_1 - L_5)$, subscribed numbers are treatment numbers
$\Delta L_{2N} = (L_2 - L_5)$ For treatment details see Table 3
$\Delta L_{3N} = (L_4 - L_5)$ $\Delta L_{1P} = (L_6 - L_5)$ $\Delta L_{1K} = (L_8 - L_5)$
$\Delta L_{2P} = (L_7 - L_5)$ $\Delta L_{2K} = (L_9 - L_5)$

** Final harvest at plant maturity

5 Discussion and conclusions

5.1 Changes in L-values during the growing period

Studies on P dynamics in soils generally assume that plant species can increase the labile P only by depletion of the labile pool resulting in a mobilization of non-labile P. But L-values have been shown to increase during the experimental cropping of soils containing residual fertilizer P (Larsen 1971). The results of this study indicate that lowland rice plants have a dual influence on P dynamics in flooded soil, i.e., a mobilization of P (up to 80 days after transplanting) followed by its immobilization (after 80 days until crop maturity). Our previous study (Alva et al. 1980), using a resin exchange method (Sibbesen 1977) for extraction of plant available P, also showed a considerable influence of rice plants on the dynamics of P in flooded soils. Crop-induced P mobilization was due to increased activity of soil microflora stimulated by a physiologically active rhizosphere, resulting in reduction of ferric phosphate into more soluble ferrous phosphate, a predominant source of P for lowland rice plants. Crop-induced P immobilization was attributed to the reoxidation of ferrous to ferric iron in the rhizosphere, due to the excretion of oxygen (Mitsui et al. 1962), diffusing from the aerial parts to the roots (Barber et al. 1962), into the soil. The possible existence of a physiological mechanism within rice plants capable of maintaining a proper balance between these contrasting processes has been discussed elsewhere (Alva et al. 1980).

5.2 The influence of varying N, P and K levels on ΔL-values and recovery of applied P

The nutrition status of plants is one of the factors affecting the oxidation-reduction potential in the rice rhizosphere, which in turn has an influence on P dynamics in flooded soils. Results of this study (Table 4) show that at a given application of P, recovery of applied P increases with increasing N application. Increasing application of N has been found to lower the redox potential markedly (Chiang and Yang 1969), probably by increasing bacterial microflora and respiration (Trolldenier 1971). This would help to mobilize P and may explain the observed positive effect of application of N on the availability of P. According to Cunningham (1964) several crop species tend to maintain a definite ratio between the uptake of cations and of anions. If lowland rice has a similar tendency, then N application (N uptake by lowland rice is generally in the NH_4^+ form) would further increase the anion uptake, thus increasing P recovery.

The influence of P application on the recovery of P during the growing period depended on the level of applied P. At the lower rate of P application (0.28 g/pot) the recovery of P was constant during the major part of the growing period, while at a higher rate (0.56 g/pot) the recovery of P decreased with time. A probable explanation for this difference is that at a higher application of P crop induced P immobilization sets in earlier due to the presence of high levels of labile P in the soil compared to the amount of P taken up. At a given rate of P application the recovery of P increased with increasing K levels. Chiang and Yang (1969) and Trolldenier (1977) have shown that increasing K application favored oxidation of the rhizosphere, a condition conducive for P immobilization resulting in lower P recovery. Tadano and Tanaka (1970) observed that this influence of K application is appreciable in soils low in K. However, K is not limiting in this soil (Alva and Bille 1980; Nielsen et al. 1979). Accordingly oxidation potential would not have been affected by K application. The reason for the observed increased recovery of P upon K application is not clear, but may be explained in the light of the cation-anion balance concept (Cunningham 1964).

5.3 Comparison between L- and E-values

The E-value, the widely adapted notation (introduced by Russel et al. 1954) for isotopically exchangeable P, is the amount of P on the surface of the soil and in soil solution that is exchangeable with the orthophosphate ion added in solution (Fried 1964). The L-values measured in this experiment were between 35-125 μg P/g soil, or 1.1-4.0 μmol P/g soil. These values are close to those reported by Larsen (1969) for different paddy soils. That study showed that isotopic equilibrium was attained by 24 days (measurements were terminated after 50 days). In the present study the fluctuations in L-values were slight up to 50 days after transplanting, indicating that the crop has no appreciable influence on labile P during the first 50 days.

The E-values in this study are considerably higher than those reported by Larsen (1967) for several paddy soils under anaerobic conditions. E-values were estimated 150 days after flooding in this study as compared to a 5 days period for Larsen (1967), which may account for the above discrepancy. This would imply that no value of E obtained at one single time can be regarded as a parameter of the exchangeable P in soils (Russell et al. 1957). Therefore, further investigations are necessary with more frequent measurement of E-values during the growing period so that the integrated effect of flooding and rice cropping on the pool of labile P can be studied. This would also allow a better comparison between L- and E-values.

E-values were considerably higher than L-values at plant maturity stage (Table 3). Russel et al. (1957) regarded E- and L-values as alternative measures for the labile pool of P in the soil. However, they also pointed to the possibility that significant differences may exist between these two measures, depending on soil characteristics. Added P can migrate between sites which have different characteristics. Some soils contain a large number of sites which have sufficient affinity for labile P ions to prevent its absorption by plants. That L-values were lower than E-values indicates that certain P fractions were retained in a form inaccessible to plants although they remained readily exchangeable. According to Russel et al. (1957) the relative magnitude of L- and E-values may change with time because of slow migration of labile P between sites with different characteristics.

Another possibility is that ^{32}P is 'sandwiched' by adsorption of $^{32}PO_4$ followed by dissolution and reprecipitation of $^{31}PO_4$ on top of $^{32}PO_4$. This may happen when a reduced soil is oxidized during the E-value determination. Therefore, it would be useful to determine E-values while keeping the soil anaerobic (using N_2 gas) and varying the period of shaking.

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A SIMPLE, LOW-COST METHOD TO COLLECT UNDISTURBED CORES OF ACID SULFATE SOIL PROFILES FOR THE STUDY OF WATER AND SOLUTE MOVEMENT DURING RECLAMATION AND USE FOR WETLAND RICE

Le Ngoc Sen
The International Rice Research Institute
Los Baños, Philippines

1 Summary

A simple, low-cost method was developed to collect, transport and instrument undisturbed soil profile cores. This method was used to test different combinations of measures to reclaim acid sulfate soils for wetland rice. The cores are large enough to accommodate several rice hills until maturity. Oil drums of 60 cm inside diameter and 90 cm length were used as lysimeter cylinders. Their surfaces were coated with epoxy paint to prevent contamination of the soil material. These cylinders were inserted into the undisturbed soil by pressure aided by excavation and trimming around the cutting edge. Soil profiles to 0.85 cm depth were thus obtained. The filled cylinders were brought to the experiment station after sealing their bottoms. Perforated PVC drainage pipes, capacitive soil moisture probes and soil moisture sampling filters were installed at different depths to drain water from the profiles, to measure the changes in soil moisture content during the oxidation process and to monitor the composition of soil solutions during reclamation and crop growth.
The present paper only describes the design of the lysimeter drums and the methods of collection and instrumentation.

2 Introduction

Research on acid sulfate soils has largely been of two main types:

fundamental laboratory experiments on individual, disturbed soil samples the results from which are not directly transferable to field conditions and reclamation trials in the field that generally do not allow for sufficient measurements to determine the rate and extent to which the different processes influence soil conditions and crop growth.

Undisturbed soil cores of large size are desirable for the study of the dynamics of soil physical and chemical changes in a closely controlled system that is similar to the field situation. Techniques to obtain undisturbed soil cores have been reported by different workers (Bannink et al. 1977, Black and Raines 1978, Craswell 1979, Mielke 1973 and Watson and Lees 1975). These methods are used to collect either small samples or large samples mostly for physical studies, but are not suited for the study of water and solute movement without contamination in a system with several growing plants. To answer the purpose a lysimeter drum was developed that met the dimensional requirements and limitations of the specific studies and prevailing field situations.

3 The lysimeter drum

3.1 Design requirements and construction

The design specifications for a lysimeter containing an undisturbed soil profile should satisfy the following requirements:

a) The lysimeter drum should be of a size and weight that allows collection of a representative soil profile core in swampy areas.

b) Samples should be large enough to accommodate several rice hills until maturity to minimize boundary effects and to average out the effects of macrostructural heterogeneities in the rhizosphere on the growth of the rice.

c) The gross weight of the soil profile core should be small enough to facilitate transport to the experiment station.

d) The materials used should be resistant to corrosion and should not contaminate the soil profile core.

Available oil drums were used to construct the lysimeters. Each has an inside diameter of 60 cm and a length of 90 cm (Figure 1). Both ends of the drum were cut out by hammer and cold chisel. The rolled edges of the drum were retained. The reinforcement ribs around the drum wall were filled with two-component plastic putty to straighten the inside wall. Holes were drilled in the drum in different positions along its length for later insertion of perforated PVC drainage pipes, soil-moisture sampling filters and capacitive soil moisture probes (Figure 1). These are used to drain the water from the profiles to monitor solute concentrations and to measure changes in soil moisture content with time along the soil profile. The holes were sealed temporarily by epoxy-painted pieces of sheet metal glued on with two-component epoxy blue. Galvanized iron covers were fabricated for bolting to the bottoms of the drums after collecting the profile cores (Figure 1). The drums and covers were painted with epoxy paint to prevent rust and contamination of the soil.

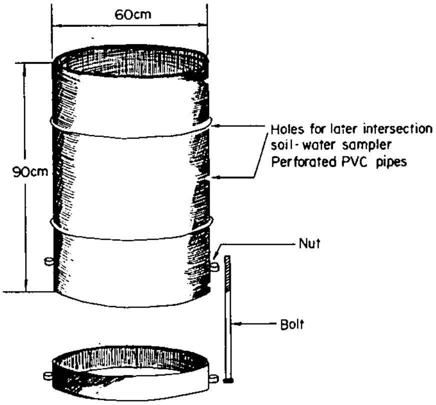

Figure 1. Diagram of a lysimeter

3.2 Collection of soil profile cores

The procedure used in obtaining the samples was to press the drum into the soil in depth increments of 5 to 10 cm by means of a wooden bar placed on top and six to ten persons stepping on it (Figure 2A). Before each incremental insertion of the drum the soil was trimmed from around the drum to a depth of 5 to 10 cm below the bottom of the cutting edge, so that only a small amount of soil had to be pared away by the cutting edge when the drum was pressed into the soil. The process was continued to the desired depth. The soil below the cutting edge was then cut in a cone shape to prevent fracture of the core while it was dragged out of the profile pit (Figure 2B). One side of the profile pit was cut to a 45° slope. The filled drum was tied with rope, turned 45 degrees (Figure 2C), laid into a wooden pallet and dragged up to the ground surface along the sloping side of the pit. The excess soil material at the bottom was trimmed level with the cutting edge. A galvanized iron cover was then bolted on to close the bottom of the drum (Figure 2D).

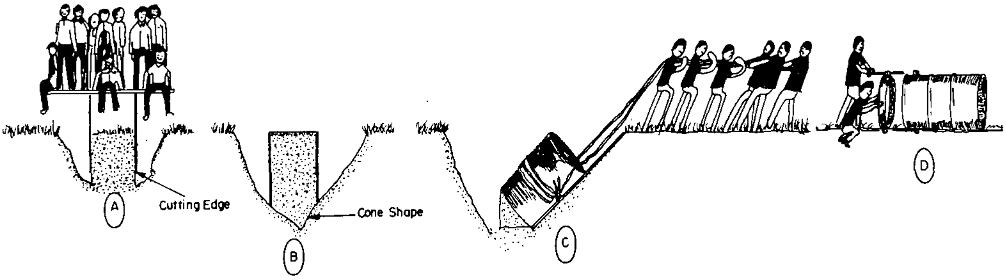

Figure 2. Scheme of field operating procedure to take undisturbed soil cores

If more than one core was to be collected the drums were placed in a row to save digging effort. Experience has shown that ten men can complete collection of 5 cores per day.

3.3 Installation and instrumentation of lysimeters

The joint between bottom cover and drum was sealed with two-component plastic putty. A perforated PVC drainage pipe of 2 cm outside diameter wrapped with nylon mesh (mosquito screen) was installed from the side of the drum at a depth depending on the treatment.

Soil moisture sampling filters, consisting of a Whatman filter tube wrapped with micropore material, were connected with glass tubes and supported by a plastic pipe with the same outside diameter as the available filters (Figure 3). These filter assemblies were installed horizontally at different depths along the profile.

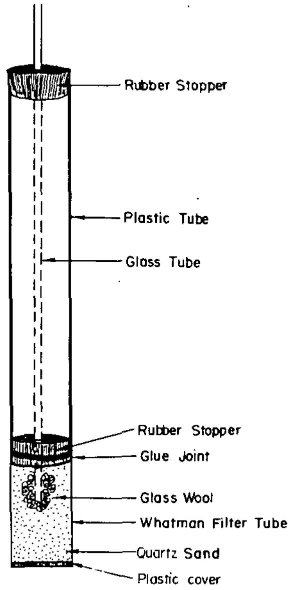

Figure 3. Soil-water sampler components

Before installing the filter assemblies, a narrow tube was bored out with a soil auger made of plastic to prevent contamination. After installing the assemblies, the joints of the plastic pipes with the lysimeter drum were sealed with two-component epoxy glue. The capacitive soil moisture probes will be installed in the same way from the opposite site of the drums. A fiberglass blanket was wrapped around the lysimeter drums to minimize horizontal heat transfer resulting from direct sunshine on one side of the drums (Figure 4). A vacuum pump is used to draw soil solution from the sampling filters into collecting tubes (Figure 5).

Figure 4. Lysimeter cylinders wrapped with fiber-glass blankets, first rice crop near maturity

Figure 5. Lysimeter cylinder with vacuum pump and collecting tubes attached to the soil moisture sampling filters

4 Performance and results

Experiments with lysimeter drums collected and instrumented by this method can provide information on several aspects important for the reclamation of acid sulfate soils, including leaching requirements, oxidation-reduction processes in the soil profile, and acidity build-up during the oxidation period.

The cost of this lysimeter is about US $ 60: one third of the cost of fiberglass or PVC pipes of the same size. Forty-eight undisturbed soil profile cores, 80 to 85 cm long, were obtained from different places in the Philippines. These are being used to study the effects of different combinations of water management and agronomic reclamation measures on the physical and chemical changes in two acid sulfate soils: a Sulfaquept and a Sulfaquent from the Philippines. Results will be reported in a later paper. Initial observations indicate that water movement slows down after leaching the cores for one month, probably due to clay sealing off the moisture sampling filters and drainage pipes.

