Selected Papers of the Dakar Symposium on Acid Sulphate Soils

Dakar, Senegal, January, 1986

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Edited by
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Preface

This selection of papers reflects the current developments in the study of Acid Sulphate Soils, which were discussed at the Third International Symposium on Acid Sulphate Soils, held in Dakar, Senegal, from 6 to 11 January 1986.

Most of the information that was presented at the Dakar Symposium elaborated on subjects that had been broached at the earlier symposia held in Wageningen (1972) and Bangkok (1981). The conclusions and recommendations of Dakar demonstrate the persistence of the problems that are encountered in investigating and using acid sulphate soils.

A matter of special concern to the editor was the diversity of criteria and terminology that was used by the symposium's participants. The semantic confusion this caused in the papers exceeded the editor's capacities in some cases. In part, this imperfection is a symptom of an – in other respects favourable – innovative development, i.e. the tendancy to consider acid sulphate soils as part of soil-water-plant systems and, consequently, to widen the disciplinary scope of the subject matter.

In Dakar, the influence of this development became apparent in a shifting of the focus to fresh aspects of conventional subjects. In this context, we mention the presentation of several cases of acid sulphate soil phenomena from upland areas. The need to study the variety and variability of essential soil properties over a wide range of temporal and spatial orders of magnitude was emphasized in several presentations. Corresponding innovations were the introduction of geostatistical analysis and improved methods of identifying active and potential acidity. The refinement of mathematical models that simulate essential processes, and the renewed attention for microbiological and plant physiological processes, are sustaining this multidisciplinary approach.

In adapted research, the same holds for various papers on pisciculture and forestry as alternatives to the conventional use of acid sulphate soils for rice cultivation and also for papers on the environmental and socio-economic aspects of reclamation projects.

The present volume contains most of the papers that demonstrate this widening diciplinary scope. Most other papers will be published in a complementary volume.

For the editing and translating of the papers into French, the editor is indebted to Dr. Nadia Pons-Ghitulescu.

The Editor.

Avant-Propos

La présente sélection des articles reflète le développement actuel des études des sols sulfatés acides, comme ceci a été mis en évidence durant le 3e Symposium International sur les Sols Sulfatés Acides, tenu à Dakar, du 6 au 11 Janvier 1986.

La plupart des informations présentées au Symposium de Dakar concernent des sujets qui ont déjà été traités durant les précédents Symposias de Wageningen (1972) et Bangkok (1981). Les conclusions et les recommandations de Dakar montrent la persistance des problèmes rencontrés dans la recherche concernant la mise en valeur des sols sulfatés acides.

Un problème d'un souci particulier pour le rédacteur a été la diversité des critères et la terminologie variée utilisées par les participants au Symposium. La confusion sémantique dont certaines des communications ont fait preuve a dépassé parfois les capacités du rédacteur. Mais comme partiellement cette imperfection est un symptôme du développement innovatif de la tendance, entre autre, de considérer les sols sulfatés acides comme partie intégrante du système sol-eau-plante et par conséquence d'élargir la champ disciplinaire du sujet, on peut la considérer comme étant une imperfection favorable.

A Dakar, l'influence de ce développement s'est manifesté par un déplacement du centre d'intérêt vers de nouveaux aspects des sujets conventionnaux. La présentation de plusieurs cas des sols sulfatés acides sur terres élevées peut être un exemple dans ce contexte. La nécessité d'étudier la variété et la variabilité des principales propriétés du sol sur grande échelle dans le temps et dans l'espace a été soulignée dans différentes publications. Des innovations analogues sont entre autre l'introduction d'analyse géostatistique et des méthodes améliorées potentielles de discernement et d'identification de l'acidité actuelle. Le perfectionnement des modèles mathématiques simulant les processus essentiels, ainsi que l'attention renouvelée pour les processus de microbiologie et de physiologie des plantes, soutienent l'approche multi-disciplinaire du sujet.

Dans le domaine de la recherche adaptée, le Symposium de Dakar a fourni des articles divers sur la pisciculture et la foresterie comme utilisation alternative à côté de l'utilisation rizicole. L'élargissement du champ disciplinaire a été démontré également par les articles concernant l'étude de l'environnement et des aspects socio-économiques des projets d'amélioration.

La publication présente contient les articles qui soulignent les développements innovateurs mentionnés. Les autres contriebution ont été publiés dans un volume complémentaire et dans une forme plus économique.

Pour la rédaction des communications présentées en français, ainsi que pour les traductions en langue française, le rédacteur reste obligé à la Dr. Nadia Pons-Ghitulescu.

Le Rédacteur.

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Morphology and genesis of actual acid sulfate soils without Jarosite in the Ha Tien Plain, Mekong Delta, Viet Nam

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1 Summary

Actual acid sulfate soils without jarosite in the sulfuric horizon occur widely in the north-western part of the Mekong Delta. They differ morphologically from acid sulfate soils with jarosite in the following aspects: they have peaty clay parent material; have a dark brown subsoil; show low porosity and saturated hydraulic conductivity; pyrite is intensively mixed in the matrix of the subsoil; the sulfuric horizon still contains pyrite; they are potentially acid to great depth.

The absence of jarosite is probably due to the low redox potential in the sulfuric horizon. Redox potential is kept low by the organic matter. Under such conditions, pyrite only oxidizes to ferrous sulfate, not to jarosite.

Résumé

Des sols sulfaté-acides sans jarosite, mais présentant toutes les autres caractéristiques de ces sols (pH < 3,5 dans l'horizon oxydé, teneur élevée en sulfures, teneur élevée en Al et Fe dans la solution de sol, saturation élevée en Al), apparaissent sur de grandes superficies dans la partie nord-ouest du Delta du Mekong, dans la Plaine de Ha Tien. Morphologiquement ils diffèrent des sols sulfaté-acides à taches de jarosite par:

- un materiau originel tourbeux;
- un sous-sol brun foncé (10 YR 4/3) à brun gris (10 YR 4/1) qui après avoir été exposé à l'air, devient en quelques minutes gris très foncé (N 3/0);
- une porosité et une conductivité hydraulique en milieu saturé, basse;
- un horizon sulfurique contenant encore de la pyrite;
- une teneur en pyrite assez importante, intimement melangé dans la matrice du sous-sol.

L'analyse de l'acidité totale et potentielle (Méthode Konsten et al 1986), montre que le sous-sol de ces sols présente une acidité actuelle et potentielle beaucoup plus élevée que les sols sulfaté-acides à taches de jarosite.

L'absence du jarosite est probablement due au faible potentiel redox de l'horizon sulfurique, qui est une conséquence de la haute teneur en matière organique. Dans telles conditions, la pyrite est oxydée en sulfate ferreux et non pas en jarosite.