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APPENDIX I
ORGANIZING COMMITTEE AND LIST OF PARTICIPANTS OF THE SECOND INTERNATIONAL SYMPOSIUM ON ACID SULPHATE SOILS
BANGKOK, THAILAND, 18-24 JANUARY 1981

Organizing Committee

- Chairman

  L.J. Pons

  Department of Soil Science and Geology, Agricultural University,
  Wageningen, The Netherlands

- Vice Chairman

  B. Gopinathan

  Soil Science Branch, Malaysian Agricultural Research and Development
  Institute, Serdang, Selangor, Malaysia

- Secretary

  Samarn Panichapong

  Soil Survey Division, Department of Land Development, Bangkhen,
  Bangkok 9, Thailand

List of Participants

CANADA

P.J. Rennie

FRANCE

C. Marius

GERMANY

N. Atanasiu

D. Goetz

INDONESIA

A. Baihaki
S. Djaka Sutami
A.L.J. van den Eelaart
D.L. Gallup
H. Martaperdana
H. Subagjo
M. Sudjadi
S. Sugeng
H. Suhardjo

MALAYSIA

X. Arulandoo
M. Zahari Bin Abu Baker
T.K. Cheong
N. Daud
C.K. Hew
S.P. Kam
L.A. Lam
M. Mohid
S.K. Ng
V.E.B. Ng
Y.M. Nor
Y.C. Poon
M. Bin Sabtu
I.K. Tan
C.C. Ting
P.Y. Toh

THE NETHERLANDS

J.P. Andriesse
N. van Breemen
H. Dost
T. van Mensvoort
L.J. Pons

THE PHILIPPINES

T. Apua
R. Brinkman
F.N. Ponnamperuma
J. Sarria
Le Ngoc Sen
V.P. Singh

SENEGAL

M. Khouma

SINGAPORE

T.Q. Kai

THAILAND

Khian Aphichonthiwong
Udom Arunakoon
Somsri Arunin
Tasnee Attanandana
Boonyong Bhabharuang
Boonsom Bhamonchant
Chaichan Chalothorn
Chutip Chanaseni
Chaleo Changprai
Thamrong Charasaiya
Charoen Charoenchamratcheep
Surapone Charoenpong
Nipun Chawpaka
Pairote Chitnusonthi
Sopon Chomchan
Adul Chotimon
Vanida Chutatis
Veerote Daorerk
Watchara Sin-Eim
E.D. Hansen
Pramote Hemsrichart
G. Hendricks

THAILAND (continued)

Kriengsak Hongto
Sant Imsmuth
Dasit Jittanoonta
Aroon Jugsujinda
Sirichai Kitarak
Nujanart Kungpisdan
Bamrung Manoch
Chakrit Manotham
P. Michael
Lek Moncharoen
Surachai Muensanek
N. Muileboom
Chalinee Niamskul
S.E. Oleson
Manu Omakupt
J.F. Osborne
Poonsak Paichayon
Samarn Panichapong
Supamard Panichsakpatana
Poonya Paosritongkum
Pongsak Phongprayoon
Sopa Photiwattutam
Somchai Pochanukul
Yinglek Pongpayack
Upatham Potisuwan
Boonyakiat Saengwan
Prapit Sanatong
Sompong Santanakanit
Sunchai Satawathananont
Pramuanpong Sindhusena
Maitri Singhavara
Chamlong Siriphan
La-Or Soonthornchai
Paibul Srisakuna
Boonyarook Suebsiri
Pinit Savanajata

THAILAND (continued)

Lek Suwantada
Seri Tanchanpongs
Boonthong Tanitisira
Vichitr Thanduan
Nakhon Thawornwong
Sopone Thongplaeu
Sorasith Vacharotayan
Taweesak Vearasilp
Rajanee Virabalin
Chumphol Wattanasarn
Pichai Wichaidist
Nuanchavee Yaibuathes
Jumpol Yoovaniyama

UNITED KINGDOM

C. Bloomfield
D. Dent
J.A. Varley

U.S.A.

H. Eswaran
W. Lynn
W.P. Panton
J.E. Witty

VIETNAM

Le Van Can
Nguyen Kim Quang
Vo Tong Xuan

APPENDIX II

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Introduction

Cette publication contient les documents essentiels présentés au deuxième symposium international sur sols sulfatés acides. Le symposium s'est tenu à Bangkok, (Thaïlande) du 18 au 24 de Janvier 1981. Plus de cent vingt participants y assistaient, provenant en grande partie des pays du sud-est de l'Asie et en moindre proportion de l'Europe, de l'Amérique du Nord et de l'Afrique Occidentale.

Plusieurs des communications présentées portent sur les problèmes des sols sulfatés acides de l'Afrique Occidentale et c'est dans cette région que le prochain symposium sera organisé dans quelques années.

Ces symposia sont de rares occasions de synthèse de l'information actuelle sur le sujet, et, pour les intéressés, qui n'ont pu assister aux symposia, les compte-rendus sont les seuls moyens pratiques de se tenir informés. Par ailleurs la littérature spécialiste apparait en forme morcelée et peu accessible.

L'expérience, après le premier symposium sur les sols sulfatés acides en 1972, a montré que les compte-rendus sont demandés par une cercle beaucoup plus vaste et nombreux que l'assistance même du symposium ne laissait supposer. A l'exception des pédologues ce cercle inclut surtout les ingénieurs et agronomes interessés dans le bien-être des communautés rurales et le développement des ressources naturelles des plaines côtières et deltas des régions tropicales.

La présente édition qui représente la synthèse au sujet la plus récente, à été produite en vue d'une distribution assez vaste. Pour faciliter sa diffusion chez les intéressés francophones le résumé suivant des actes du symposium de Bangkok à été préparé.

Résolutions générales

1. Les participants au $2^{-è}$ symposium international des sols sulfatés acides (18-21 janvier 1981) remercient chaleureusement le Ministre de l'Agriculture et le Directeur Général du Département de Développement Rural du Royaume de Thaïlande, pour l'accord qu'ils nous ont donné d'organiser le symposium en Thaïlande, et leur réel support aux activités de la Société Internationale de la Science du Sol. Nos

remerciements vont aussi à Monsieur Panichapong et ses collaborateurs, qui ont été infatigables dans leurs efforts pour la réussite du symposium et dont les interventions ont été déterminantes pour son haut niveau professionel et scientifique.

Nous remercions également les Directeurs des Centres Régionaux ainsi que leurs collaborateurs, pour leur hospitalité et leur cooperation efficace.

Nous profitons de l'occasion offerte, pour remercier vivement les collègues malais et tout particulièrement le Directeur de l'Institut Malais de Recherche pour l'Agriculture et le Développement (MARDI) et les autres membres de cet institut, pour l'organisation de l'excursion qui a suivi la conférence, en Malaisie.

2. Nous constatons avec satisfaction:
   - une attention accrue vis-à-vis des problèmes des sols sulfatés acides;
   - l'accroissement de la recherche fondamentale et appliquée ayant comme but le développement agricole de ces sols, surtout dans des pays du sud-est de l'Asie et de l'Afrique occidentale;
   - du progrès dans l'amélioration des sols sulfatés acides par le chaulage, la submersión et le contrôle de la nappe phréatique;
   - le progrès dans le développement des utilisations substituantes des sols sulfatés acides;
   - une contribution à la compréhension des problèmes, à moyen des modèles théoriques et des expériences, et aussi à l'importance des études au champ par rapport à celles de laboratoire, à la fois pour le renforcement de la recherche fondamentale et pour la démonstration en conditions pratiques de nouvelles méthodes d'aménagement.

   Ensuite nous constatons expressément:
   - l'importance d'étudier ces sols, non comme entités isolées mais plutôt comme des composants d'un système intégral et vivant de terre, eau, plantes et l'homme.

     Toute récupération de terrains affecte un grand nombre de facettes connexes du milieu; il faut donc, développer une gamme de méthodes d'aménagement qui ont en vue, non seulement les implications affectant le milieu, mais aussi les conséquences sociales et économiques;

- que des conditions sociales et physiographiques différentes imposent de traitements différents des problèmes de sols sulfatés acides.

3. Pas mal de problèmes persistent. Les discussions du symposium ont montré que les sols sulfatés acides sont toujours des sols difficiles.
   - Certain anciens critères pour l'identification et la mise en valeur des sols sulfatés acides ont été remis en cause. De nouvelles méthodes ont été proposées.
   - Pour la communication professionelle et la transmission de l'expérience et de la technologie entre pays et régions, il nous faut un langage et terminologie unitaire. Dans cet ordre d'idées nous appuyons les efforts de la Société Internationale de la Science du Sol pour développer un Système International de Base de Classification des Sols.
   - Nous avons besoin de critères communs pour l'expérimentation au champ, d'un code de méthodes appropié de caractérisation des sites expérimentaux, permettant que des résultats et de l'expérience obtenus dans un site, soient applicables dans des sites similaires.
   - Il manque des projets de surveillance et d'enrégistrement systématique (monitoring) de longue durée pour diverses pratiques d'aménagement en milieux représentatifs.
   - Il existe toujours un vaste hiatus entre le développement de la technologie propre et son application pratique.
   - Les connaissances sur la physiologie des plantes et tout spécialement sur les racines des végétaux dans les conditions d'extrême acidité, sont assez réduites. Des recherches de base et de nouvelles méthodes doivent être envisagées pour une sélection plus efficace et efficiente des plantes de culture tolérantes à l'acidité et dans le cas précis du riz, de croissance rapide.

4. La diminution continuelle des ressources en terrains cultivables exigera une récupération et mise en valeur accrue des sols sulfatés acides ainsi que des autres terres difficiles ou marginales. Il en résulte un besoin urgent d'information, d'instruction et de technologie dans ce domaine, et en somme un effort concerté de recherches

fondamentales et appliquées est necessaire.

Pour coordonner cet effort nous *recommandons* l'organisation d'un groupe de travail international avec les objectifs suivants:

- Ramasser et évaluer les informations concernant tant les nouveaux systèmes d'aménagement que les traditionnels, une partie de ces derniers n'étant pas intensifs du point de vue capital et ne reclament donc pas, des travaux massifs de génie, d'amélioration et de fertilisation.
- Formuler des méthodes pour l'amélioration des sols sulfatés acides pour des zones agro-écologiques diverses.
- Examiner les propositions pour la classification et la caractérisation des sols.
- Formuler des critères pour la reconnaissance des problèmes posés par les sols sulfatés acides.
- Préparer un guide des méthodes expérimentales et une liste complète pour la caractérisation des sites expérimentaux, dans le *contexte du milieu physique et les aspects économiques et sociaux.*
- Vulgariser les résultats, non seulement par la publication de bulletins, mais aussi par des contacts à divers niveaux, avec des organisations et personnes interessées dans le développement et la mise en valeur des terres.

5. Nous *recommandons* d'organiser le 3$^{-\text{è}}$ symposium dans quatre ans en Afrique occidentale; le groupe de travail devra assister le pays et les organisations accueillantes dans la préparation du symposium; il veillera aussi à obtenir des supports financiers pour la recherche et pour une large participation des spécialistes des pays en voie de développement où sont concentrés les problèmes des sols sulfatés acides ainsi que leur potentiel productif.

6. Pour terminer, nous demandons un effort tout particulier aux gouvernements, aux organisations internationales et nationales de développement agricole, et aux institutions privées, pour soutenir ce programme de stimulation et de coordination de la recherche. Nous espérons ainsi surmonter les derniers problèmes des sols sulfatés acides et de leur milieu et ainsi pouvoir utiliser leur potentiel productif qui est très souvent sous-estimé.

Conclusions et Recommandations Techniques

Recommandations pour la recherche fondamentale

1. Une classification des mécanismes physiologiques de la tolérance pour de hautes téneurs en Fe^{2+} dans la solution du sol, s'avère nécessaire.

2. Il faut développer des méthodes de triage et de sélection de variétés tolérantes aux Fe et Al, qui sont à la fois simples et rapides et à grande échelle.

3. Il y a un besoin urgent d'une publication, sous forme facilement accessible et compréhensible, traitant des aspects physico-chimiques et biologiques de l'oxydation de la pyrite et des processus de migration des acides dans le sol et en dehors, par l'eau de drainage et de surface.

4. L'étude des principaux facteurs déterminant le taux du processus de réduction après submersion et le taux de l'augmentation du pH jusqu'au-dessus des niveaux où la toxicité de Fe et Al peut apparaître, est particulièrement intéressante.

5. Pour la prédiction du taux de progression des procédés de récupération des sols sulfatés acides et des processus du sol qui en découlent, il est nécessaire de développer des modèles théoriques. Ces modèles doivent être composés des sous-modèles commensurables.
   Un exemple de sous-modèle très important est celui de la description des vides (pores) des sols sulfatés acides, de leur développement d'année en année et de leur fluctuation saisonnière.
   Un autre sous-modèle, concerne la relation entre le mouvement de l'eau à la surface du sol (eau d'irrigation, eau de pluie ou eau acide de surface) ainsi que dans le sol et le transport interne et l'évacuation des acides ainsi que l'intensité de la réduction.

6. Une importance croissante on doit accorder à la connaissance des variations régionales et zonales des éléments constitutifs des matériaux originels des sols sulfatés acides, tels la teneur en pyrite,

en Fe, Mg, Ca, K, et minéraux argileux, ainsi que à leur influence déterminante sur les réactions des sols vis-à-vis la récupération et la mise en valeur.

Recommandations pour les recherches appliquées

1. Il est évident que l'accent de la recherche doit être mis sur des aménagements à bas-coût d'investissement. Elle doit se référer surtout aux problèmes de l'accessibilité de l'eau, de l'amélioration des sols et de leur fertilisation. La recherche pratiquée doit surtout avoir en vue la riziculture.
   Cependant l'étude de la pisciculture et de l'arboriculture est aussi nécessaire.
   Dans ce domaine, des résultats remarquables ont été obtenus par la pisciculture dans les mangroves; de même, par la plantation des arbres comme le casuarina, l'éucalyptus, le citronnier, le manguier et le bananier dans les régions à climat de mousson; le palmier à huile et le cacaoyer dans les régions à humidité permanente; le cocotier, dans les deux régions.
   Des recherches futures dans ce domaine doivent être stimulées, ainsi que l'identification dans les différents pays des groupes de recherche à but et intérêt commun, qui pourront être incités à la coopération et à l'éxchange d'expériences. Les organisations internationales pour le développement agricole, doivent coopérer à l'aboutisement de cette tâche.

2. Recommandations en vue de la riziculture.
   - L'accent des recherches doit être mis sur la création d'un système d'aménagement du sol et de maîtrise des nappes phréatiques que, d'une part retient l'oxydation de la pyrite autant que possible et, d'autre part permet le prompt lessivage des substances acides inévitablement libérées. Cette formule compte pour tous les aménagements quelle que soit leur échelle.
     Les recherches doivent être envisagées dans le cadre d'un programme établi pour au moins trois ans consécutîfs et dont les observations de base incluent un relèvement de la situation initiale et

l'enrégistrement systématique (monitoring) de la performance des plantes et de la cynétique de la composition du sol et de l'eau en fonction des saisons et du régime d'eau. Pour faciliter la comparaison des résultats, des méthodes standard pour les analyses, évaluations et descriptions doivent être élaborées.
Une attention toute particulière doit être accordée à l'eau de surface acide et son effet sur le milieu.

- L'application du chaulage à doses relativement basses (quelques t/ha) a donné des résultats prometteurs en Thaïlande mais par contre, extrémement médiocres au Vietnam. La cause de ces résultats différents doit être recherchée.
  De même, les études sur l'application des engrais doivent être concentrées sur l'obtention d'un rendement maximum de l'utilisation du phosphore, spécialement sous forme de roches phosphatées. Quoique dans la plupart des sols sulfatés acides, l'azote se trouve en quantité limitée, son application une fois faite, ne pose pas de problèmes.
- Un autre domaine de recherche intéressant, concerne l'influence du labour sur le lessivage, étant entendu que le labourage des sols secs plutôt que humides, serait propice au lessivage.
- Des méthodes de cultures de courte durée, comme celles du soja, melon d'eau, maïs, sorgho, sésame, alternant avec le riz, et impliquant un soin adéquat du sol des rizières, doivent être developpées pour une utilisation optimale des sols sulfatés acides.

3. Sélection des variétés.

L'introduction à large échelle de cultures à courte période de végétation avec une tolérance élevée à l'acidité et salinité est une nécessité immédiate.
Un effort tout particulier devra être fait pour comparer les différentes variétés traditionelles de riz bien adaptées aux conditions d'acidité sulfatique dans de pays divers.

Les Orientations pour les Recherches Futures sur les Sols Sulfatés Acides

R. Brinkman
Institut International de la Recherche du Riz
Los Baños, Philippines

Avant de se poser la question de savoir quelles sont les recherches à entreprendre sur les sols sulfatés acides, il est nécessaire de définir le problème ou les problèmes qui doivent être résolus par ces recherches.

Les problèmes des sols sulfatés acides comprennent deux aspects principaux:

- la formation rapide, en une seule fois ou de manière répétée, d'acide dépassant la capacité-tampon du sol (faisant suite à l'oxydation de la pyrite) jusqu'à devenir toxique pour la croissance des plantes, ou des poissons;
- le taux bas ou le prix élevé de l'élimination ou de la neutralisation temporaire ou pérmanente de l'acidité.

Des problèmes secondaires, mais plus persistants, sont l'acidité potentielle résiduelle et la forte fixation du phosphore dans la partie supérieure du sol et dans le sous-sol de nombreux sols sulfatés acides récupérés. Ces problèmes imposent des pratiques de contrôle d'eau et de traitement de sol adéquates.

Une attention spéciale doit être portée sur les effets de la récupération de grandes surfaces de sols sulfatés acides sur le milieu. Il faut bien considérer que le défrichement et la mise en valeur de ces sols impliquent des changements dans la végétation et dans le régime d'eau et que la libération de quantités d'acides peuvent affecter non seulement la terre en place mais aussi le terrain et l'eau en aval (y compris les eaux côtières et la mer), sans compter la vie des plantes, des animaux locaux et de l'aval, ainsi que de la population qui vit dans cette même région ou à proximité.

Des recherches fondamentales, aussi bien que des recherches appliquées sont nécessaires pour la mise en valeur des sols sulfatés acides. Elles seront traitées dans l'ordre suivant.

1 Nature et propriétés des sédiments

Des recherches fondamentales sont encore nécessaires pour comprendre l'ampleur des problèmes posés par les sols sulfatés acides. Quoiqu' il y ait un modèle général géogénétique de la formation de pyrite dans les sédiments, il reste à le soumettre à l'épreuve.
Des méthodes de terrain, facilement utilisables pour caractériser les sédiments à pyrites ne sont pas encore généralement appropriées.
La quantité totale de l'acidité potentielle en excès par rapport à la capacité de neutralisation du sol, n'est probablement pas aussi importante qu'on le supposait auparavant. Pourtant, les sols sans excès d'acidité potentielle et ceux avec une acidité potentielle excessive apparaissent généralement en association et il faut des méthodes de prélèvement adéquates pour les séparer et les caractériser de manière distincte. Cela sera d'autant plus aisé que la nature des sédiments et les processus de sédimentation seront bien mis en evidence et clairement décrits pour chaque estuaire et aussi quand les rapports entre les conditions de sédimentation, les types de végétation et l'accumulation de la pyrite, seront établis. Cependant il faut continuer avec les méthodes disponibles en les améliorant à mesure qu'avancent les recherches fondamentales.

1.1 *Caractéristiques stables, constantes à l'intérieur d'une région*

Certaines propriétés des sédiments influençant la nature et l'orientation des processus d'oxydation et de neutralisation (telles que la teneur en fer et en manganèse, la minéralogie des argiles et la capacité d'échange cationique de l'argile) ont tendance à varier d'un estuaire à l'autre, mais sont pratiquement constantes à l'intérieur d'un même estuaire. La description de ces propriétés constitue une base de comparaison pour les résultats des méthodes expérimentales de récupération de différentes régions. Par exemple, les sols sulfatés acides provenant de sédiments kaolinitiques avec une faible CEC et une très basse teneur en Ca échangeable repondent au chaulage d'une manière différente que ceux dérivés de sédiments smectitiques à bas pourcentage de Ca mais possédant une teneur absolue de Ca échangeable adéquate.

1.2 *Caractéristiques variant avec le temps, la profondeur et le site*

Les teneurs en pyrite et en matière organique varient avec la profondeur dans le même type de sol ainsi que sur courte distance dans le même paysage particulièrement près des marigots avec des levées naturelles.
Ces teneurs varient aussi, rapidement en fonction du temps après le drainage, mais à des taux décroissant vers le sous-sol.
La distribution des horizons ou couches sulfidiques à différentes profondeurs dans les diverses formes du paysage, est probablement l'information la plus importante qu'une cartographie détaillée doit faire ressortir. Ces données sont appuyées par des caractéristiques associées, telles que la teneur en argile et la consistance du sol, ainsi que des détails sur la couleur et les taches.
Il semble que nous nous sommes approchés d'une définition des critères propres à l'identification au champ des sols sulfatés acides actuels et potentiels, mais néanmoins il serait encore très utile que des pédologues travaillant dans differentes régions se réunissent pour discuter et comparer les critères approuvées dans leurs domaines d'expérience. Il est probable, qu'en dépit de la grande variation des critères distinctifs signalée par la littérature, ce problème de relèvement peutêtre simplifié par une évaluation systématique des connaissances qui sont actuellement dispersées.

2 Processus d'oxydation, de réduction et de transport

2.1 *Oxydation*

Les processus physico-chimiques et biologiques de l'oxydation de la pyrite, ainsi que les aspects qualitatifs des processus de transport des produits acides dans le sol et de là vers les eaux de drainage et les eaux superficielles, sont assez bien connus par un cercle de pédologues toujours très restreint.
Cependant aucun ouvrage sous forme facilement compréhensible et

accessible n'a été publié jusqu' à présent.

2.2 *Réduction*

Quels sont les facteurs qui influencent la progression des processus de reduction résultant de l'inondation? Par exemple le taux de production du fer ou des sulfures? Un modèle quantitatif ou semi-quantitatif est nécessaire pour prédire ou expliquer les grandes différences entre les sols quant à la train et à l'allure des développement vers des niveaux de pH et des teneurs en Al inoffensives. Il doit aussi expliquer l'apparition éphémère de la toxicité en Fe et S ou l'absence de l'un ou de l'autre, durant le processus de réduction. Probablement les paramètres du modèle, doivent être estimés d'une manière pragmatique parce-que les informations sur les taux des réactions biologiques sont limitées. Le modèle lui-même, doit être fermement enraciné sur une base physico-chimique déjà connue.

2.3 *Un modèle intégral*

Les données ainsi obtenues sur l'oxydation et la réduction doivent être intégrées dans un modèle compréhensif qui établit les rapports entre, d'une part le mouvement de l'eau dans le sol et à la surface du sol (par irrigation ou inondation naturelle), d'autre part le transport et l'élimination des acides ainsi que les taux de réduction. Un tel modèle intégral devrait aider à estimer quantitativement les conséquences de l'intervention de récupération pour le développement des sols mêmes ainsi que pour l'évacuation des acides, qui est une des conséquences à longue portée souvent sous-estimées. L'état chimique de l'eau d'irrigation ou d'inondation, doit être pris en considération si ces eaux contiennent plus que des traces de bicarbonates, d'acides ou de sels.

2.4 *Vides des sols et mouvements de l'eau*

Un sub-modèle du modèle intégral, inclut les relations des vides observables dans le sol (tant des permanents que des temporaires) avec le mouvement de l'eau à la surface et à l'intérieur du sol. Cela nécessite une description simple des systèmes de vides, comprenant: a) leur distribution dans un temps donné; b) les changements progressifs dans la forme des systèmes de vides dans les années suivant l'intervention récupérante; c) la fluctuation saisonnière des vides et tout particulièrement la fluctuation des craquelures. On peut dire qu'actuellement seul le premier aspect est étudié convenablement. Pour qu'un tel système descriptif soit cohérent et possède une valeur de prévision, des études sur les facteurs influençant la stabilité physique des vides dans les sols acides argileux sont nécessaires.

3 Des études de tolérance

Les sols sulfatés acides supportent mieux certaines cultures que d'autres. Il y a de grandes différences entre les espèces et les variétés de plantes (le riz par exemple) pour ce qui concerne leur tolérance à l'acidité, à la haute teneur en Al ou Fe, à la faible teneur en phosphore assimilable. Ces différences doivent être mises à profit par le moyen du tri et de la sélection des plantes, appuyés sur des recherches soutenues concernant la physiologie de la tolérance de ces plantes.

3.1 Méthodes rapides de tri et de sélection

Des méthodes rapides, valables et peu couteuses dans le tri et la sélection sont nécessaires pour obtenir des lignes ou populations de plantes à haut niveau de tolérance.

Une méthode suggérée par Gunawardena de l'IRRI pour la sélection de la tolérance à la salinité combine deux techniques éxistantes. L'une est un essai gradué, par exemple l'utilisation d'une toposequence avec une gradation des facteurs limitatifs: dans ce cas une profondeur de plus en plus faible de la couche d'acidité extrême.

L'autre, utilise une population à mâles stériles, à ségrégation continue. Cette population est semée ou transplantée en larges bandes étendues sur toute la séquence graduée. La survivance décroit vers le coté d'extrêmes conditions et seules les plantes produisant des semences dans les conditions les plus sévères, sont récoltées pour continuer la sélection la saison suivante. Cette sélection jusqu' à la limite de la survivance et de la production est en faveur des plantes individuelles les plus tolérantes. La détermination d'un rapport entre la tolérance et les caractères morphologiques des plantes - par exemple l'allure de la croissance initiale de racines - aiderait à rendre la sélection plus rapide et plus simple.

3.2 Poissons

Une sélection analogue des espèces des poissons pour la tolérance à l'acidité et aux toxines élargirait les possibilités de production et diminuerait les frais d'installation pour la pisciculture dans les zones de sols sulfatés acides.

4 Expériences agronomiques

4.1 Culture du riz submergée; application rèduite de chaux

Les expériences sur la culture du riz submergée en sols sulfatés acides, doivent mettre en comparaison d'une part le drainage superficiel suivi de la présubmersion avec du chaulage variant depuis des doses très faibles (par ex. 100 ou 200 kg/ha) jusqu' à des quantités habituellement considérées nécessaires, d'autre part des méthodes d'amélioration plus élaborées. L'objectif expérimental doit aussi comprendre une large gamme d'application du phosphore, tant comme phosphate soluble dans l'eau (disséminé et incorporé dans le sol avant le repiquage, ou appliqué localement après le repiquage) que sous forme de phosphates naturels à bas-prix (pulvérisés, disséminés et incorporés dans le sol).
L'effet du chaulage dans la riziculture en sols sulfatés acides se présente de trois manières: Dans les sols à basse CEC et teneur extrêmement basse en Ca échangeable et autres bases, un effet nutritif se fera sentir probablement à très faibles doses de carbonate de chaux. Dans les sols à haute CEC, à concentration totale très élevée en acides et réaction extrêmement acide, des quantités de quelques tonnes par ha sont

nécessaires pour la répression du niveau toxique de l'Al pendant les premières étapes de croissance du riz, particulièrement dans les sols à faible teneur en matière organique et en fer libre.
Dans tout sol sulfaté acide, à l'état humide et à teneurs en fer libre et matière organique assez modérées, de petites quantités de chaux - finement émiettée - appliquées à la surface du sol et non incorporées, peuvent déclencher la réduction par une amélioration locale des conditions pour l'activité microbiologique. A partir de tels micro-sites la réduction peut se répandre dans la masse du sol aussi loin que la matière organique facilement réductrice est présente. Dans les cas où ce dernier processus est le résultat principal du chaulage on ne peut pas espérer encore un effet résiduel. Toutefois, les doses nécessaires sont tellement faibles que l'apport annuel chaque début de saison humide est bien rémunérateur.

4.2 Cultures de terrains drainés; drainage minimal vis-à-vis drainage maximal

Dans le cas des cultures de terrains drainés, l'effet réducteur n'est pas applicable. Pour ces cultures, les acides libres doivent être éliminés ou neutralisés. Pour cela, en principe il y a deux façons: la méthode du drainage minimal et la méthode du drainage maximal. La dernière est plus efficace dans les régions avec une saison sèche prononcée alternant avec une période de bonne disponibilité d'eau soit pluviale, soit d'irrigation. De bonnes terres, aptes à des cultures diverses, peuvent en résulter pourvu que le matériau d'origine sulfidique soit pourvu dès le début d'un système tubulaire de macropores stables. Sinon, l'oxydation ne progresse pas assez rapidement en profondeur pour rendre possible une elimination des acides par lessivage jusqu' à la profondeur desirée (de 0,5 à 1 m). La méthode du drainage minimal (adéquate pour un climat à courte période de sécheresse) amène toujours le risque d'ascension capillaire dans la zone racinaire des acides formés par oxydation, surtout durant la saison sèche ou pendant une période de penurie d'eau d'irrigation. Les dégâts qui en résultent peuvent être considérables, spécialement pour les cultures perennes. Dans le cas où l'effet négatif de l'ascencion capillaire des toxines se répète fréquemment, on peut considérer un drainage plus profond. Pourtant une telle mesure est seulement praticable avant la substitution de l'ancienne plantation, parce que l'effet initial de l'approfondissement du niveau de drainage est le déclenchement temporaire d'acides et toxines dont la capacité nocive surpasse le dégat produit par l'ascension capillaire périodique, qu'on a voulu remédier.

4.3 *Aménagement des sols sulfatés acides et salés pour les cultures*

Dans le cas d'aménagement des sols sulfatés acides et salés pour l'agriculture, il sera utile de comparer la méthode conventionnelle de lessivage des sels par l'eau douce avec une autre méthode, notamment: l'assèchement préliminaire et l'oxydation du sol salé jusqu' à une profondeur de 0,5 m à 1 m, suivis par un ajustement du niveau du drainage par des barrages ou des fermetures à clapets placées à des profondeurs appropriés. De cette manière, on fait une utilisation maximale des sels présents dans le sol pour éliminer les acides. L'acidité restante est immobilisée dans les horizons inférieurs. Là où il y a de l'eau salée ou saumâtre, elle peut être utilisée pour le premier lessivage après oxydation, l'efficacité du déplacement des acides étant augmentée par les sels dissous.

De telles expériences devraient précéder l'utilisation des sols pour le riz submergé ou les cultures sèches et pourraient conduire à des conditions similaires, ou peut-être plus favorables à la croissance des plantes que celles décrits précédemment pour les sols sulfatés acides non-salés, compte tenu évidemment de la disponibilité d'eau douce pendant toute l'année.

4.4 *Etangs à poissons*

Dans le cas des étangs à poissons sur sols sulfatés acides, il faut des expériences pour déterminer la taille optimum des alevins, les doses et la fréquence de l'application des engrais phosphatés et les cultures les plus économiques comme plantes de couverture sur les digues.

4.5 *Enrégistrement des caractéristiques de sites expérimentals*

Partout où il y a eu des expériences sur les sols sulfatés acides, certaines données concernant le sol lui-même, le climat ou le temps, et le régime de l'eau sont indispensables pour l'interprétation et la présentation des résultats expérimentaux. Le caractère de ces données circonstancielles indispensables est illustré par les exemples suivants:
En ce qui concerne le sol, d'importantes propriétés à connaître sont: l'épaisseur de la couche supérieure non sulfatée acide; le pH; la CEC; la composition des cations; la teneur en matière organique et en fer libre de cette couche et des horizons inférieurs; la perméabilité en milieu saturé pour les horizons de profondeur et la géométrie des macropores; la profondeur de la limite de l'oxydation; les taux estimatifs et les diréctions du mouvement de l'eau durant la période de végétation, à la surface du sol et un peu en dessous de la zone racinaire. En ce qui concerne le régime de l'eau, les données les plus importantes sont: la profondeur du drainage et l'intervalle des drains, les quantités d'eau d'irrigation nécessaires, la distribution des précipitations et de l'évapotranspiration, avant et pendant la période de végétation.

4.6 *Priorité d'expériences sur la culture de riz submergée*

Dans la longue liste de recherches à envisager sur les sols sulfatés acides, la plus importante est probablement la recherche au champ pour la culture submergée du riz, avec différentes méthodes de gestion d'eau et diverses doses de carbonate de chaux (depuis les plus faibles jusqu'à des doses modérées). Cette recherche devra se réaliser dans une gamme de sites dans les régions diverses en condition d'eau douce ainsi que salée.
Les données indispensables sont: la description des sols, les conditions hydrologiques et les détails de l'aménagement dans chaque site. Les résultats devront être publiés de manière cohérente. Par une comparaison systématique on pourrait ainsi arriver à déterminer des méthodes d'amélioration et d'aménagement presque optimales, pour une large gamme de conditions.