2 Introduction

Field studies of the acid sulfate soil areas of the Mekong delta revealed the occurrence of extensive tracts of acid sulfate soils without the conspicuous straw-yellow jarosite mottles in the oxidized zone, but having all other properties associated with acid sulfate soils: a very low pH < 3.5 in the oxidized horizon; high sulfate, aluminum and iron contents in the soil solution; a high Al saturation percentage. Detailed soil profile descriptions of such profiles were made in the field. Samples for thin sections were taken from actual acid sulfate soils without and with jarosite, for micromorphological study.

3 Morphological observations

The morphological studies showed differences in several characteristics between profiles with and profiles without jarosite.

Profiles without jarosite generally have a dark brown (10YR 4/3) to dark grey (10YR 4/1) subsoil. Upon exposure to the air, the colour of the subsoil of these profiles without jarosite changes to very dark grey (N 3/0) within a few minutes. In many cases profiles with jarosite have grey, blueish grey or greenish grey subsoils with a value higher than 4, and in variably a chroma of 1.
The colour does not change upon exposure.

The subsoils of profiles without jarosite have a high organic matter content (10-15 mass percent). The organic matter is intensively mixed in the soil matrix, fibrous, and densely packed. The subsoils of profiles with jarosite have a low organic matter content. Organic matter in these soils is usually found as partly decomposed root or leaf remnants.

The subsoils of profiles without jarosite have few very fine pores, and a low saturated hydraulic conductivity. The porosity in the subsoils of profiles with jarosite is high: medium sized or coarse continuous vertical pores are common and there are many fine pores. The saturated hydraulic conductivity is high.

Micromorphological observations confirmed the finely fragmented nature of the organic matter and the intensive mixing with the matrix clay in the suboils of the profiles without jarosite. A part of the organic matter could be recognized as having cellular structure. Most of these parts were only fragments of leaves or roots. Pyrite, too, was found intensively mixed into the clay matrix. It did not only occur associated with organic matter, but also in the clay, separated from organic matter.

In acid sulfate soils with jarosite, little or no finely fragmented organic matter is found mixed with the matrix clay. Clearly recognizable half decomposed roots and leaves form the majority of the organic matter in these subsoils. The pyrite is concentrated in the root channels and associated with the organic matter.

The lower part of the sulfuric horizon of profiles without jarosite still contains pyrite, seen as isolated pyrite framboids. In sulfuric horizons of acid sulfate soils normally pyrite and jarosite are spatially separated with the exception of cases in which the initial supply of oxygen is abundant and sudden, for example upon artificial drainage (Miedema et al. 1974). The presence of small remnants of pyrite evenly distributed over the lower part of the sulfuric horizon in acid sulfate soils without jarosite may be an indication of the slowness of the pyrite oxidation in these soils.

In a few places pyrite centres are surrounded by iron (hydr)oxydes but the structure of the framboids is still visible. This phenomenon may have to be attributed to quick oxidation during preparation of the thin sections. No pyrite was seen in the lower part of the sulfuric horizon of profiles with jarosite.

Thin sections of the sulfuric horizon of profiles without macroscopically visible jarosite do show some small traces of jarosite along the few macropores present. However, these are incorporated in the soil and do not occur as pure jarositans along root channels, as is the case in the acid sulfate soils with jarosite mottles.

Analysis of total and potential acid by the method of Konsten et al. (1986) has shown that the subsoils and substrata of soils without jarosite have much higher actual + potential acid contents then soils with jarosite (Brinkman et al. 1986). Pyrite contents up to 4% using the method of Begheyn et al. (1978) have been found in the pyritic subsoil of the profiles without jarosite.

4 Discussion: genesis of acid sulfate soils without jarosite

4.1 Sedimentation of the parent material

The high organic matter content of the sediment can be explained by the age of the sediment: it was formed more than 5500 years ago in a period of rising sealevel and slow sedimentation affecting large areas (Pons 1986; Brinkman et al. 1986). The fragmented and fibrous nature of the organic matter and the intensive mixing of organic matter and pyrite with the matrix clay indicate that originally clayey sediments and peat must have been eroded, reworked, mixed and redeposited by action of the sea. The low macroporosity of the sediment indicates that there was no significant period of mangrove forest vegetation after the redeposition because mangrove roots normally produce common coarse and medium tubular pores.

4.2 Drainage and acidification

When such a dense, highly organic sediment with low porosity is drained, it remains water-saturated due to its spongy structure, and oxidation is very slow. Oxygen diffuses slowly into the water-saturated sediment; microbial decomposition of organic matter keeps the Eh low. Therefore it is likely that upon drainage of the sediment the Eh rises to a level which permits the oxidation of sulfide to sulfate, but not the oxidation of Fe (II):

$$FeS_2 + 7/2\,0_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

Jarosite is formed at low pH (less than 4.0) and at Eh higher than about 400 mV (van Breemen 1976). At lower Eh values, pyrite can still be oxidized, but only to dissolved ferrous sulfate, pH values measured in the sulfuric horizon of acid sulfate soils without jarosite are in the range of 2.4 – 2.6; Eh values are between 300 and 400 mV, measured by pushing a Pt electrode directly into the mud, after standardization by comparison with a ferrous/ferric solution with an Eh of 430 mV.

The presence of high concentrations of ferrous iron in the Vietnamese acid sulfate soils without jarosite was confirmed by a field test. An aqueous solution of 5% potassium ferric cyanide was added to the soil solution from sulfuric horizons in profiles without jarosite, and showed a strong colour change to dark blue (ferrous ferric cyanide), indicating high concentrations of dissolved ferrous iron. Laboratory analysis showed ferrous iron concentrations in the vicinity of 500 to 1000 ppm Fe, or pFe between 1.5 and 2.

A stability diagram (Figure 1) of jarosite and dissolved ferrous sulphate was calculated for various levels of pFe. Lower values of pFe (meaning high concentrations of ferrous iron) move the boundary between the stability zone of jarosite and dissolved ferrous iron sulfate downwards considerably. However, the above mentioned values of Eh and pH show stability of dissolved ferrous sulfate.

Micromorphological observations confirmed the slow progress of the oxidation process by the presence of partly oxidized pyrite in the lower part of the sulfuric horizon.

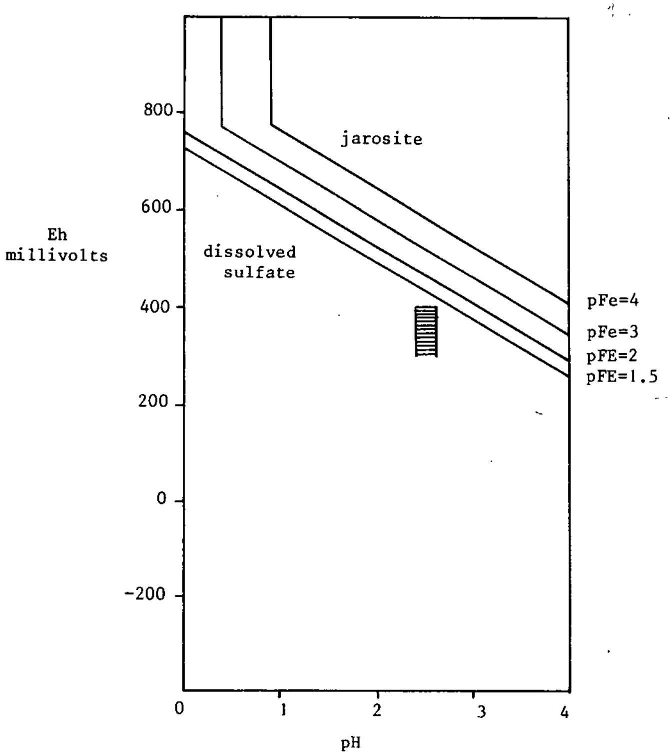

Figure 1 Stability diagram of jarosite and dissolved sulfate. Lines indicate solubility isotherms for jarosite at different levels of Fe^{2+}. Shaded area indicates pH and Eh measurements in Vietnamese acid sulfate soils without jarosite.