Aspects sociaux et économiques de l'amélioration des zones à sols sulfatés acides

R. Brinkman
Institut International de la Recherche du Riz
Los Baños, Philippines

La plupart des participants à ce symposium sont intensivement engagés dans le développement de zones à sols sulfatés acides, dans les aspects techniques, scientifiques ou administratifs de leur utilisation. Il semble donc raisonnable, de commencer notre discussion par les raisons sociales et économiques de notre travail, et les implications possibles de nos recommandations tel qu'elles affectent la population et le milieu physique où ces sols se trouvent. C'est seulement après, que nous nous concentrerons sur les détails scientifiques et techniques du développement.

Les changements d'un écosystème doivent être appréciés avec beaucoup de précautions. D'abord pour prévenir les dégâts sociaux et économiques qu'ils peuvent provoquer aux familles diréctement intéressées, qu'elles soient de la région même, du voisinage, ou d'ailleurs, et ensuite pour prévenir l'appauvrissement irréversible de la diversité de la nature qui contient des ressources connues et inconnues.

Aprés avoir passé en revue la distribution et l'extension des sols sulfatés acides en géneral, je distinguerai les sols des zones à eaux salées de ceux des zones à eaux douces. Le problème principal pour les sols sulfatés acides salés est de décider s'il faut, ou pas, les garder et les protéger dans leur état naturel. Pour les sols sulfatés acides des zones à eau douce, le principal problème social et économique est de créer un plan effectif de développement qui mette à profit au maximum la variabilité des sols et les aptitudes du paysannat en vue d'une amélioration progressive et la rectification des erreurs antérieures.

1 La distribution de la population

Le monde est très peuplé. L'homme vit dans une grande variété d'environnements mais pas partout. Quand la population peut se déplacer librement à l'intérieur d'une certaine région, elle tend à se disséminer de telle manière que la productivité du travail s'égalise entre les différents endroits. La grande différence dans la densité de population d'un endroit à l'autre, reflète, au moins en partie, la possibilité d'acquérir un produit, étant donnés les niveaux de ressources utilisables et de la technologie. Alors, il y a de grandes superficies restées inhabitées parce qu'elles sont inutilisables au stade technologique actuel; à toute superficie vide ou presque vide de population, on trouve une raison écologique: nous citerons comme exemple le manque d'eau dans le désert arabe. La non-utilisation, apparaît donc, faute d'une technologie convenable ou parce que de meilleurs possibilités s'offrent ailleurs. A court terme, il peut y avoir d'autres raisons: historiques, politiques ou d'infrastructure physique. Pourtant à long terme, les raisons sont plutôt l'indisponibilité de technologie appropriée et la disponibilité d'options substituantes économiques. La négligence de ces facteurs dans pas mal de projets de colonisation a provoqué de graves sacrifices et pertes de capital de développement.

2 Présence et extension des sols sulfatés acides

L'extension universelle des sols sulfatés acides est à peu près de 13 millions d'ha, c'est-à-dire environ 1% des terrains cultivés du monde. Si l'extension des sols sulfatés acides est comparée avec l'extension des autres sols marginaux (tab. 1, pag. 23) il est clair que les sols tourbeux, salins ou sodiques par exemple, sont de loin plus répandus et aussi plus persistants. La condition d'acidité sulfatique des sols est un problème de durée limitée et affectant seulement une petite partie de l'ensemble des sols difficiles avec lesquels la population du globe est confrontée. D'autre part plusieurs de ces autres sols difficiles, présentent outre leurs limitations pédologiques inhérentes, des défauts circonstanciels graves et se trouvent très loin des concentrations de populations. Les sols sulfatés acides, au contraire, apparaissent en géneral sous des climats favorables à la production alimentaire (Tab. 2, pag. 23); et souvent à proximité des zones cotières et plaines alluviales à population dense, et leur développement est donc, d'un interêt immédiat.

En comparaison avec les sols sulfatés acides, la surface des sols tourbeux est plus grande (fig. 1, pag. 24). Parfois, de grandes superficies de tourbes non-utilisables sont entourées de sols sulfatés acides servant de zone de transition vers des terres de meilleure qualité. Dans le sens géographique, les sols sulfatés acides sont donc considérés comme marginaux. Pour l'amélioration des grandes superficies centrales des tourbes, il n'existe pas encore de recettes valables du point de vue économique et technique. Pour la récupération de certains sols acides sulfatés, des méthodes pratiques sont déja connues, pour d'autres, pas encore. Nos efforts pour développer ces derniers sols acides sulfatés risquent toujours l'insuccès total ou partiel. Aussi, dans ce sens, nous travaillons en marge des possibilités techniques et économiques.

3 Raisons de développement

Il est dommage que les décisions sur le développement des terres sulfatés acides et sur l'orientation de leur récupération fassent souvent défaut compte tenu des propriétes physico-chimiques de ces sols. De telles décisions peuvent être influencées par les problèmes démographiques ou d'emploi dans l'environnement proche ou lointain, ou encore par la demande pour de nouvelles terres pour la production commerciale. Les vastes zones à sols sulfatés acides de la plaine côtière du nordest de l'Amérique du Sud (fig. 2, pag. 26) sont situées généralement entre une bande littorale à terres productives et les terres hautes de l'intérieur. Au Guyana elles se sont développées en réservoirs d'eau d'irrigation pour les cultures de canne à sucre et de riz au bord de la mer. Cet emploi extensif, sans aucun besoin d'amélioration des sols, a été possible, grâce à la relative abondance de terrains par rapport à la population. Une situation similaire apparaît aussi ailleurs en Amérique du Sud. En Afrique occidentale les sols sulfatés acides (fig. 2, pag. 26) sont soumis à une pression plus grande. Le plus grand nombre d'habitants rapporté aux ressources en terrains cultivables se trouve dans le sud et le sud-est de l'Asie, où de grandes superficies de sols sulfatés acides ont été récupérées par la population, souvent sans assistance scientifique. C'est surtout dans la plaine centrale de Thaïlande, en Indonésie et au Vietnam que la pression démographique impose d'urgents besoins de développements des terres basses. Ce sont justement ces pressions et nécessités qui sont à la base de la décision d'organiser le $2^{-è}$ symposium International des Sols Sulfatés Acides en Thaïlande.

4 Modes d'utilisation et leurs implications socio-économiques

Une grande variété d'utilisations des sols sulfatés acides est possible:

- Pour tous les types de sols sulfatés acides, y compris les superficies adjacentes des tourbes: réserve de la nature, réservoirs d'eau à bas-niveau, en vue de l'irrigation et la protection hydrologique.
- Pour les superficies intérieures à eau douce: culture submergée du riz, culture de cautchouc, de palmier à huile, de l'ananas.
- Dans les zones de marées, à végétation de mangrove ou de palmiers: production de biomasse en vue d'énergie, production de bois, et d'écorce.
- Dans les zones côtières salinisées: étangs de pisciculture à eau saumâtre, salines dans les climats à saison sèche prononcée.
- Pour les rivages à eau salée: viviers de poissons, coquillages, crustacés etc. Ceci nous reporte à la première utilisation indiquée: la protection des écosystèmes naturels.

Ainsi deux catégories de sols sulfatés acides peuveut être distinguées, chacune ayant un développement propre, avec différentes implications socio-économiques: celles des zones à eau donce et celles des zones à eau salée.

4.1 Zones à eau salée

L'aménagement socio-économiques des zones à eau salée, est compliqué par l'embarras du choix des modes d'utilisation. Chacune d'elles paraît practiquable dans une superficie limitée, mais a des implications écologiques dans un environnement étendu, surtout en affectant l'eau de marée et l'utilisation des pêcheries jusqu'à la mer. Ces possibilités et conséquences doivent être prises en considération en décidant de la mise en valeur.

L'écosystème naturel de la mangrove dont une partie est localisée sur des sols potentiellement sulfatés acides, est bien noté comme le plus diversifié et le plus productif du monde, bien qu'il soit encore incomplètement étudié.

Aux Philippines (Gonzales 1978) des poissons de plus de 40 familles ont été identifiés pour les zones à mangroves, ainsi que beaucoup d'espèces de crevettes, crabes et huitres. On y pêche des alevins et des couvains de crevettes pour la pisciculture. La mangrove paraît être le vivier et le début de la chaîne alimentaire pour une large partie de la vie marine; la disparition du bord de mangrove d'un littoral peut affecter la pêche maritime de manière sérieuse et même désastreuse. Les palétuviers et les palmiers sont eux mêmes des ressources de plusieurs produits: aux Philippines par exemple: matière première pour la fabrication de fibres textiles, tanin pour les tanneries, bois de chauffage et charbon de bois, du chaume, des matériaux de charpente, du vinaigre et du vin de palme, bois de construction et d'ébénisterie.

A part la conservation de l'écosystème originel les genres d'utilisation de la mangrove les plus importants sont: les salines, les étangs à poissons et la riziculture submergée. Dans ces cas, la mise en valeur des terres exige des interventions énergiques sur la végétation, le terrain et le régime d'eau, produisant dans les sols sulfatés acides, au moins pendant la période de récupération, de grandes quantités d'acides dont une partie est évacuée vers la mer. Il est très important dans les grands projets de mise en valeur d'envisager les dégâts provoqués dans les bordures littorales par les acides libérés en amont, et de modérer ces dégâts par un dosage adéquat de l'extension et de l'intensité des travaux de récupération qui produisent les acides. A ce propos, j'aimerais citer quelques mots de José Yanolo, secrétaire du Département de Resources Naturelles de Manila, prononcés en 1977 à l'occasion de la Conférence Internationale sur le Développement d'Estuaires et Mangroves:

> 'Nous avous le devoir de respecter notre milieu et de le traiter avec considération et avec soin. C'est un réel danger que dans notre empressement à produire et à développer nous négligions les limitations de l'écosystème. Avons nous suffisamment réfléchi au fait qu'aucune technologie ne peut

> jamais récréer une espèce disparue par l'extinction ou ne peut reconstruire des cycles chimiques et biologiques fondamentaux? Notre attitude vers le développement des mangroves et des estuaires doit être basée sur la déférence et le respect pour la connexité universelle et complexe mais toujours limitée de l'environnement dont nous sommes tous les habitants.' (Yanolo, 1978)

Salines, rizières submergées ou étangs à poissons. Si des zones à sols sulfatés acides salés doivent être récupérées il n'y a généralement pas des grands problèmes d'infrastructure. Les principaux besoins sont les routes de raccordement entres les centres de production, de commerce et de services.

Au Bangladesh par exemple, il y a une petite zone à sols sulfatés acides nommée Chakaria Sunderbans. Cette zone couverte de palétuviers, était salinisée sous l'influence de la marée et pas encore acide. La population locale se mit à récupérer le terrain en vue de riziculture à submersion par l'eau de pluie, mais à l'exclusion des marées le sol s'acidifia à l'extrême. La production de riz chuta et dans certains champs, le riz ne poussa pas du tout. Alors, la population qui vivait sur les terres hautes adjacentes, transformat les rizières improductives en salines. En certains endroits, dans ces salines, de l'eau très acide surgissait à la surface en traversant le sol. Ces endroits furent isolés et rendus inoffensifs par des diguettes spéciales. Quoique les salines ne soient productives qu'environ 4 mois par an pendant la saison sêche, le revenu annuel par ha fût plus grand qu'avec de bonnes rizières.

Aux Philippines où la majorité des terrains à sols sulfatés acides sont de type salin, ils se présentent comme des superficies réduites non loin des villages avec écoles et marchés. Bien que l'infrastructure soit favorable et les procédés effectifs d'amélioration et d'aménagement assez bien connus dans ces contrées, il reste des problèmes socio-économiques graves.

Dans les sols sulfatés acides côtiers de Sorsogon par exemple, dans le midi de l'île de Luzon la riziculture submergée ne donne environ que 250 kg/ha. Les quelques fermiers continuent à cultiver ces rizières peu productives faute d'autres possibilités et parce que leurs fermes sont relativement grandes. Mais sur ces terres la riziculture tend de plus en plus à perdre du terrain, parce que d'une part les fermiers quittent leurs champs pour la ville et d'autre part les rizières sont transformées en piscines à eau saumâtre. Ceci est une opération de génie civile importante et coûteuse mais prometteuse au point de vue de viabilité économique. Pourtant dans cette conversion en piscines il y a un danger social important. La conversion demande pas mal de capital et l'accès à l'eau de marée salée pour chaque étang. Ces deux aspects portent avec eux le risque de disparité sociale croissante, en favorisant les riches envers les pauvres qui perdent leurs terres. De tels développements peuvent être prévenus par la construction de canaux publics donnant sur l'eau de marée, ainsi que par des crédits à moyen terme disponibles aux fermiers peu aisés.

4.2 La zône à eau douce

Les sols potentiellement sulfatés acides en milieu à eau douce semblent constituer un ecosystème naturel moins varié et moins valable comparé à ceux en milieu salin. La récupération et l'utilisation des sols sulfatés acides à eau douce posent généralement de plus grands problèmes techniques d'infrastructure, économiques et sociaux que les sols sulfatés acides au bord de la mer et à eau salée. Ceux là apparaissent en général en surfaces plus étendues et hors des zones où l'amplitude de marée peut effectivement influer sur le drainage et l'irrigation. Il manque l'eau salée pour accélérer le lessivage d'acides. Les eaux de drainage acides doivent être évacuées sans nuir aux terres en aval. C'est généralement plus difficile et couteux de pourvoir ces zones d'accès et de services. Pour autant qu'il existe de méthodes efficaces de récupérer ces sols pour la riziculture submergée ou pour les cultures sèches adaptées, leurs viabilité économique n'est pas toujours assurée même a bas prix de main d'oevre. La colonisation à grande échelle de vastes superficies de terres nouvelles, trop distant d'anciennes contrées pour profiter des services existantes, demande l'installation et le développement d'une infrastructure complète, incluant des systèmes nouveaux d'organisation sociale, administrative et de production.

Les terrains à sols sulfatés acides ne sont pas nécessairement homogènes. Ils peuvent varier du point de vue de l'acidité, même sur de courtes distances, et souvent il n'y a pas de problèmes d'acidité sur les levées naturelles des rivages. Pour les sols à acidité très sevère il semble que jusqu'à présent, on n'ait pas trouvé de méthodes d'amélioration efficaces et économiques. Pour les autres, moins sévères, il y a des techniques de récupération et d'amélioration à la fois practiques et économiques.

Celles-ci se sont développées, d'une part par des recherches et des expériences scientifiques, d'autre part empiriquement par la population vivant dans la périphérie des zones à sols sulfatés acides et dépendant de ces sols pour sa subsistance.

Des riziculteurs du Delta du Mékong par exemple, utilisent un système de drainage superficiel, à réseau dense de fossés peu profonds. Les premières pluies de la saison humide lavent une bonne partie des acides des couches supérieures du sol, vers les fossés. Là, les acides sont partiellement immobilisés par réduction, partiellement evacués vers les rivières. Au moment où les pluies ont fait monter la nappe d'eau au dessus de la surface, la plus grande partie des acides à été lessivée de la couche supérieure du sol et ce qui reste est immobilisé par une réduction locale. Les rendements obtenus sont d'environ 2,5 t/ha, alors que sans l'utilisation de ce système de drainage ils étaient de 0,5 t/ha.

5 Echecs et succès

5.1 Les Pays-Bas pendant les trois derniers siècles

En 1641 le fameux ingénieur hollandais surnomé Leeghwater (littéralement: vide - d'eau) élabora le plan de drainage du Haarlemmermeer, le plus grand lac intérieur d'Hollande. Ce lac avait une profondeur de 4 m, un fond argileux et une superficie de 18000 ha. Le drainer âvec les moulins à vent existants, était une tâche trop difficile. Deux siècles plus tard, le gouvernement hollandais commença ce travail avec des machines à vapeur anglaises. Le drainage fût un succès, la colonisation fût un désastre. Des sols sulfatés acides dans le fond du lac, résultant du drainage, développèrent une acidité tellement sevère et persistante, que deux générations de fermiers s'appauvrirent en dépit d'efforts acharnés, ou bien dûrent abandonner leurs terres.