Acknowledgements

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Les sols du domaine fluvio-marin de Casamance (Sénégal): Evolution récente et reevaluation des contraintes majeures pour leur mise en valeur

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1 Résumé

La situation pluviométrique que connaît la Casamance depuis une quinzaine d'années, a entraîné une sécheresse aux conséquences dramatiques pour le domaine fluvio-marin.

L'augmentation considérable des surfaces salées de 'tannes' au détriment de la mangrove à palétuviers en voie de dégradation, et une progression du front de salinité vers les plateaux, en sont les conséquences les plus visibles; la salinité croissante à tous les niveaux des bassins-versants, masque l'acidité des sols. La chronologie de cette évolution se retrouve dans les différents bassins-versant, selon un gradient latitudinal. Au niveau des aménagements, cette inversion des contraintes pédologiques majeures, amène à reconsidérer la conception et la situation des ouvrages anti-sels ainsi que le mode de récupération des ces terres déjà acidifiées et hypersalées en particulier par poldérisation avec drainage.

Summary

Low rainfall for the last fifteen years has had dramatic consequences on the mangrove soils of the Casamance. The most visible effect has been the expansion of the salty 'tannes' at the expense of the already degraded mangrove forest and toward the plateau. This increasing salinity masks soil acidity. In each watershed this evolution is taking place more rapidly in the north than the south. This inversion of soil constraints, requires a reevaluation of the models of anti-salt dams and the techniques for rehabilitating these acid, very salty lands through dikes and drainage.

2 Introduction

Le domaine fluvio-marin de Casamance, dans la partie Sud du territoire Sénégalais, couvert par le domaine climatique soudanien à soudano-guinéen, présente une grande variété de sols, tous développés sur des sédiments récents. Ces sols ont connu ou connaissent encore sous les conditions actuelles, une potentialité sulfatée-acide, mais leur niveau d'évolution est aujourd'hui très variable selon les sites; en outre, la sécheresse persistante depuis plus de quinze ans et aggravée ces dernières années, a accéleré leur transformation en beaucoup d'endroits. Cette dynamique qui se poursuit, remet en cause l'aménagement de ces sols dont la problématique établie sur des données anciennes, antérieures à cette évolution, doit être révisée.

3 Typologie des bassins-versants

Le domaine fluvio-marin de Casamance qui couvre près de 400 000 ha, est occupé à l'aval du plateau continental, par une séquence classique de sols, organisée selon trois grandes unités (Figure 1) (Lamagat et Loyer, 1985):

- En tête de vallée, se raccordant aux 'sols gris' de fin de pente, sont différenciés des sols Hydromorphes à gley ou pseudogley, argileux (localement sableux) et soumis à l'influence d'une nappe phréatique d'eau douce, normalement peu profonde. Des traces d'anciennes invasions marines peuvent y être décelées en profondeur sous forme de racines de palétuviers. Cette unité est ocupée par des rizières douces et totalement aménagée en parcelles endiguées ce qui limite considérablement le ruissellement sur ces sols. La transition avec l'unité aval se fait par plusieurs niveaux de terrasses emboîtées et occupées par des sols Peu Evolués et Hydromorphes également sains et rizicultivés.
- En raccordement avec la zone des terrasses, les sols de 'tannes' (mot vernaculaire sénégalais désignant des surfaces salées, dénudées ou occupées par une strate herbacée), sont atteints par les marées de vives eaux et totalement depourvus de végétation ('tannes' vifs), à croûte saline ou structure poudreuse; ils sont anastomosés avec des unités de 'tannes' à halophytes ou herbeux exondés. Ces unités qui, sous climat guinéen, sont peu étendues ou même inexistantes, sont occupées ici par des sols parasulfatés acides relativement evolués par rapport à la vasière dont ils sont issus, chimiquement encore acides (pH de l'ordre de 4), mais ayant subi une certaine maturation physique. Les sulfates y précipitent sous formes diverses, jarosite, parfois gypse, et même sulfates d'aluminium hydratés (Alunite, Pickéringite); la nappe y est très peu profonde (0 à 120 cm selon la marée et la situation).
- Les vasières à mangrove proprement dite, soumises à l'influence des marées biquotidiennes, sont plus ou moins riches en fibres selon la nature de peuplement de palétuviers, des Rhizophora aux Avicennia, adaptés à un niveau de salinité croissant. Leur potentialité acide, due à la richesse de ces fibres en produits sulfurés, est neutralisée tant que la submersion s'y maintient. Ces vases par ailleurs très riches en matière organique, ont traditionnellement constitué de bonnes terres de riziculture profonde, sous réserve de précautions quant à leur dessalinisation et contre leur acidification, que les paysans maîtrisent bien (billonage et submersion). La dégradation de ces sols par oxydation consécutive à un drainage naturel ou anthropique, conduit à une acidification brutale dite irréversible (sols sulfatés acides à pH $\leq$ 3) (Vieillefon 1984, Marius 1984).

4 Evolution récente

Cette séquence peut être considérée en Casamance, représentative de la période à pluviométrie normale, antérieure aux années 1967/1968, avec un gradient depuis le climat guinéen méridional, où le terme intermédiaire de 'tanne' est peu ou pas représenté, au climat soudano-guinéen ou il est nettement différencié dans les séquences.