Dans une perspective séculaire, les sols sulfatés acides sont un phenomène temporaire. A l'état naturel, humide en permanence, les acides sont cachés sous forme de pyrite et les sols peuvent subsister sans changement pendant de longues périodes. C'est avec le drainage que se déclenche l'acidification extrème qui rend impossibles les mesures d'amélioration qui sont praticables dans l'assèchément des marécages à sols normaux. Après des décades de lavage, à l'eau d'irrigation ou de pluie, si le drainage est maintenu, une grande partie des acides est evacuées et le sol devient modérément apte à quelques types d'utilisations. Dans une centaine d'années, même des bonnes terres cultivables peuvent en résulter, témoin le Haarlemmermeer qui est aujourd'hui une contrée agricole prospère.

5.2 *Colonisation planifiée*

Un exemple plus récent est celui du polder crée peu de temps avant 1960 au Guyana, en Amérique du Sud près de Georgetown, où en quelques années, 90% des riziculteurs à peine établis abandonnèrent leurs champs. Ce fût un énorme désastre social et économique.

Actuellement, dans plusieurs pays, des colonisations planifiées sont envisagées ou bien en train d'être exécutées dans de zones à sols sulfatés acides. Les responsables des investissements dans ces développements planifiés actuellement demandent que les projets tiennent compte des aspects socio-économiques. Nous autres, en tant que techniciens comme planificateurs, nous sommes souvent optimistes en nous assurant que nous ferons mieux que nos prédécesseurs. N'est ce pas qu'en connaissant leurs fautes nous saurons les éviter? Mais, est ce que cela veut dire qu'il n'y aura plus jamais d'échecs comme auparavant?

Nous devons bien avoir conscience de notre responsabilité en cas d'échecs, avec leurs conséquences non seulement des résultats négatifs matériels et écologiques, mais aussi de dissolutions sociales.

Les expressions 'social' et, pire, 'socio' ne sont pas de préfixes ornementaux du mot 'économique', sinon de parts équivalentes d'expressions composées. Le trait d'union signifie dans ce cas que les aspects sociaux sont liés directement aux aspects économiques. Ce n'est pas une liaison q'on peut abandonner à la Providence, au contraire en considérant le succès social dans notre planification nous augmenterons la probabilité du succès économique des projets de colonisation. A ce propos il vaut la peine d'examiner le système de colonisation dite spontanée, décrit dans ce qui suit.

5.3 *Colonisation spontanée*

Il se passe un processus organique et graduel de développement de terrains et d'occupation dans l'île de Palawan aux Philippines (James 1978) et dans les marécages côtiers de Kalimantan et Sumatera en Indonésie (Collier 1979). Ici, les quelques pionniers Buginois, creusent pour commencer un petit bout de canal principal donnant sur le fleuve, ensuite un canal transversal, secondaire, pour desservir le terrain des deux côtés. A mesure qu'avance le défrichement et qu'une base économique soit établie, des membres des familles et des voisins viennent se joindre aux pionniers, pour les aider à cultiver et plus tard pour récupérer un terrain adjacent à eux mêmes sous la direction des pionniers. Progressivement le canal principal est allongé et d'autres canaux secondaires sont ajoutés.

Là où il se présentent des problèmes, le défrichement est abandonné pour l'instant en attendant que le drainage prolongé par les canaux rende peu a peu ces terrains cultivables.

Alors de tels échecs locaux et momentanés sont amortis par la structure sociale déjà développée et ne détruisent pas l'économie locale.

Par le système d'apprentissage, les colons qui viennent d'arriver disposent de méthodes de mise en valeur empiriquement adaptés aux conditions locales. Confrontés avec d'insuccès partiels ils sont portés à continuer par l'engagement de leur effort et de leur temps dans la colonisation. L'aggrandissement graduel de la superficie cultivée permet l'organisation de services et la structure sociale de se développer et perfectionner sans heurts.

5.4 *Une comparaison*

On a une image tout à fait différente si on considère les grands projets gouvernementaux de récupération de terres et de colonisation massive.

Les investissements totaux par ha peuvent être les mêmes ou plus élevés maix le taux d'abandon et des échecs est plus élevé que dans les colonisations spontanées. Les colons des projets gouvernementaux proviennent de lieux différents, ne se connaissent pas entre eux, arrivent tous sans expérience locale et se trouvent sans appui des prédécesseurs. Il n'y a pas encore de structure sociale et ce sont seulement les services techniques gouvernementaux débutants qui doivent tout faire pour que les colons restent sur place et actifs, jusqu' à ce que se soit développée une base économique et une structure sociale qui peuvent stabiliser la nouvelle communauté.

Cette comparaison n'a pas pour but de montrer que la colonisation spontanée constitue une panacée contre tous les maux économiques et sociaux des colonisations planifiées gouvernementales. Souvent les pionniers des colonisations spontanées sont des leaders sociaux, des personnes indépendantes et rélativement aisées. Les colons des projets gouvernementaux sont généralement des non-aisés, dépourvus de ressources et d'options dans leurs domiciles d'origines. Nonobstant il ne convient pas de les déraciner et de les déplacer, avec des crédits et des engrais fournis par le gouvernement, dans un vide social.

6 L'habileté du colon comme cheville ouvrière du développement

Il nous faut isoler et adapter les éléments positifs de la colonisation spontanée à l'usage des projets gouvernementaux. Un de ces éléments est la participation active des même colons qui les permette de s'abriter contre certaines erreurs des politiciens, des planificateurs et de nous autres, les professionels scientifiques. Un autre elément est la flexibilité en vue des difficultés de terrain. Dans quelques grands projets planifiés on l'a récemment appliqué. Dans les plans d'aménagements les éléments d'infrastructure et d'amenagement secondaires et tertiaire ne sont qu'en partie mis au point pour exécution immédiate, le reste constitue une réserve à développer plus tard selon l'expérience obtenue avec l'exploitation de zones-pilotes. De tels aménagements permettent d'amortir les échecs et d'appliquer des améliorations en phases et progressivement à échelle plus grande.

Ce système demande de grandes superficies inoccupées, et il est surtout indiqué dans une situation de frontière. Dans une telle situation, sortant de terres déjà occupées, les fermiers, en partie accompagnés de pédologues, peuvent pénétrer dans la zone adjacente inoccupée incluant de sols sulfatés acides, par défrichements expérimentaux à petite échelle et à peu de frais. Là où les expériences réussissent on les applique immédiatement sur des terrains adjacents, pendant que dans les secteurs difficiles l'avancement des défrichements est retenu temporairement. Ainsi le processus de mise en valeur des terrains se poursuit de façon graduelle et en disposition organique, plutôt comme les vagues de la marée montante sur la plage.

C'est une erreur que de vouloir sélectionner tous les colons d'un projet donné, d'un seul coup. Surtout le groupe pionnier doit être choisi avec beaucoup de soin, selon des critères d'habileté agricole, d'ingéniosité et d'organisateur. Autant que possible ils seront choisis avec la participation de leurs communautés d'origines. Il est souhaitable que les colons d'un secteur de la frontière soient tous originaires des villages voisins et disposés à la coopération. Quand plus tard arriveront progressivement d'autres colons, ceux ci y trouveront des prédécesseurs dans une diversité de situations et d'expériences de défrichements et de mise en valeur des terres.

La bonne volonté à la colonisation doit être appuyée par pas mal d'assistance directe, surtout au début. Plus tard l'empressement sera encouragé au fur et à mesure que réussiront les efforts pionniers et que l'information sur le progrès sera arrivée jusqu'aux villages d'origine. Cela augmentera la probabilité des succès futurs et l'assistance directe aux colons pourra être amoindrie. Ainsi plus de ressources publiques seront disponibles pour l'infrastructure.

La question cruciale dans la mise en valeur des nouvelles zones à sols sulfatés acides est de mobiliser la capacité des communautés, d'élargir leur base d'expériences en s'adaptant aux situations existentielles nouvelles. A cette fin, à la fois l'habileté technique, l'organisation sociale et la mutualité des communautés de colons ne doivent jamais être epuisées mais au contraire doivent être renforcées. Quand ils investissent activement leurs efforts dans les terrains défrichés, plutôt que s'y trouver déplacés individuellement, amorcés par des crédits et des engrais, les colons gagnent de l'interêt à leurs nouvelles terres, ils ne penseront pas à s'en aller après avoir vendu la charrue et les plaques de toiture prêtées, au contraire, ensemble ils feront un succès de la récupération même des sols sulfatés acides.

Dans un ensemble d'autre ordre c'est notre tâche de perfectionner, la base scientifique, la technique de la récupération et l'amélioration de sols sulfatés acides, utilisant au maximum les divers résultats empiriques des colons et fermiers.

Note: Pour les références voir pagina 36.

Resumés des communications sur la genèse, la géographie et la classification des sols sulfatés acides ainsi que sur la prédiction du développement d'acidité

L.J. Pons et N. van Breemen

Facteurs déterminant la formation d'acidité potentielle dans les dépôts de marée

Les sédiments potentiellement acides, contiennent un excès des sulfures, surtout pyrites, en rapport avec les substances neutralisantes.

Les éléments essentiels pour la formation des pyrites sont:

1) les sulfates (provenant de l'eau de mer);
2) les minéraux contenant du fer (dans les sédiments minéraux);
3) la matière organique métabolisable (fournie par les sédiments et surtout par la végétation);
4) les bactéries qui réduisent les sulfates (toujours présents);
5) le milieu anaérobique (boue réduite);
6) l'aération temporaire, limitée pour l'oxydation partielle des sulfures en polysulfures (par l'oscillation de marée de la nappe d'eau);
7) l'évacuation de l'excès de l'alcalinité (par drainage durant la marée basse);
8) les conditions faiblement acides (dans la boue partiellement oxydée).

La capacité de neutraliser les acides dépend de:

9) la somme des bases échangeables (pouvant neutraliser comme 0,5%

pyrite-S);

10) la teneur en minéraux silicatés facilement altérables (pouvant neutraliser comme 1% pyrite-S);

11) la teneur en carbonates (3% $CaCO_3$ pouvant neutraliser 1% pyrite).

Des conditions favorables à la formation de la pyrite existent dans les zones littoralles bien accessibles par les marées à eau salée ou saumâtre, déposant des sédiments argileux dans une dense végétation qui s'établit au dessous du niveau des hautes marées (Telmatophytes: mangrove, roseaux, joncs).

L'accumulation de pyrite pouvant devenir dangereuse, se produit seulement là où ces conditions persistent pendant au moin de dizaines d'années. C'est le cas des litoraux à peu près stationnaires, où le processus de subsidence est contrebalancé par la sédimentation. Dans cette situation, dans les climats tropicaux humides se sont surtout les palétuviers rouges (Rhizophoraceae) qui contribuent à la stabilité du milieu où la pyrite s'accumule. Cette végétation, ainsi que celle de roseaux des climats tempérés humides, combine la tolérance pour une large gamme de salinité, oscillation de marée et taux de sédimentation, avec la production des grandes masses de matière organique racinaire métabolisable.

Dans les estuaires des climats tropicaux humides, associés aux bassins fluviatiles à roches acides, on trouve des sédiments kaolinitiques à faible teneur en bases échangeables et dépourvus des carbonates. Quoiqu'ils ont la même teneur en pyrite, on doit les considérer comme les sédiments avec la potentialité d'acidité la plus grande, à cause de leur basse capacité de neutralisation. Actuellement, on les trouve par exemple, dans les estuaires des fleuves de l'Afrique occidentale, du nord de Sénégal jusqu'au Cameroun, tout particulièrement, dans les estuaires associés à des petits bassins fluviatiles acides.

Les grandes extensions de sédiments potentiellement acides situées dans l'intérieur des deltas du Chao Phrya, du Mékong, de l'Orénoque et des plaines côtières de Sumatera et des Guyanes, se sont formées durant le Holocène inférieur depuis la dernière glaciation jusqu'à environ 5000 A.P. Dans la zone temperée, par exemple dans les Pays Bas, on trouve les mêmes dépôts potentiellement acides de moindre extension. Cette période fût marquée par une montée relative du niveau de la mer. Cependant dans les zones en considération les surfaces de dépôt avec leur végétation dense demeuraient proches du niveau moyen de la mer par un accroissement surtout vertical, maintenant le système intensif de criques, grâce à des taux éleveés de sédimentation et à l'adaptation des mangroves. Il en resultaient des dépôts d'argiles de grande epaisseur, enrichis en matière organique fibreuse et en pyrite.

Avec la stabilisation du niveau de la mer dès environ 5000 A.P., dans les mêmes zones littorales l'accroissement vertical ne pouvait plus absorber les quantités de sédiments disponibles et comme suite se produisait un colmatage des estuaires et un accroissement latérale et rapide des plaines maritimes avec une déposition jusqu'au niveau de marées hautes. Dans ces conditions de taux de sédimentation relativement élevé l'ensemble du littoral non-entamé, avec une mince zone influencée par la marée et par la végétation de mangrove, se déplace rapidement en sens latéral, et en conséquence la formation et l'accumulation de pyrite et d'acidité potentielle dans les dépôts restent faibles. Les exemples en sont les dépôts côtiers récents des Guyanes, du Mékong, de l'Irrawady et d'autres grands deltas tropicaux, ainsi que le delta du Rhin. Dans ce dernier cas, le taux de sédimentation s'est encore accru à cause de l'érosion dans le bassin fluvial pendant les derniers 2000 ans. Conformément on peut espérer une décroissance de l'accumulation d'acidité potentielle dans les littoraux tropicaux où l'érosion continentale apporte à l'accroissement du taux de sédimentation en milieu de marées.

P. Thomas et J.A. Varley

Une levée cartographique de sols sulphidique (à pyrites) en milieu de marée et tropical

L'article décrit l'expérience de la cartographie des sols sulphidiques (à pyrite) de mangrove dans une section de la Gambie. Le but était de déterminer et localiser l'acidité potentielle dans ces sols en vue d'un projet impliquant une baisse de le nappe d'eau dans la zone. Les problèmes à surmonter etaient de deux sortes: logistiques et méthodologiques. Les problèmes logistiques proviennent de l'inhospitalité et l'inaccessibilité de la zone, de difficiles communications entre terrain et laboratoire et de la courte durée du temps disponible. Les problèmes méthodologiques résultent de l'imperfection des méthodes usuelles

d'identification des sols sulphidiques. Les propriétés essentielles de ces sols sont très sensibles à l'aération. Leur détermination directe demande des analyses au laboratoire des échantillons y arrivant en état anaérobie. Cela complique l'échantillonage, l'emballage et le transport des échantillons et leur préparation dans le laboratoire, et ajoute aux difficultés logistiques. Pour éviter de telles complications, la plupart de méthodes usuelles déterminent de propriétés dite co-variantes, soit circonstancielles ou intrinsèques dont le rapport aux propriétés essentielles est généralement hypothétique ou d'application locale.
Une autre méthode est l'incubation aérobie d'echantillons frais et le mesure (monitoring) du pH en fonction du temps. L'incubation aérobie simule l'effet du drainage sur le sol en place, et la baisse du pH résulte directement de l'acidité potentielle du même sol.
Dans la présente opération cette méthode là a été développée pour application au champ et comparée et combinée avec de méthodes cartographiques et pédo-morphométriques classiques et avec de déterminations en laboratoire du soufre total et de pyrite sur des échantillons à peine oxydées, cela grâce à l'emploi d'un emballage en doubles sacs de matière plastique, hermétiquement scellés et par de moyens de communication et facilités de laboratoire très expéditives. L'incubation aérobie avec mesures du pH pendant deux mois, résultait la méthode d'identification de sols sulphidiques la plus valable. Elle donnait un rapport consistant à la teneur en pyrite et, en combinaison avec des prélèvements dans un réseau de traverses parallèles, elle facilitait l'interprétation d'indicateurs circonstenciels et pédo-morphométriques.
Avec ces méthodes la cartographie de sols sulphidiques en milieu de mangrove est bien practiquable pourvu que l'organisation logistique soit adéquate.