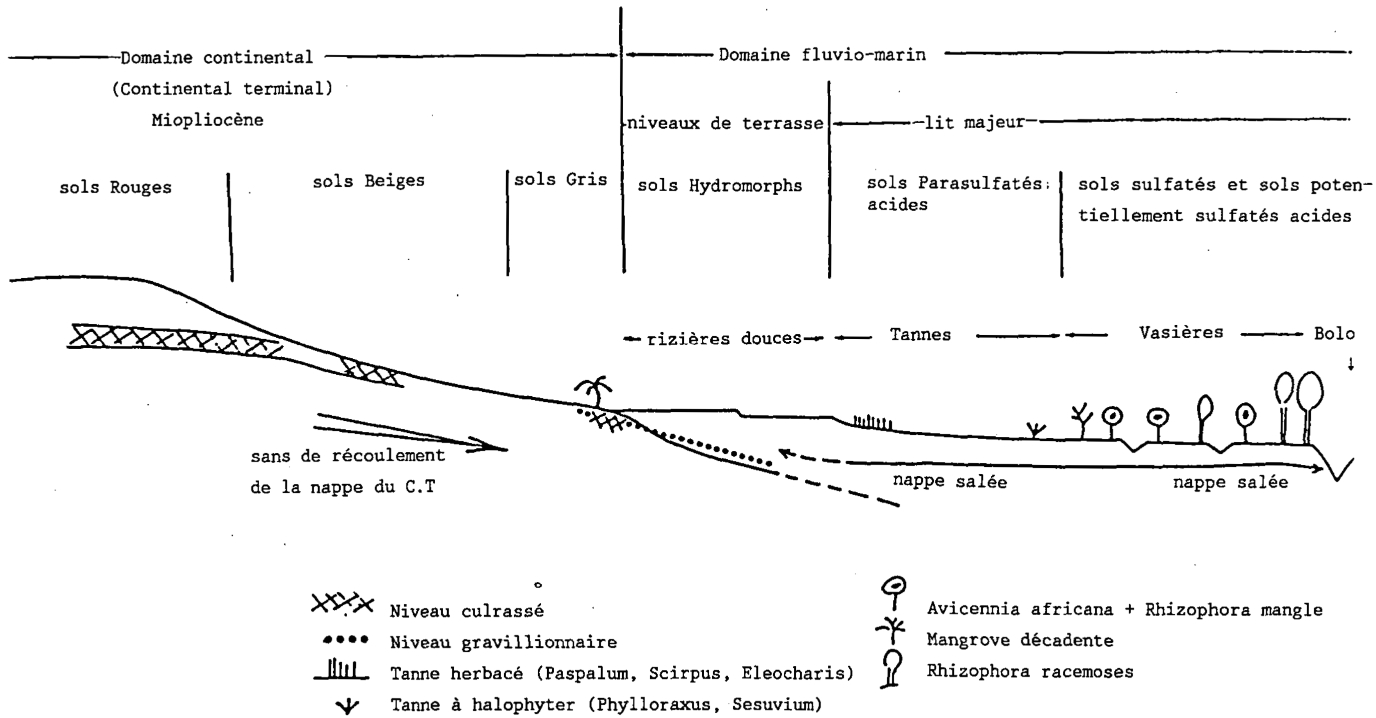


Figure 1 Schéma d'une toposéquence classique transversalement au marigot

Ces dernières années, en raison de la persistance des conditions pluviométriques déficitaires, on assiste à une dégradation chronologique des diverses séquences que le gradient latitudinal met particulièrement en évidence et dont le processus est le suivant:

- Le déficit en eaux pluviales a profondément affecté la qualité des eaux qu'elles soient de surface ou de nappes dans les bassins-versants; en 1983 par exemple, des mesures faites (Le Reste, 1983) ont montré que, en fin de saison des pluies, la salinité du profil en long du fleuve Casamance était inversée par rapport à la normale; les eaux amont (au niveau de Diattakounda) étant plus chargées que celles de l'ocean.
- Parallèlement, des campagnes de mesure réalisées en 1983 et 1984 sur le bassin-versant du marigot de Koubalan (Boivin et Le Brusq 1984 et 1985) ont mis en évidence deux faits particulièrement préoccupants:
  - d'une part, la présence au niveau des 'tannes' et des vasières, de nappes peu profondes deux à trois fois plus sallées que l'eau de mer (80 à 120 mmhos/cm) et de solutions du sol également très chargées (5 à 15 mmhos/cm sur extrait 1/5);
  - d'autre part, des niveaux piézométriques inversés qui montrent que ces nappes drainent, en saison sèche des 'tannes' vers le plateau continental.

Sous l'effet du processus évaporatoire intense qui se manifeste pendant la longue saison sèche et chaude (8 mois) cette salinisation qui affecte les sols et les eaux, envahit le paysage masquant l'acidification, avec comme conséquences les plus visibles:

- Au niveau des 'vasières', un rétrécissement de la mangrove à Rhizophora sur les bras principaux; sa disparition presque totale sur les bras secondaires; son remplacement par une mangrove à Avicennia mieux adaptée à l'excès de sel, mais elle-même atteinte actuellement de mortalité massive.
- Au niveau des 'tannes', une augmentation considérable des surfaces hypersalées et stériles ('tannes' vifs) développées aux dépens de la mangrove et qui occupent la majeure partie des bassins de la rive droite (Baïla, Bignona, Soungrourou); sur le bassin de Koubalan par exemple, la mangrove régresse, de 34% de la superficie du moyen bassin en 1969, à 16% en 1984 (Boivin et Le Brusq 1985).
- Au niveau des rizières douces, l'abaissement de la nappe d'eau douce et sa contamination par les nappes salées ont comme première conséquence une salinisation et un abandon par la riziculture des zones de bordure (terrasses) avec dans les bassins les plus septentrionaux (Soungrourou), une intrusion du front salin jusqu'à la palmeraie partiellement atteinte de mortalité. Les différentes étapes de cette évolution chronologique peuvent être retrouvées dans les différents bassins du Sud au Nord du territoire (Figure 2 et 3).
- A l'extrême Sud, les marigots de la rive gauche du fleuve, type Anyak, où du fait de la configuration même du bassin versant (altitude) et de sa situation méridionale plus humide, seules les unités rizières douces et vasières sont représentées; le bassin de Guidel montre un profil en long pratiquement similaire avec très peu de tannes; la création d'un réseau de drainage entre 1968 et 1974, a en outre dégradé une partie des sols potentiellement sulfatés acides de cette vallée (Marius et Cheval 1983).
- Plus au Nord, les marigots de Koubalan et Tapilane présentent la succession rizières douces, 'tannes' et vasières, ces dernières en voie de dégradation. Les marigots de Baïla et Bignona ont la même configuration avec actuellement une augmentation considérable des surfaces de tannes par rapport aux années humides; ceci est le cas de tous les affluents de la rive droite du fleuve.