D.L. Dent et R.W. Raiswell

Modèles quantitatifs pour prédire le taux et l'intensité du développement de l'acidité sulfaté: étude concrète en Gambie

La quantité d'acides produit à la suite du drainage dans des matériaux sulfidiques, peut être calculée à partir de la quantité de sulfures de pyrite en excès sur la capacité neutralisante du sol en utilisant un modèle statique.

Un modèle dynamique dans le quel le taux de l'oxydation sulfidique est supposé être controlé par le taux de diffusion de l'oxygène parmi les espaces poreux remplis d'eau, a été développé. Le taux de production d'acide est ainsi détérminé par (1) l'excès de la teneur en pyrite S du matériau et (2) le rapport surface-volume, c'est à dire la structure du sol: à la suite du drainage, le sol non-mûr est fissuré en grands prismes allongés. Dans le modèle dynamique cette structure prismatique à été représentée par des cylindres. La teneur en pyrite S, ainsi que le développement de la structure du sol apparaissent dans la nature dans des ordres de valeurs qui ont des effets significatifs sur le taux de la formation des acides. Des tableaux ont été composés montrant l'influence de la teneur en S et de la dimension d'éléments structuraux sur la production des acides.

Le modèle est appliqué sur les sols potentiellement acides de Gambie. Un développement rapide d'acidité sevère est indiqué si le niveau de la nappe phréatique est abaissé. Les valeurs précises du pH du sol et de l'eau du fleuve dépendront du régime de drainage et de l'efficacité du lessivage des acides des sols vers l'eau de drainage.

S. Paramananthan et B. Gopinathan

Problèmes de classification des sols à horizons sulfidiques de la Malaisie Péninsulaire

Une séquence de sols sulfatés acides développés sur les argiles côtieres de la Malaisie Péninsulaire est décrite. La maturation du sol après la construction de drains a conduit au développement d'horizons cambique et sulfurique. Le matériau sous-jacent est généralement sulfidique. Deux séquences semblables sont étudiées, l'une sur alluvions marines, l'autre sur dépôts d'eau saumâtres. Celle-ci est caractérisée par une teneur en matière organique élevée. Les problèmes liés à la cartographie et à la classification sont signalés et des changements à la *soil taxonomy* pour répondre aux anomalies sont proposés.

C. Marius

Les sols sulfatés acides des mangroves du Sénégal et de la Gambie

Au Sénégal et en Gambie, la mangrove occupe les plaines intratidales avec la forèt à palétuviers, en bordure des cours d'eaux et les tannes - marais maritimes - en partie herbacés et en partie, nus. Les sols sont sulfatés acides, généralement très peu développés et formés d'argiles ou de sables tourbeux et sulfidiques. Ces sols sont soumis à l'inondation quotidienne par la marée.

La mangrove qui couvre une superficie d'environ 500.000 ha est principalement localisée dans les estuaires de la Casamance, de la Gambie, du Saloum et du Sénégal. A l'exception de la Gambie où le débit du fleuve est suffisamment élevé pour diluer la salinité de l'eau pendant la courte saison des pluies (Juin/Juillet - Octobre/Novembre), dans les trois autres estuaires, la marée est salée pendant toute l'année. La pluviométrie moyenne annuelle jusqu'en 1972 était de 400 mm dans le Nord (Sénégal) et de l'ordre de 1550 mm dans le Sud (Casamance). Mais depuis 1972, elle n'est plus en moyenne que de 250 mm dans le Nord et 1200 mm dans le Sud. De ce fait, la salinité et l'aridité du sol ont augmenté et les zones de tannes se sont étendues aux dépens de la forêt de mangrove.

Les études pédologiques qui ont commencé vers 1960 se sont intensifiés depuis 1967 avec les problèmes posés par l'acidification des sols des polders nouvellement aménagés.

L'agriculture des zones à mangroves est essentiellement consacrée à la production du riz dans les polders traditionnels et modernes en Casamance et en Gambie.

L'aménagement traditionnel à petite échelle des mangroves a été basé sur un drainage peu profond et une inondation controlée avec l'eau salée pour prévenir l'assèchement des horizons profonds pendant la saison sèche. Le riz est cultivé sur des billons construits avec l'horizon superficiel seulement.

Les billons sont dessalés par les premières pluies. La salinité est généralement un problème plus sérieux que l'acidité dans les rizieres traditionelles.

Les grands aménagements modernes avaient été conçus pour stopper de manière définitive l'intrusion des marées et pour dessaler les sols par un drainage profond et un lessivage des sels avec de l'eau douce stockée en amont de grands barrages. Ce type d'aménagement conduit à une acidification rapide et brutale des sols.

La diminution des réserves en eau douce depuis 1972 a accru à la fois les problèmes de salinité et d'acidité, aussi bien dans les rizières traditionnelles que dans les aménagements moderns.

La productivité des zones aménagées pourrait être restaurée en combinant l'inondation contrôlée de l'eau salée et la culture du riz sur billons avec un nouveau système de contrôle de l'eau douce et une dessalinisation peu profonde des sols.

Résumés des communications sur la productivité des sols sulfatés acides affectés par le chaulage, les engrais, les différents régimes d'eau, la tolérance des variétés et les pratiques culturales dans d'expériences, de systèmes d'aménagement traditionnels et de grands projets de récupération

Tasnee Attanandana et Sorasith Vacharotayan

Caractéristiques chimiques et état de fertilité des sols sulfatés acides en Thaïlande

La couche supérieure (0-25 cm) de deux *Typic Tropaquepts* (Ratchaburi série sur matériau originel fluviatile et Bangkok série sur argile marine à sous-sol calcaire) et trois *Sulfic Tropaquepts* (séries Sena, Rangsit et Rangsit phase très acide) a été étudiée afin de connaître ses propriétés intrinsèques et son état de fertilité. Les expériences ont été effectuées en vases de végétation, le sol analysé étant planté en riz et soumis aux traitements de fertilisation à N, P et K. L'effet du chaulage a aussi été essayé sur le Rangsit phase très acide.

Les sols étudiés sont les sols habituellement utilisés pour la riziculture dans la Plaine Centrale de la Thaïlande, classés du point de vue de leur aptitude à cette culture, comme très bons en ce qui concerne, les *Typic Tropaquepts* (séries Bangkok et Ratchaburi) et respectivement bons modérés et pauvres pour les séries Sena, Rangsit et Rangsit phase très acide des *Sulfic Tropaquepts*.

Les caractéristiques intrinsèques, de la couche supérieure de ces sols ont été détérminées en laboratoire et leur état de fertilité en serre. Les résultats sont discutés par rapport à l'aptitude de ces sols à la riziculture.

Les résultats des analyses mécaniques, montrent des conditions différentes de sédimentation du matériau originel: eau saumâtre et milieu marécageux pour les *Sulfic Tropaquepts*; fluviatile et marine pour les *Typic Tropaquepts*. La minéralogie des argiles ne reflête pas ces conditions, mais elle montre des différences entre les séries non-acides et acides. Ces dernières, ont une teneur relativement peu élevée en smectite qui est partiellement interstratifiée en aluminium à la suite de l'altération en milieu fortement acide. Les caractéristiques chimiques font apparaître des différences en acidité marquées. Les *Sulfic Tropaquepts* ont un pH très bas, d'environ 3,9-4,8 (3,9 Rangsit phase très acide, 4,7 Sena, 4,8 Rangsit) et les *Typic Tropaquepts* sont faiblement acides (pH 5.2 pour Bangkok, 5.8 pour Ratchaburi). Avec la progression de l'acidité les teneurs en S et Al total augmentent et celles en CaO, MnO_2 total, Fe et Mn extractibles, et en P, Ca et Si assimilables diminuent.

Sans engrais, les récoltes sont pauvres sur tous ces sols, mais l'exemple le plus concluant est fourni par le Rangsit phase très acide. Dans tous les autres sols, les plantes étaient saines et donnaient des récoltes de 28,2 à 34,3 g de matière sêche/pot. Le riz planté sur le Rangsit phase très acide, qu'il soit chaulé (equivalent de 13 tonnes/ha) ou non, mourut peu après la transplantation; et les récoltes atteignent seulement 2,1-2,9 g/pot.

Tous les sols ont répondu à la fertilisation complète, mais les récoltes maximales atteintes par le Rangsit phase très acide sans chaulage, restaient environ de 30%, et avec chaulage toujours de 20% en-dessous des récoltes des autres sols. Sur les *Typic Tropaquepts*, des doses relativement faibles d'engrais ont apporté de sérieuses augmentations de récolte. Les *Sulfic Tropaquepts* demandent des doses plus élevées, notamment de P. La série Rangsit phase très acide, avec ou sans chaulage, a été la seule a ne réagir à aucun engrais en l'absence du P. L'application du chaulage a augmenté l'efficacité des engrais mais elle n'a pas éliminée la déficience initiale en phosphore. Pour obtenir des récoltes de 150-200 g/pot, la série Rangsit phase très acide nécessite des doses égales d'azote, mais des quantités doubles ou triples de phosphore comparées à celles reclamées par les séries Sena et Rangsit. Comme le manque de phosphore est associé avec la fixation et à l'extrême acidité du sol, l'acidité potentielle dans les sols sulfatés acides peut être considérée comme la cause de la déficience réitérante en phosphore.

La teneur en éléments nutritifs des plantes est étroitement liée aux conditions des sols. Sur la série Rangsit phase très acide elle a été très élevée en Al, S et Na et très basse en P, Si, Mg, Ca et K comparée à celle sur les autres sols. Avec chaulage et fertilisation complète les différences pour les teneurs en Mg, Ca, K et Al, S diminuaient sensiblement, mais les teneurs en P et Si restaient constamment plus basses. En ce qui concerne le Fe on n'a pas constaté une teneur anormalement élevée ni de symptômes de toxicité.

Une vue d'ensemble sur les résultats, corroborés par les analyses des sols et plantes, nous permet de conclure que des trois séries des sols sulfatés acides étudiées, le Rangsit phase très acide seul, présente des propriétés intrinsèques qui déterminent des récoltes faibles. La couche supérieure des autres séries (Sena et Rangsit) bien que fortement acide, présente une productivité potentielle au moins égale à celle des séries modérément et faiblement acides (Bangkok et Ratchaburi). La différence dans l'estimation des aptitudes de ces quatre dernières séries de sols est dû à de causes externes, comme par exemple l'état et le mouvement de l'eau et l'influence du sous-sol, et non aux propriétés intrinsèques des couches arables.

L'amélioration de la productivité de Rangsit phase très acide demande l'amélioration des facteurs intrinsèques de la couche arable tel notamment l'élimination de son acidité résiduelle et ensuite l'augmentation de la teneur en phosphore. Ceci pourra se réaliser par l'augmentation de la fréquence du drainage de l'eau de surface combiné avec l'application du chaulage suivi d'amendements avec de roches phosphatées.

Charoen Charoenchamratcheep, Boonthong Tantisira,
Phairoj Chitnuson et Vachara Sin-Aiem
Les effets du chaulage et des applications d'engrais sur les sols sulfatés acides pour l'amélioration de la production du riz en Thaïlande

Les sols sulfatés acides couvrent dans la Plaine Centrale de la Thaïlande une superficie d'environ 800.000 ha, dont plus de 95% est utilisée pour la riziculture. A cause de leur pH bas et de leur niveau de fertilité faible, les rendements en riz sont très faibles. Pour accroître la production du riz et pour apporter au maximum le profit net, l'amélioration des sols sulfatés acides au moyen du chaulage et des applications d'engrais, a été étudiée et les résultats sont fournis dans cet article.

Quatre séries de sols sulfatés acides ayant différentes valeurs de pH, profondeur d'accumulation de jarosite et classe d'aptitude pour la riziculture (notamment le Rangsit phase très acide, le Rangsit, le Maha Phot et l'Ayutthaya) ont été choisies dans 8 sites différents. La couche supérieure (0-20 cm) de chaque série a été analysée du point de vue chimique avant le début des expériences. Les variétés de riz plantées ont été: RD7, qui est une variété à haute productivité peu affectée par la photopériodicité, et des variétés locales sensibles à la photopériodicité.

La marne, le sulfate d'ammonium, le phosphate d'ammonium et la roche phosphatée ont été appliqueés sur un complèxe à petites parcelles en quatre répétitions, la dispersion étant au hasard.

Sur les sols modérément acides (Maha Phot et Auytthaya séries), l'application de marne a eu peu d'effet sur la récolte. L'application de sulfate d'ammonium (150 kg/ha) seul, ou en combinaison avec la roche phosphatée (1250 kg/ha) a conduit à des récoltes supérieures. Le maximum de profit net, a été obtenu après l'application combinée d'une quantité de 6,25 à 12,5 t/ha de marne et 187,5 kg/ha de phosphate d'ammonium ou avec sulfate d'ammonium seul.

Sur la série fortement acide (Rangsit) le riz a réagi très favorablement à l'application combinée de marne (6,25 - 18,75 t/ha) et du phosphate d'ammonium (187,50 kg/ha). Des résultats similaires ont été obtenus avec 6,25 à 12,5 t/ha marne, 1250 kg/ha roche phosphatée et 150 kg/ha sulfate d'ammonium. La rentabilité de ces traitements dépend de la fertilité des sols et surtout du prix des engrais.

Sur la série extrêmement acide (Rangsit phase très acide) une application de 6,25 à 12,5 t/ha de marne, 1250 kg/ha de roche phosphatée et 150 kg/ha de sulfate d'ammonium ou 12,5 t/ha de marne avec 187,5 kg/ha de phosphate d'ammonium ont donné le maximum de récolte ainsi que le maximum de profit.

Methee Maneewon, Nakorn Thawornwong et
Boonthong Tantisira
Etude sur les doses de marne pour la production du riz sur
les sols sulfatés acides de Thaïlande

Des expériences au champ ont été effectuées avec du riz sur trois séries de sols sulfatés acides, d'acidité extrême (pH 3.9), forte (pH 4.2) et modérée (pH 4.6) et aptitude rizicole respectivement faible, modérée et bonne. Quatre niveaux du marnage (0, 3.125, 6.25 ton/ha et marnage à pH 4.5) ont été combinés avec deux niveaux d'application d'engrais (0 et un ensemble de 156.25 kg/ha de phosphate d'ammonium 16-20-0 au moment du répiquage et 6.25 kg/ha de sulfate d'ammonium à 21% N vers la période de taille). L'expérience concerne quatre cultures saisonnières pendant quatre années consécutives. Le marnage avait lieu un seule fois au début et l'application d'engrais se répétait toutes les années.

Dans le sol extrêmement acide (Rangsit phase très acide), l'application combinée d'engrais et de marne a apporté une grande augmentation de récolte et par suite, une augmentation significative du profit net.

Dans le sol fortement acide (série Rangsit) l'application de marne, sans engrais a eu un effet non-significatif sur la récolte totale pendant les 4 années d'expérimentation. Toutefois, certaines années le marnage a eu un effet favorable sur le sol, effet qui a varié selon les particularités du climat. Le marnage à raison de 3,1 t/ha combiné avec l'application d'engrais a donné le maximum de profit.

Dans les sols sulfatés modérément acides (série Maha Phot), l'application d'engrais seul a été suffisante pour l'amélioration du sol. Le marnage à raison de 3,1 t/ha, combiné avec l'application d'engrais a apporté une importante augmentation de récolte et implicitement du profit net. Le surplus, couvre largement le prix du marnage.

Le Van Can

Le phosphate naturel dans la production du riz sur sols sulfatés acides du Vietnam

Au Vietnam, les sols sulfatés acides couvrent plus de 2 million d'hectares dans le Delta du Mékong, au Sud, et plus de 200.000 hectares dans le Delta du Fleuve Rouge, au Nord.

Pour leur amélioration, la roche phosphatée dont on trouve des importants gisements à Lao Kay au Vietnam du Nord, s'est avérée efficace. Les résultats des essais effectués depuis 1960 ont montré que la roche phosphatée de Lao Kay dite 'pauvre' (15-28% P_2O_5), est un engrais à effets particulièrement favorables, pour les sols acides à bas niveau de phosphore, ainsi que pour les sols sulfatés acides. Sur ces derniers, l'effet résiduel est très fort, dû au fait que les microcristaux du phosphate de Lao Kay 'pauvre' sont agglomérés en granules formées d'un noyau de phosphate de calcium, entourées d'une cutane d'hydroxyde de fer qui étant progressivement dissoute par les acides dans les sols sulfatés acides, ralentit la disponibilité du phosphate.

Depuis l'unification du pays, le phosphate de Lao Kay a été introduit avec succés dans la riziculture sur sols sulfatés acides du Delta du Mékong, en remplacement des phosphates importés. Comme réponse à la demande accrue pour le phosphate de Lao Kay, au Sud, le gouvernement donne une haute priorité à son transport et à sa distribution, tout en procédant aux recherches de gisements de phosphates naturels locaux.

X. Arulandoo et S.P. Kam

Amélioration des sols sulfatés acides dans le projet d'irrigation de Muda, Kedah, Malaisie Péninsulaire

L'article présente les expériences effectuées au champ pour étudier l'influence de l'incorporation de la paille de riz, du chaulage et de l'application des engrais chimiques pour l'amélioration des sols sulfatés acides.

L'application du carbonate de chaux à raison de 2.5 t/ha a apporté une augmentation substantielle de la production du riz par suite de l'amélioration générale du développement des plantes et de l'amélioration de leur état de nutrition. En plus, un effet secondaire favorable sur la récolte suivante a été constaté. L'incorporation dans le sol des résidus des récoltes a apporté une augmentation de la matière sèche et de la teneur en K dans les plantes et a influencé favorablement la production de grains. L'incorporation de paille n'a pas eu d'effet secondaire. En ce qui concerne les engrais à N, P et K, des résultats très satisfaisants ont été obtenus par l'application de 90 kg N/ha, 50 kg P_2O_5/ha et 40 kg K_2O/ha. L'absence d'engrais phosphatés a produit des symptômes de carence de phosphore et a retardé d'environ 2 semaines la maturité des plantes. L'application des engrais potassiques dans l'étape de tallage a apporté une augmentation de la production de grains.

F.N. Ponnamperuma et J.L. Solivas

Amélioration d'un sol sulfaté acide pour la culture du riz par application du dioxide de manganèse et chaulage

L'article signale les effets du $CaCO_3$ (5 t/ha) et MnO_2 (100 kg/ha) appliqués séparément ou en combinaison, sur les symptômes de la toxicité en fer et la récolte de deux variétés de riz cultivées dans un champ à sol sulfaté acide dans la province d'Albay, Philippines, pendant la saison sèche de 1980. Les deux variétés de riz expérimentées ont été IR 26 (variété modérément susceptible) et IR 43 (variété modérément tolérante).

En ce qui concerne la résistance à la toxicité du fer, dans les premières 4 à 8 semaines après la transplantation, les meilleurs résultats ont été obtenus avec la variété IR 43 traitée avec $CaCO_3$ et MnO_2. Les résultats les moins satisfaisants ont été obtenus avec la variété IR 26 sans application de $CaCO_3$ et MnO_2. L'analyse de l'intensité des symptômes de toxicité a montré des différences significatives entre les deux variétés, une diminution négligeable de la toxicité du fer après le traitement à $CaCO_3$ et une diminution spectaculaire des symptômes de toxicité après le traitement à MnO_2.

En ce qui concerne la production de grains, les meilleurs résultats ont

été obtenus avec la variété IR 43 traitée avec MnO_2. L'application du $CaCO_3$ n'a apporté aucune augmentation de récolte. Les résultats les moins satisfaisants ont été donnés par la variété IR 26 sans application de $CaCO_3$ et MnO_2. L'analyse des variations a mis en évidence une augmentation de récolte non significative après l'application du $CaCO_3$, une différence remarquable entre les deux variétés expérimentées, une augmentation importante de la récolte comme suite au traitement à MnO_2.
IR 26 a donné une augmentation de récolte de 1,2 t/ha par l'application du MnO_2 en présence du $CaCO_3$, tandis que IR 43, a donné un profit de 2,2 t/ha, seulement à la suite de l'application du MnO_2. En présence de MnO_2, le $CaCO_3$ augmente la récolte de IR 26 avec 0,5 t/ha, mais pas du tout celle de IR 43, qui cependant peut donner un accroissement de 1,3 t/ha après l'application du $CaCO_3$ en l'absence de MnO_2.
D'autres études sur la toxicité du fer, révèlent une faible teneur en manganèse total ainsi qu' en manganèse soluble dans de sols sulfatés acides. Ceci suggère que la sévérité de la toxicité du fer pourrait être réduite par l'augmentation de la teneur en Mn soluble en eau. Les expériences préliminaires de culture en solution, le confirment (Institut International de la Recherche du riz, 1979). L'augmentation évidente de la récolte obtenue dans l'expérience présente, par l'application du MnO_2 peut être due à son action physiologique neutralisante sur la toxicité du fer.
Si l'éfficacité de l'application de MnO_2, en quantité d'environ 100 kg/ha pourrait être démontrée sur une gamme de sols sulfatés acides, l'application du MnO_2 associé à l'utilisation des variétés tolérantes à la toxicité du fer constituerait encore plus, une méthode d'amélioration. Dans ce cas, le chaulage pourra être réduit à un supplément. De futures recherches pourront établir si des quantités encore plus réduites de MnO_2 seront suffisantes, combien de temps les effets secondaires subsisteront et dans quelle mésure des petites quantités de MnO_2 pourront remplacer des tonnes de $CaCO_3$.

M. Touré

Amélioration des sols sulfatés acides. Rôle de la chaux agricole, de la cendre de bois, de l'herbe verte et de la présubmersion

Les tentatives de mise en valeur du domaine fluviomarin tropical par voie de poldérisation, aboutissent dans bien des cas à la formation de sols sulfatés acides impropres à toute culture.

Au Sénégal le développement des plantes sur ces sols est empêché par les facteurs suivants: (a) l'excès de cations métalliques (Al^{3+}, Mn^{4+}, Fe^{3+}); (b) la teneur élevée en sels solubles à base chlorurée sulfatée sodique, avec le magnésium comme élément dominant du complexe absorbant; (c) l'acidité naturelle ou potentielle très élevée; et (d) la fertilité naturelle faible, caractèrisée par une carence marquée en azote et phosphore.

Pour mettre en valeur ces sols, les techniques d'amélioration doivent être capables de supprimer ou d'atténuer la production des toxines et de relever la réaction du sol à des seuils supportables pour les plantes de culture. Le présent article a pour objet la présentation de résultats d'une expérience sur le sol de Tobor, séché et lessivé avec l'eau distillée jusqu'à une conductivité électrique restant inférieur à 2 mmhos/cm après 72 heures de submersion. Comme amendements ont été éprouvées la chaux agricole, la cendre de sciure de bois et la poudre de mauvaises herbes en conditions de serres, dans des microrizières repiquées avec des plantes de 3 semaines d'âge, de la variété IR 8. A part la submersion normale, simultanée au repiquage, une présubmersion de quatre semaines à été appliquée.

La chaux agricole et la cendre de bois ont été utilisées à deux niveaux: une faible dose (12 et 4 t/ha respectivement) combinée avec la présubmersion et une forte dose (28 et 16 t/ha) sans présubmersion. La poudre des mauvaises herbes a été utilisée à un seul niveau à raison de 1%, avec présubmersion.

Une fumure minérale de 100 ppm de N, P, K a été appliquée avant le repiquage. Un complément de 30 ppm N a également été apporté un mois après repiquage. Grâce a un système de drainage, une partie de la solution de sol a été recueillie en milieu inerte, à des intervalles réguliers et analysée pour: le pH, le Eh et la CEC; le fer et la manganèse; les matières oxydables; les bicarbonates et les acides organiques; les sulfates et le phosphore; l'azote minéral. Des analyses de tissus végétaux (feuille, paille et graines) ont également été effectuées pour: Fe, Mn, Si, P et K.

L'utilisation des techniques mentionées n'a pas atteint les résultats espérés.

L'obstacle principal dans ces sols provient de la difficulté de stabiliser la composition chimique de la solution du sol, par le seul biais du lessivage énergique. Des réactions permanentes d'échange et d'équilibre entre phases maintiennent une teneur en toxines élevée. La composante microbiologique, de par sa spécificité, constitue également une contrainte, d'autant plus importante qu'elle est mal appréhendée.

A part le lessivage, toute technique essayée a été sans résultat réel. La chaux agricole et l'herbe verte incorporée ont conduit à une forte réduction du milieu ce qui se traduit par une libération massive de composés réduits toxiques.

La cendre de bois a eu une faible influence sur les processus dynamiques de la solution du sol et en combinaison avec la présubmersion, un faible effet stabilisant, exprimé par une diminution du niveau de certaines toxines, telles le fer et les acides organiques. Elle peut constituer un matériau d'avenir pour l'amélioration de ce genre de sol.

M. Khouma et M. Touré

Effets du chaulage et du phosphore sur les rendements du riz sur sols sulfatés acides de Casamance (Sénégal)

On compte environ 600.000 hectares de sols sulfatés acides dans la Plaine Côtière du Sénégal. En Casamance, dans le sud du pays, ces sols sont utilisés pour la riziculture. Les principales contraintes sont: la disponibilité en eau douce, la salinité, l'acidité, combinée avec de toxicités et la carence en phosphore. La topographie facilite le contrôle des niveaux de l'eau.

En réponse aux propositions du Comité d'Organisation du $2^{\bar{e}}$ Symposium International des Sols Sulfatés Acides, une expérience au champ, factorielle, a été conduite avec deux variétés de riz, deux niveaux de phosphore et trois niveaux de chaulage, dans deux sites à sols sulfatés

acides, pendant la saison humide des années 1979-1980.
En 1979 aucune différence significative n'est apparue entre les deux variétés, au niveau des rendements en grains. Le phosphore a eu un effet positif significatif quel que soit le pH qui lui est associé. Au niveau de la production de paille des différences significatives sont notées en faveur de la variété locale, avec une moyenne de 4,5 t/ha contre 2,9 t/ha pour l'IR 1529.
Les résultats de la deuxième année de culture sont moins sélectifs tant au niveau des rendements en grains qu'au niveau de la production de paille. L'analyse statistique ne révèle pas de différence significative entre les différents critères de traitements et de variétés. L'hétérogénéité des résultats provient surtout de la difficulté de reprise des jeunes plants de riz qui ont souffert de la salinité assez importante du sol. La pluviométrie, à cause de son insuffisance et son irrégularité, n'a pas toujours permis d'atténuer les effets du sel. Une irrigation d'appoint a souvent été nécessaire. La variété moderne à cycle court, IR 1529, a manifestement souffert plus de la salinité, et son cycle de croissance a été nettement plus long que celui de la variété locale, qui est relativement tolérante à la salinité, mais produit de grandes quantités de paille. L'effet du pH n'est pas très perceptible dans l'expression des rendements. Les effets favorables de la submersion sur le relèvement du pH des sols acides, ont sans doute contribué à la levée de cette contrainte. Le superphosphate triple a eu un effet favorable indifféremment des sols et des variétés de riz. On a noté aucun effect du chaulage sur les rendements.
On conclut, qu'avec suffisamment d'eau douce et la correction de la carence en phosphore, la riziculture est possible sur les sols sulfatés acides du Sénégal.

Vo-Tong Xuan, Nguyen Kim Quang et Le Quang Tri

La riziculture sur les sols sulfatés acides de la partie Vietnamienne du Delta du Mékong

Dans la partie Vietnamienne du Delta du Mékong environ 60% des terrains sont affectés par les processus d'acidification sulfatique. Les riziculteurs locaux ont développé par essais et erreurs, divers systèmes

d'aménagements, destinés a surmonter les conditions adverses de sols. Le présent article, decrit deux de ces systèmes, particulièrement efficaces, basés tous deux sur la riziculture à régime pluvial: a) un système à drainage superficiel intensif, donnant des rendements de 4 t/ha de paddy sur sols potentiellement sulfatés acides et faiblement sulfatés acides et (b) un système 'éludant' l'acidité, donnant des rendements de 6 t/ha, sur sols sulfatés acides bien développés.
Le dernier utilise des variétés de riz à courte période de végétation, dont le répiquage peut se faire après que le sol a été lessivé des substances toxiques jusqu'à des niveaux supportables, par les pluies de la première période de la saison humide.

P.Y. Toh et Y.C. Poon

Effets de l'aménagement hydraulique sur les rendements des palmiers à huile sur sols sulfatés acides en Malaisie Péninsulaire

Les rendements des palmiers à huile sur différents types de sols sulfatés acides sont examinés en relation avec les différents types d'aménagements hydrauliques.
Dans les zones sévèrement et modérément acides, les rendements ont augmenté de manière appréciable quand après une période de drainage profond, le niveau de la nappe a été relevé. On enrégistrait des augmentations de 36,3% et 17,6% respectivement dans les 4 premières années consécutives à l'élévation du niveau de la nappe. Ces rendements ont été ensuite maintenus à leur niveau.
Des recommendations pratiques sont donnés pour maintenir la nappe à un niveau élevé, avec des mesures pour une évacuation périodique des drains des plantations.

A.L.J. van den Eelaart

Problèmes de la récupération et la mise en culture des zones de marée de Sumatra et Kalimantan, Indonésie

Les zones à marée de l'Indonésie sont déjà mises en culture sur une grande échelle. Des transmigrations et récupérations soit spontanées, soit dirigées par les autorités se poursuivent continuellement à un rythme rapide. La grande partie s'emploie à la riziculture submergée. Les rizières n'ont qu'une mince nappe d'eau de surface même au maximum pluvial, à cause de la grande perméabilité des sols. Pourtant la nappe phréatique reste haute durant toute l'année. L'irrigation à l'eau de marée douce est limitée aux superficies voisines des rivières. Les inondations profondes se produisent seulement là, ou l'action de l'eau de marée est faible ou absente. L'humidité permanente et la submersion peu profonde provoquent un développement abondant des manvaises herbes, ce qui constitue un problème agronomique majeur.

Les sols potentiellement acides occupent des grandes superficies; mais l'acidité potentielle n'affecte généralement pas la couche supérieure de 0 à 30 cm. Ce qui est important pour ces sols, est de garder le niveau de la nappe phréatique à faible profondeur pour prévenir ainsi la forte oxydation de la pyrite. Une limitation importante inhérante à ces terrains est la présence des sols organiques. Avec la technologie peu coûteuse en vigueur, les sols ne sont pas récupérables pour la riziculture submergée quand la couche organique supérieure est plus épaisse que de 70 cm. Conserver les terrains tourbeux en condition de submersion, est encore plus difficile que sur les sols argileux, ceux-là ayant une pérméabilité latérale encore plus haute. De plus, les sols organiques sont généralement pauvres en substances nutritives pour les plantes et ils développent dans l'eau de surface stagnante des composants organiques toxiques; pendant la saison sèche ils risquent de s'assécher irréversiblement.