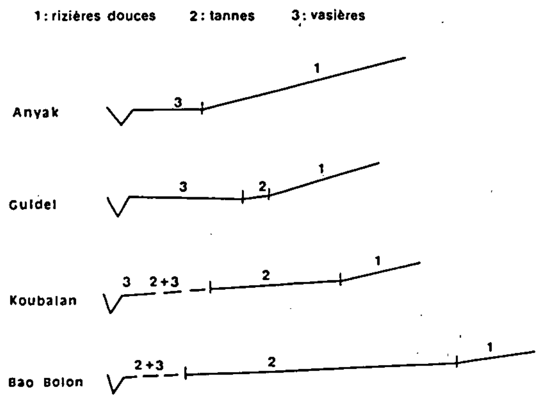
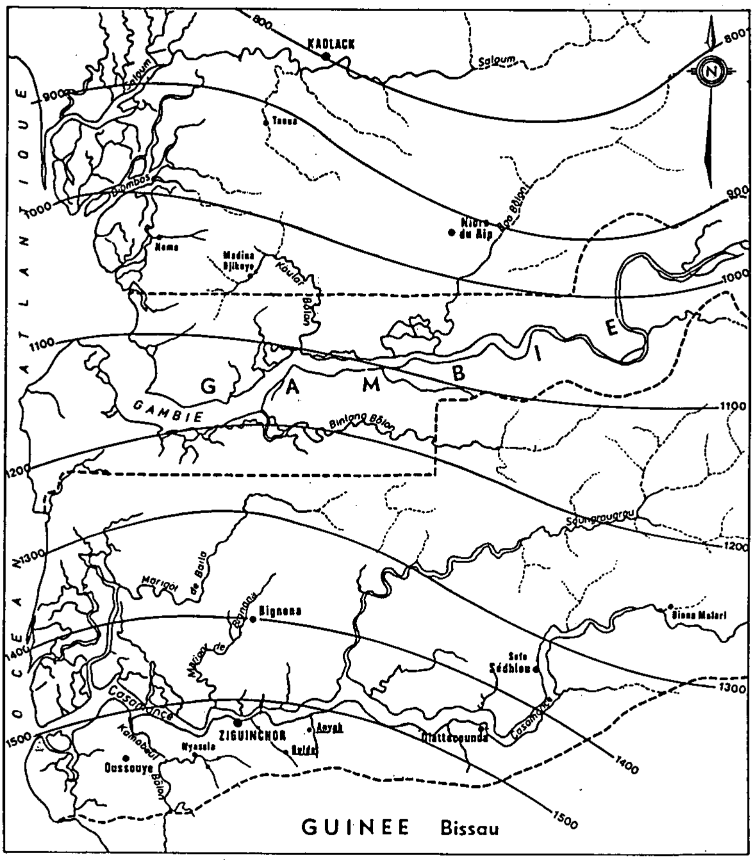


Figure 2 Représentation schématique des séquences fluvio-marines dans differents bassins-versants



Echelle = 1/1250000 environ

Figure 3 Carte de situation et isohyètes moyennes annuelles (période humide)

- Un cas extrême d'évolution, bien qu'il soit en dehors de la Casamance, est celui du Bao-Bolon dans le Siné-Saloum. Cet affluent de la Gambie, pratiquement coupé du cours d'eau principal, constitue un vaste bassin évaporatoire couvert par un immense 'tanne' vif, sulfaté acide et hypersalé, entrecoupé de lambeaux de 'tanne' herbeux. Les parties rizières douces et vasières de la séquence y sont très peu représentées.

Il apparaît donc aujourd'hui après ce long cycle de sécheresse, que l'acidité, si elle est toujours potentielle dans les mangroves et spectaculaire à ses débuts (pH voisin de 2) (Marius 1985), est aujourd'hui masquée par une salinité extrême qui affecte tous les niveaux des bassins fluvio-marins et plus particulièrement les 'tannes'. Le pouvoir tampon de certains constituants favorisant une lente remontée du pH au niveau des sols.

5 Les aménagements hydro-agricoles

La riziculture profonde traditionnellement pratiquée par les paysans dans les vasières, a servi de modèle à d'audacieux projets de barrages destinés à étendre cette pratique sur ces terres marginales potentiellement acides, mais riches en matière organique. Ces ouvrages, dont la conception remonte à 25 années, doivent remplir la double fonction de réservoir d'eau douce pour le dessalement des rizières, et aussi protection contre l'acidification grâce à la submersion par l'eau salée en contre saison culturale; la poldérisation de ces vases étant à proscrire. Or, la situation depuis cette phase de conception, a considérablement évolué sur le plan pluviométrique engendrant des changements profonds dans la configuration même des sous-bassins (Cf. ci-dessus). La question qui se pose donc aujourd'hui au sujet des futurs ouvrages, est leur justification même. Sous les conditions actuelles de dominance des surfaces de 'tannes' et de mangroves degradées, ce type d'aménagement à double sens est en effet inadapté puisque d'une part, l'acidification s'est déjà produite et que d'autre part, la fonction réservoir même du barrage situé en aval, n'est plus pleinement assurée.

Devant cet état de fait, la mobilisation paysanne aidée par la Société de Développement Régional (SOMIVAC), a depuis 1983 conçu et réalisé des digues anti-sels situées très en amont des bras secondaires et coupant définitivement ceux-ci de l'influence marine, ceci de façon à protéger les rizières douces menacées et récupérer une partie des terres salées de 'tannes'. Le problème est d'évacuer rapidement une quantité maximale de sel, en profondeur des sols en limitant le ruissellement et en forçant l'infiltration. Un aménagement modulé allant de l'amont vers l'aval, avec un barrage à la limite aval de la zone de mortalité des palétuviers, un réseau de diguettes de billons et de drains au niveau des parcelles, un recreusement du lit mineur, une évacuation des eàux salées par vanne de fond au niveau de la digue (stratification des eaux), un pompage éventuellement, sont autant de mesures qui peuvent faciliter ce dessalement. Il s'agit en fait d'une véritable poldérisation qui ne comporte aucun risque vis-à-vis de l'acidification des sols qui a déjà été réalisée.

La potentialité agricole des ces sols sulfatés acides, une fois dessalés est mal connue, néanmoins le cas des rizières douces traditionelles qui ont des pH bas est intéressant à considérer: des prairies très productrices y ont été observées sur des sols à pH de

3 et 3,5 et en présence de nappes à pH 2,5. Par ailleurs, les premiers essais réalisés en cases lysimétriques sur ces sols hypersalés et acidifiés (Orstom/Dakar 1985) montrent une bonne reprise et une bonne production du riz repiqué après dessalement. L'acidité en soi, en absence de sel, n'est donc pas toujours un obstacle à la croissance végétale, alors que l'on atteint très vite le seuil de tolérance des plantes en présence de sel.

D'une manière générale, on peut différencier quatre types de problématiques pédologiques concernant l'aménagement de ces bassins-versants fluvio-marins:
- l'acidité potentielle;
- l'acidité actuelle;
- l'excès de sel;
- l'acidité résiduelle.

Ces quatre facteurs limitants sont plus ou moins représentés, simultanément ou non, selon le degré d'évolution des sols, lui-même fonction de la topographie, des précipitations etc...

Les zones à acidité potentielle (zones actuelles de Mangrove en général) ne peuvent être aménagées que sur le principe d'un barrage anti-sel. Encore semble-t-il que le fonctionnement de ce dernier ne puisse pas permettre la riziculture dans le contexte de sécheresse que nous connaissons, elles seraient en revanche favorables à la pisciculture et à foresterie (palétuviers).

Les zones ne connaissant pas d'acidité potentielle (y compris les zones acidifiées) sont poldérisables et doivent être poldérisées pour éviter une propagation dramatique de la salure vers l'amont des bassins.

6 Conclusion

Il apparaît donc important aujourd'hui de resituer les projets d'aménagements dans leur contexte actuel, de façon à ne décider du type de barrage et de son site d'implantation qu'en ayant une connaissance précise des paramètres hydrologiques et pédologiques de ces bassins-versants en pleine évolution. Devant des situations aussi diversifiées dans l'espace et dans le temps, il est recommandé que chaque cas fasse l'objet d'une approche personnalisée pour aider à résoudre de la façon la plus judicieuse les problèmes de l'aménagement hydro-agricole en Casamance.

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The process of pyrite formation in mangrove soils

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1 Summary

Undisturbed soil samples were collected from mangrove areas in the west coast of Peninsular Thailand. Soil thin sections were prepared and plant debris was separated from these soil samples. The soil thin sections were observed under a light microscope. Samples of the plant debris were observed under light microscopes and a scanning electron microscope and also were analyzed for pyrite by X-ray diffraction method.

On the basis of the results of these investigations, we proposed a new comprehensive hypothesis of pyrite formation in mangrove soils. That is, pyrite is mainly formed in a boundary zone between the upper more oxidized horizons and the lower strongly reduced horizons. In this zone, H_2S formed in the lower horizons will react with ferric compounds deposited in the upper horizons.

Most of the ferric compounds are the pseudomorphs of microorganisms including aquatic fungi which grow in the fairly well decomposed plant debris. Within these pseudomorphs pyrite particles substitute for the ferric compounds. When the plant debris is strongly decomposed, pyrite particles may occur free from the plant debris. If pyrite-rich horizons are eroded, plant debris and pyrite particles are transported and sedimented at remote places.

Résumé

Des échantillons en structure naturelle ont été prélevés de treize Sulfaquents Typiques de mangroves de la région côtière de la Thaïlande peninsulaire (Figure 1) afin d'étudier les processus de la formation de la pyrite.

Les lames minces préparées et les débris des plantes séparés à partir de ces échantillons, ont été examinés au microscope polarisant et au microscope binoculaire. Une partie de débris ont été également examinés au microscope électronique et analysés aux rayons X, en vue de la détermination de la pyrite.

Les observations faites, ont montrés que:

- les crystaux de pyrite sont rares dans les horizons superficiels (20-30 cm), tandis qu'ils sont fréquents dans les horizons plus profonds.
- les crystaux de pyrite se trouvent particulièrement dans les restes de racines en voie de décomposition desquelles elles se détachent, au fur et à mesure, que la décomposition avance.
- un examen détaillé de la pyrite, permet de constater que les crystaux de pyrite sont

groupés en sphères ressemblant aux spongiaires et en colliers ressemblant aux hyphes de certaines fungies aquatiques qui sont responsables de la décomposition des restes des plantes présentes dans les sols mal drainés.

- dans les horizons superficiels où la quantité de pyrite est très faible, les mêmes spongiaires ont une couleur brun rougeâtre à cause des hydroxides de fer qu'ils contiennent.

Basés sur ces observations, les auteurs proposent une nouvelle hypothèse sur la formation de la pyrite dans les sols de mangrove.

En lignes générales dans les sols de mangroves on distingue une zone supérieure plus ou moins oxydée jusqu'à environ 20 à 30 cm avec peu de pyrite et une zone inférieure fortement réduite, avec beaucoup de pyrite.

Dans la zone inférieure le H_2S se forme à partir de SO_4^{2-}, en présence de la matière organique et le Fe^2 des certains constituants de Fe^3, et aussi en présence de le matières organique en voie de décomposition. Dans la zone supérieure, continuellement nourrie avec de la matière organique fraîche, les racines fines sont décomposées par les micro-organismes. Dans un premier stade, cette décomposition contribue à une forte réduction, tandis que dans un deuxième stade, des bactéries autotrophes et fungi aquatiques actionnent dans un milieu oxydé. C'est ainsi que les spongiaires et les hyphes se forment. Le Fe^2, venant des horizons réduits s'accumule comme hydroxydes ferriques dans ces pseudomorphes. Suit après le H_2S qui venant de mêmes horizons, réactione avec le $Fe(OH)_3$ et forme le Fe S et le S^0 (où S_n^{2-}) qui s'unissant, donnent le FeS_2. C'est ainsi qu'on trouve des spheroides et des filaments de FeS_2 ressemblant aux hyphes de fungies qui ont remplacé le Fe^{3+}.

Par sédimentation lente, la zone de la formation active de pyrite monte et l'horizon pyritique se développe.

Au fur et à mésure que la décomposition des débris de plantes avance, une partie des sphéroides pyritiques se décompose libérant des crystaux de pyrite 'libres' qui suite à l'érosion arrivent dans les sédiments où ils n'ont aucune rélation avec les tissus végétaux.

2 Introduction

Unripe reduced soil materials (or sediments) in mangrove areas are famous for their high content of pyrite. It has been widely accepted that active H_2S formation is responsible for this large accumulation of pyrite. The active H_2S formation, in turn, is considered to be maintained by abundant supply of SO_4^{2-} from the sea water and organic matter from the mangrove vegetation (Rickard 1973; Vijarnsorn 1985).

However, the following aspects of pyrite formation cannot readily be understood as a mere result of H_2S formation:

- Upper horizons (or layers) of about 20-30 cm have a far lower pyrite content than deeper horizons (or layers);
- Pyrite occurs often in spherical or framboid clusters of micro cristalline particles (Rickard 1973; Van Dam and Pons 1973);
- Some pyrite particles are contained in organic debris (mainly plant debris) but others are free from plant debris (Rickard 1973; Van Dam and Pons 1973);
- Pyrite is formed in strongly reduced soil material in which it is expected that H_2S be formed after complete reduction of ferric compounds (Van Dam and Pons 1973),

resulting in formation of FeS rather than of pyrite.
In this report, we will propose a hypothesis which can solve all of the above mentioned problematic aspects of pyrite formation.

3 Materials and methods

3.1 Soil

Undisturbed soil samples were collected from 13 sites on tidal flats in mangrove areas on the west coast of peninsular Thailand (Figure 1). All sampled soils are Typic Sulfaquents; a description of a representative soil profile is given in Annex I.

3.2 Preparation of soil thin sections

The moist soil samples were treated with acetone and oven-dried at 60 °C for more than two weeks. These dehydrated samples were impregnated with polyester resin solution (polyester: monostyrene = 1:1 v/v) under reduced pressure. The impregnated samples were sectioned and polished according to the method of Stoop (4).