La seconde culture n'est practiquée que rarement dans les zones de marée. L'irrigation dans la saison rélativement sèche est limitée par la carence d'eau de bonne qualité. Les précipitations pendant cette saison sont insuffisantes pour la submersion des rizières et le riz risque d'y souffrir de la sécheresse en dépit de la faible profondeur de la nappe phréatique. D'un autre coté, des culture sèches à cycle court, succédant au riz, souffrent dans la plus grande partie des années du drainage insuffisant.

Pour accroître la productivité du riz, la submersion des rizières doit être maintenue à un niveau plus haut. Ceci est possible par la construction dans les champs de diguettes à noyau argileux imperméable et d'écluses ou barrages de retenue dans les canaux de drainage. Cependant un certain mouvement d'eau de surface doit être réalisé pour prévenir la stagnation de l'eau qui a apparemment un effet défavorable sur le développement du riz.

Dans l'île de Kalimantan des expériences avec la riziculture double à submersion pluviale (utilisant des variétés de riz résistantes à la sécheresse) se sont montrées prometteuses. Pour les projets supportés financièrement par la Banque Mondiale (IBRD) on a proposé des cultures doubles alternes de riz et de culture sèche à cycle court. Cela demandera un abaissement graduel et prudent de l'eau phréatique pour améliorer les conditions des cultures sèches. Des observations préliminaires dans les champs des fermiers, indiquent que les cultures sèches sont possibles même dans les sols à potentialité sulfaté acide. Un autre effet positif de ce système, est le contrôle plus efficace des mauvaises herbes. L'aménagement hydraulique pour les cultures sèches requiert un réseau dense de fossés peu profondes, avec une structure automatique des fermetures à clapets pour le contrôle du niveau d'eau. Un abaissement excessif du niveau d'eau phréatique en fin de saison sèche, peut être prévenu en faisant entrer l'eau de marée par les fermetures à clapets.

Ainsi l'arboriculture a des possiblités dans les plaines de zones de marée, pourvu que des méthodes adéquates de récupération et mise en culture soient développées et practiquées, comme c'est déjà le cas, localement, pour la culture du cocotier.

F.N. Ponnamperuma et J.L. Solivas

Réactions des variétés de riz à la toxicité du fer sur un sol sulfaté acide

La toxicité du fer dans les sols sulfatés acides est un facteur limitant important pour la croissance et le développement du riz. Bien qu'elle puisse être allégée par le chaulage et le drainage, une solution plus simple et plus économique est celle de la sélection des variétés tolérantes.

Un total de 420 variétés de riz ont été essayées pendant trois saisons (sèche et humide en 1979 et sèche en 1980) dans une expérience dans un champ de ferme à Malinao, province d'Albay, Philippines, sur un sol sulfaté acide (Sulfaquept). 41 variétés se sont montrées tolérantes à la toxicité du fer. La toxicité etait particulièrement sévère durant la saison humide, due apparemment à la forte acidification du sol pendant la saison sèche précédente. Pourtant les variété tolérantes faisaient mieux que les susceptibles dans toutes les saisons. Le degré de tolérance était déterminé par des essais de triage en masse et les résultats corroborés par de déterminations de rendements. Les variétés tolérantes ont donné une production de grains d'environ 3 t/ha quand la toxicité a été très élevée et plus de 6 t/ha quand elle a été modérée. Les variétés séléctionnées permettent d'éviter l'utilisation d'amendements très coûteux (comme le carbonate de chaux par exemple).

Hidenori Wada, Jongruk Chunchareonsook,
Supamard Panichsakpatana, Paiboon Prabuddham,
Tasnee Attanandana et Chakrapong Chermsiri
L'eau, le sol et le riz dans un sol sulfaté acide de
Thaïlande

Quatre parcelles expérimentales, ont été choisies à la Station Expérimentale de Rangsit comme sites d'investigation. Le mouvement vertical de l'eau et la perte par lessivage des substances solubles seraient minimales dans ce sol pendant la plupart des périodes de submersion bien que le drainage interne de ce sol soit extrémement faible. L'eau d'inondation est acidifée et enrichie en SO_4^-, Cl^-, Na^+ et Mg^{2+} par le sol. Ces faits montrent que les substances accumulées dans le sol submergé tendent à diffuser vers le haut et à être transférés à l'eau d'inondation. A l'interface sol-eau se forme une très mince couche acide et oxydée qui peut inhiber en partie les processus de nitrification et dénitrification du sol superficiel. Le profil vertical du Fe^{2+} et NH_4^+ dans l'horizon Apg supporte l'idée d'une diffusion vers le haut de ces substances. Le déplacement de NH_4^+ dans le courant de l'eau d'inondation est proposé comme l'un des principaux processus de la perte en azote du sol sulfaté acide. L'activité de la fixation d'azote qui est faible au début, devient très élevée au stade de la floraison pour diminuer ensuite au moment de la récolte. La diminution de l'activité des fixateurs d'azote dans la dernière période peut avoir été causée par une diminution de la population des microorganismes actifs. L'azote absorbé par les plants de riz se trouve être sensiblement égal au taux de l'azote assimilable du sol.

Resumés des communications concernant la pisciculture affectée par les sols sulfatés acides

R. Brinkman et V.P. Singh

Amélioration rapide des étangs piscicoles à eau saumâtre en sols sulfatés acides

L'amélioration pour l'agriculture des sols sulfatés acides est généralement considérée comme un processus très lent.
De même la productivité des étangs piscicoles à eau saumâtre, sur sols sulfatés acides reste très faible pendant les premières 5 à 15 années après leur construction ou leur réexcavation profonde. Ceci est dû au faible développement des algues qui constituent la nourriture des poissons, et à la mortalité intermittente des poissons à cause de l'extrême acidité de l'eau provenant du suintement des digues environnantes pendant les pluies après les longues périodes de sécheresse.
Pourtant à proximité des criques de marée et en climat à saison sèche prononcée, il y a d'amples opportunités de manipuler l'eau des étangs et ainsi de récupérer à la fois les fonds et les digues d'une piscine pendant une seule saison sèche selon une procédé simple et à frais modérés.
Le procédé consiste dans un fort dessèchement et en labourage superficiel à sec du fond de l'étang jusqu'à ce qu'il craque à une profondeur d'environ 10 cm, suivis d'inondations repetées avec de l'eau salée ou saumâtre. L'eau est rafraîchie tous les deux jours jusqu'à ce que le pH reste supérieur à 5. Ce cycle de dessiccation complète et inondations se fait à plusieurs reprises jusqu'à ce que le pH de la première inondation après la dessiccation reste au dessus d'environ 5. Ainsi les acides dans le fond sont éliminés par diffusion vers l'eau de surface plutôt que par le lessivage dans le soussol.
Les travaux d'amélioration des digues sont simultanés. On construit d'abord des diguettes le long des deux bords du sommet plat des digues,

ou bien on creuse un fossé médian peu profond. Des diguettes transversales sont ajoutées aux endroits où l'élévation des digues change. L'eau salée ou saumâtre est pompée dans les petits bassins sur le sommet des digues en même temps qu'on inonde le fond de l'étang. De même, les digues sont séchées en même temps que le fond de l'étang.

Avec ce procédé, les étangs piscicoles à eau saumâtre de sols sulfatés acides, sont devenus productifs en une seule saison sèche suivant la construction ou la réexcavation. Les poissons Chanos Chanos ont donné une production d'environ 0,4-0,5 t/ha à chaque quadrimestre, ce qui représente une production similaire à celle obtenue dans les étangs à eau saumâtre bien aménagés des argiles marines non-acides.

V.P. Singh

Cinétique de l'acidification pendant l'inondation après asséchement d'un matériau sulfaté acide: Implications pour l'aménagement des étangs piscicoles à eau saumâtre

Des expériences pour simuler les conditions en étangs piscicoles creusés en argiles sulfatées acides et non-acides (neutres mais avec carence en P) dans la zone de marée des Philippines ont été menées dans des bassins en fibres de verre contenant 35 cm de sol, séché auparavant, submergé avec 30 cm d'eau saumâtre. Après 3 semaines d'inondation initiale, la composition de l'eau superficielle et de lessivage a été déterminée chaque semaine pendant 30 semaines. L'eau d'inondation à été rafraîchie à la semaine 18. Des essais d'apports d'engrais comprenant des applications d'azote et de phosphate dans l'eau superficielle ainsi qu'un contrôle sans engrais, ont été menés.

La croissance des algues dans l'eau superficielle a été très faible sur sol sulfaté acide et bonne sur sol neutre.

Sur sol sulfaté acide, le pH de l'eau a diminué progressivement de 4 à 3. Les concentrations en Al se sont élevées et tombées 2 fois de 0-3 mg/l aux semaines 0 et 18 à des maximas comprises entre 14 et 26 mg/l aux semaines 10 et 28. Les sulfates se sont élevées d'une teneur initiale de 2 g/l à des valeurs comprises entre 4,3 et 6,2 g/l, sans décroître au moment du changement de l'eau d'inondation.

Les teneurs en Fe s'élevaient de 0 à 7-10 mg/l à la semaine 18, puis brusquement à des maximas de 20-25 mg/l après le changement d'eau, suivis de fortes fluctuations allant de 0,5 à 34 mg/l.

Sur sols neutres, le pH de l'eau demeurait élevé et au dessus de 7, avec une augmentation temporaire à la semaine 18 au moment du changement d'eau. Les concentrations en Al se situaient au dessous de 0,2 mg/l, tandis que les sulfates variaient de 3050 mg/l à des teneurs comprises entre 3400 et 4000 mg/l. Les concentrations en fer s'élevaient de 0,2 mg/l à 2 mg/l aux semaines 6 et 7 puis décroissaient progressivement jusq' à environ 0,1 mg/l.

Le pH de l'eau de lessivage du sol sulfaté acide s'élevait de moins de 4 jusq' à environ 5,5; l'Al décroissait progressivement de 40 à moins de 2 mg/l. Les sulfates variaient entre 7200 et 8500 mg/l. Le fer s'élevait progressivement de 1000 mg/l à environ 3500 mg/l avec une diminution brutale à la semaine 22.

Dans l'eau de lessivage des sols neutres, le pH se situait entre 6 et 7, l'Al entre 0,1 et 1 mg/l, les sulfates s'élevaient de 2100 à 4200 mg/l à le semaine 20. Les teneurs en Fe étaient de 5 à 100 mg/l à la semaine 5 et se maintenaient ensuite à ce niveau.

Les expériences sur les divers traitements de fertilisation n'ont montré aucune influence des applications de N et de P sur la cinétique des deux types de sol submergés. Dans les étangs piscicoles sur sol sulfaté acide aucun effet positif ne se peut être espéré de la fertilisation avant l'amélioration de la couche superficielle des fonds. Dans les étangs améliorés l'effet de la fertilisation est toujours de courte durée et pour une fertilisation efficiente il faut practiquer d'applications fréquentes de faibles doses d'engrais.

V.P. Singh

L'amélioration et la mise en valeur de sols sulfatés acides dans la pisciculture en étangs à eau saumâtre.

Expériences aux Philippines

La productivité d'étangs piscicoles dans les zones de sols sulfatés acides est affectée par l'état de l'amélioration des fonds et les digues, le traitement des fonds d'étang drainés temporairement entre les cultures, la fréquence et le mode de fertilisation, et les pratiques de placement d'alevins. Dans les zones de sols sulfatés acides des valeurs de pH (d'échantillons pris des fonds séchés à l'air) inférieures à 5 sont corrélatives à la carence en P et celles au dessous de 4,5 aux concentrations d'aluminium potentiellement dangereuses pour la pisciculture. De sols de fonds extrêmement acides persistent ainsi pendant plus d'un mois d'inondation. Par contre avec un chaulage léger et superficiel à raison de 0,5 t de la chaux par ha avant l'inondation, le pH du sol de fond monte rapidement après la submersion dû à la réduction. Dans les expériences sur étangs partiellement améliorés, le meilleur développement d'algues a été obtenu avec le chaulage combiné avec une application (dans l'eau) d'engrais à rapport N à P_2O_5 de 2 à 1 ou 4 à 1, appliqués fréqemment à faibles doses. Les applications de P ne restaient effectives que pendant 2 semaines, indifférent de leur dose. De larges doses de chaux par elles mêmes ne sont pas effectives dans la récupération d'étangs sulfatés acides.

Bien practique est le chaulage modéré combiné avec le procédé d'amélioration, décrit par Brinkman et Singh (ce symposium) constituant d'une reïtération de dessèchement et labourage superficiel du fond et des digues suivie par de submersions et drainages répétés.

Résumés des communications diverses

A.K. Alva et S. Larsen

Application de la technique des traceurs pour l'étude de la dynamique des phosphates dans un sol sulfaté acide submergé

Les techniques des traceurs sont efficaces pour étudier la dynamique du P dans un sol sulfaté acide submergé cultivé en riz. Cette étude porte sur les transformations du P labile d'un sol sulfaté acide de la Plaine Centrale de Thaïlande.

Pendant la période de croissance du riz, le P assimilable a été estimé par la détermination de la dilution isotopique du P absorbi par les plantes (valeur L) et aussi en déterminant l'échange isotopique dans le sol (valeur E). L'influence des différents niveaux de N, P et K appliqués sur le P labile et la récupération du P appliqué, ont été examinés dans une chambre de croissance. Pendant la période de croissance les valeurs L ont augmenté jusqu'à 80 jours après le repiquage et subséquemment, ont diminué vers la maturité de la plante, dû à la mobilisation du phosphore par les plantes, suivi d'une immobilisation. L'influence de la culture du riz sur le P labile a été appréciable 50 jours après le repiquage. Les valeurs L et la récupération du P appliqué, pour un taux uniforme d'application de P, ont augmenté avec l'enrichissement en N et K. Pour un niveau donné d'application de N et K accompagné d'un enrichissement faible en P, la récupération du P appliqué est resté constant pendant la majeure partie de la période de croissance tandis qu'à des niveaux élevés d'enrichissement de P, la récupération en P décroit pendant la période de croissance. Les influences de la nutrition minérale sur la dynamique de P sont discutés. Des valeurs E sont considérablement plus élevées que les valeurs L au stade de la maturité de la plante. Les causes possibles de cette divergence sont discutées.

Le Ngoc Sen

Une méthode simple et peu coûteuse pour prélever des échantillons en structure naturelle de profils de sols sulfatés acides, pour l'étude du mouvement de l'eau et de la solution du sol durant l'amélioration et la riziculture

Une méthode simple, à bas prix, a été élaborée pour prélever, transporter et équiper des échantillons cylindriques de sol non perturbés. Cette méthode a été utilisée pour tester les différentes combinaisons des mesures de récupéreration des sols sulfatés acides pour la riziculture. Les échantillons doivent être assez grands pour pouvoir recevoir plusieurs plantules de riz jusqu'à leur maturité. Des bidons de pétrole ayant un diamètre intérieur de 50 cm et une longueur de 90 cm ont été utilisés à la fois comme sonde et comme lysimètre. Les fonds des deux côtés sont dégagés et réconstruits en convercles démontables et toute la surface métallique a été protégée avec une peinture inerte. Le cylindre ainsi obtenu est pressé dans le sol pendant que le sol autour du bord tranchant est entaillé. Des profils de sol d'une profondeur de 0,85 cm ont été ainsi obtenus. Des cylindres remplis les fonds sont scellés et l'ensemble apportée dans la station expérimentale. Des tuyaux de matière plastique, pourvu de filtres sont installés dans les perforations à différentes profondeurs du profil pour y déterminer l'humidité et la composition de la solution du sol durant l'amélioration du sol et la croissance des plantes.

Quoique cette méthode soit plus proche des conditions naturelles de terrain que la méthode des pots de végétation, elle ne permet pas de mesurer les effets de l'écoulement latéral de l'eau.

Le présent article, décrit seulement la méthode de travail, les dessins des cylindres lysimètre, la technique d'encaissement et l'équipement. Les résultats obtenus seront publiés prochainement.