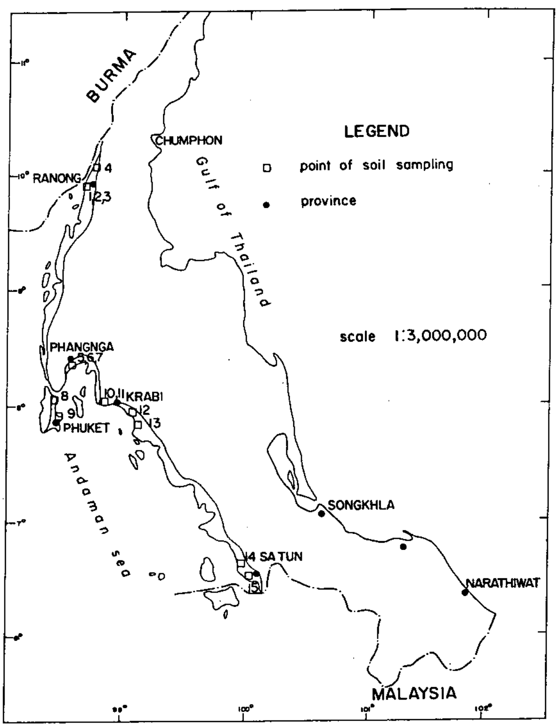

Figure 1 Location of the study area

3.3 Separation of plant debris

A few grams of soil samples were placed in a beaker, gently dispersed in water and passed through a 150 mesh screen (Wada and Kanazawa 1970). Plant debris on the screen was collected and preserved in 10% formalin solution.

3.4 Observation of soil thin sections and preparations of plant debris

The soil thin sections were examined under a microscope in a usual way. The plant debris was at first placed in a Petri dish and examined under a binocular microscope (6.3-80x) (X-Tr, Olympus, Japan). Some of the plant debris was picked up by forceps, transferred to a slide glass and mounted with lactophenol cotton blue (Wada et al. 1978). This preparation was examined under a microscope equipped with a polarizer and an analyzer (40-1,500x) (BHB, Olympus, Japan). A part of the plant debris was examined with a scanning electron microscope (40-150,000x) (JS-510, Hitachi, Japan) and was also analyzed by X-ray diffraction (Geigerflex 2013, Rigakudenki, Japan).

4 Results and discussion

4.1 Observation of soil thin sections

In general, pyrite particles were rare in the upper horizons of 20-30 cm deep and abundant in the lower horizons in accordance with the analytical data previously reported (Vijarnsorn 1985).

In the pyrite-rich horizons, pyrite particles are either embedded in plant debris or scattered in the soil matrix. In both cases individual pyrite cristals often form clusters in a wide variation of size and number of particles. The number and population density of the pyrite clusters contained in plant debris tended to increase with the advance of decomposition of the plant debris (Figure 2). The embedment of pyrite in plant tissue becomes obscure where the plant debris is strongly decomposed and there is a gradual transition to areas where pyrite particles seem to be scattered in the soil matrix without any spatial association with plant debris (Figure 2). However, careful examination revealed that these free pyrite particles and clusters are often covered with thin reddish brown halos (Figure 3). These reddish brown halos were considered to be humified organic substances, remnants of plant debris. It was also considered that some plant debris may have been decomposing and disappearing without further accumulation of pyrite particles inside. That is, pyrite formation and decomposition of plant debris are closely related but somewhat independent processes. On the basis of these observations, we proposed a process of pyrite accumulation inside and outside plant debris with the advance of decomposition of plant debris as illustrated in Figure 4.

The above discussion and conclusion only holds for plant debris supplied in situ by the standing mangrove vegetation e.i. autochtonous plant debris. In deep horizons at Ranong, plant debris showed little variation in particle size and degree of decomposition, and the debris particles were oriented parallel to laminae of sedimentation as revealed by mica particles. This fact suggests that this plant debris has been transported

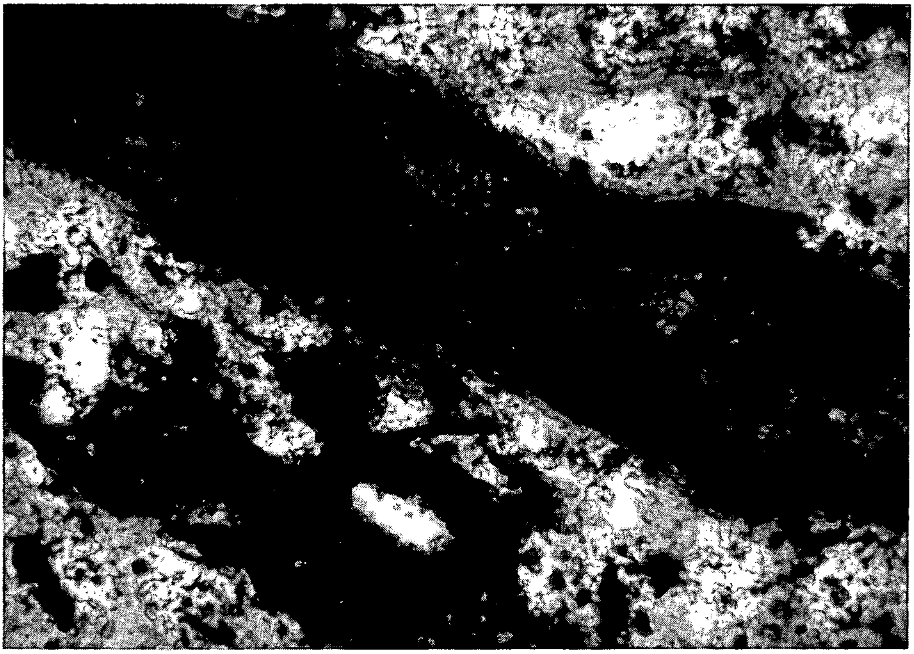

Figure 2 Pyrite particles associated with plant debris. Upper plant debris is rather fresh and contains a few pyrite particles. Lower plant debris is fairly well decomposed and contains a large number of pyrite particles. (Satul Province, 32-50 cm) 100 x

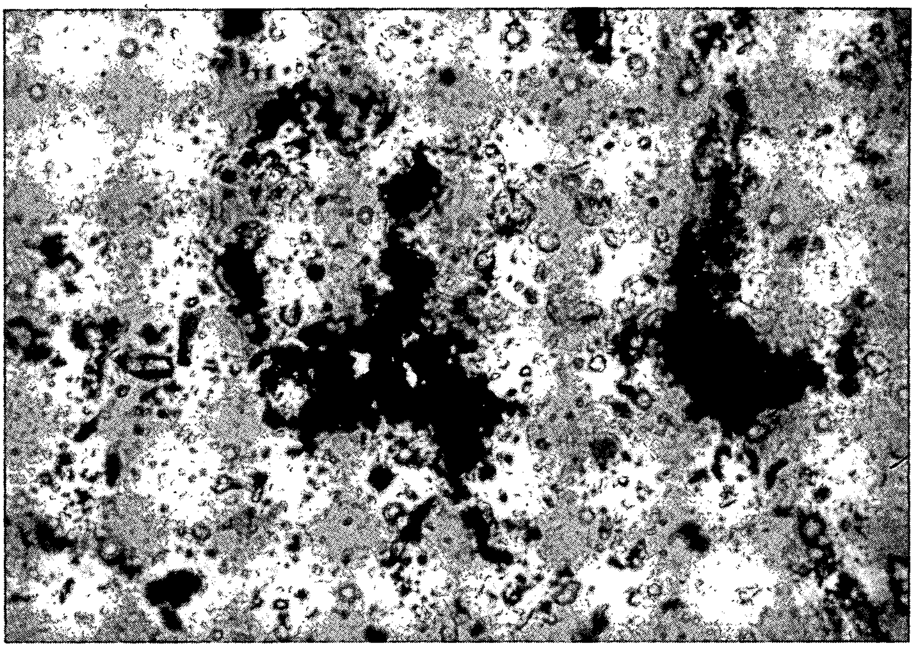

Figure 3 Pyrite particles free from organic debris with reddish brown halo (Phangnga Province, 30-80 cm) 200 x

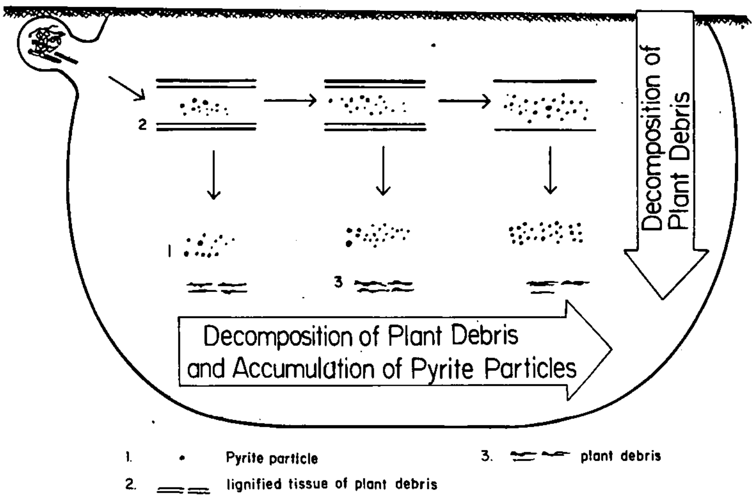

Figure 4 Relation between pyrite particles and plant debris

from a remote place and sedimented along with mineral particles in the deep and clam Ranong Bay, where faunal pedoturbation is not active. This type of plant debris can be called allochthonous (Van Dam and Pons 1973). It is dense and dark brown and not associated with pyrite particles. This indicates that this allochthonous plant debris consists of lignified remnants of the strongly decomposed plant debris. However, Van Dam and Pons (1973) recognized allochthonous plant debris containing pyrite particles. Their allochthonous plant debris appeared to be not strongly decomposed. Apparently there are several types of allochthonous plant debris.

Allochthonous plant debris must be related with autochtonous plant debris, because the former is derived from the latter. If the moderately decomposed plant debris containing pyrite particles, is transported and sedimented without marked disintegration, we can expect that the resulting allochthonous plant debris retain pyrite particles. On the contrary, if material with strongly decomposed autochtonous plant debris with disengaged pyrite particles is transported and sedimented, the resulting allochthonous plant debris will not contain pyrite particles.

The 'free pyrite particles' will be transported separately from the plant debris and sedimented along with mineral particles.

4.2 Observation of plant debris preparations

Most of the plant debris was found to be remains of fine roots of mangrove trees in various stages of decompositon. Even cursory observations at a low magnification sufficed to confirm the relationship between plant debris and pyrite particles, earlier recognized by observing soil thin sections.

In the pyrite-rich horizons, weakly decomposed plant debris contains none or very few pyrite particles while fairly well decomposed plant debris (most of it remnants of the epidermis of the fine roots taking the shape of transparent tubes) contains numerous pyrite particles. Actually, at a low magnification, pyrite clusters appear as black patches in the plant debris. Some of the fairly well decomposed plant debris is completely black due to a large accumulation of pyrite particles. The plant debris with black patches effervesces with hydrogen peroxide solution. After termination of the effervescence, the black patches had disappeared and the solution become acid. This simple chemical test indicates that these black patches indeed consist of pyrite particles. X-ray diffraction confirmed that the black patches are pure crystals of pyrite.

The configuration and position of the black patches inside plant debris is similar to that of microorganisms growing inside decomposing plant debris in submerged paddy soils (Wada 1980). In fact most of the pyrite particles reside inside the walls of the transparent tubes of root remnants. These observations suggest that pyrite formation is closely related with microbial growth in the decomposing plant debris.

At higher magnifications, the peculiar shapes and the distribution pattern of the pyrite particles were recognized more clearly. Pyrite particles inside the cell structure of plant debris, occur either as framboidal spherical accumulations or as tiny individual cubes (Figures 5, 6). In some of the cells pyrite clusters are interconnected by filaments of small pyrite particles and there filaments even connect clusters in adjacent cells (Figure 7).

The pyrite particles and clusters are easily detached from the plant debris by crushing of samples. After crushing many of the framboidal pyrite clusters had fallen apart into tiny cristals, but often fragments of framboids together with connecting pyrite filaments remained unimpaired (Figure 8).

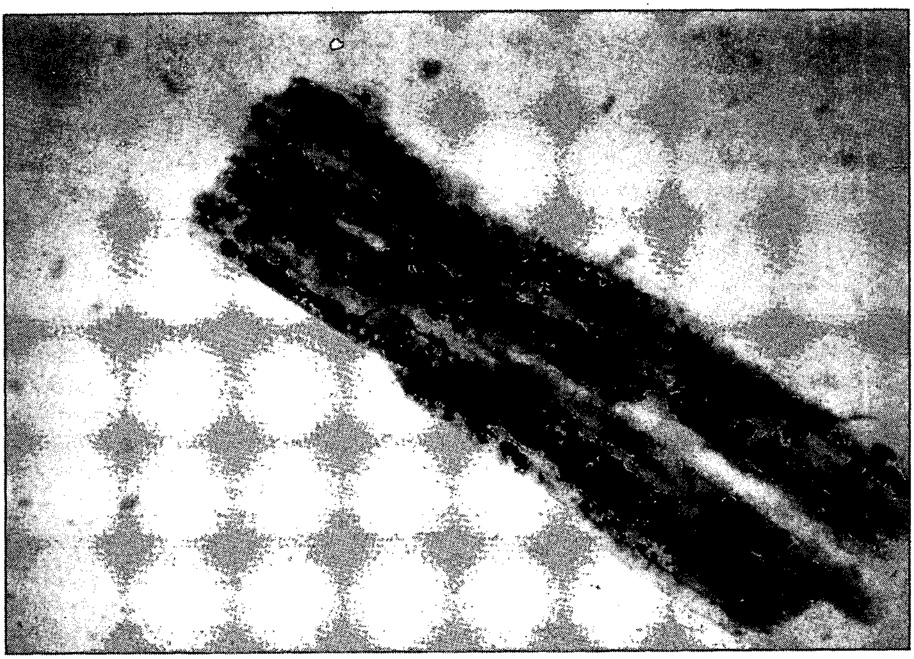

Figure 5 A transparent tube-shaped piece of plant debris containing numerous pyrite particles (Phangnga Province, 50-80 cm) 100 x

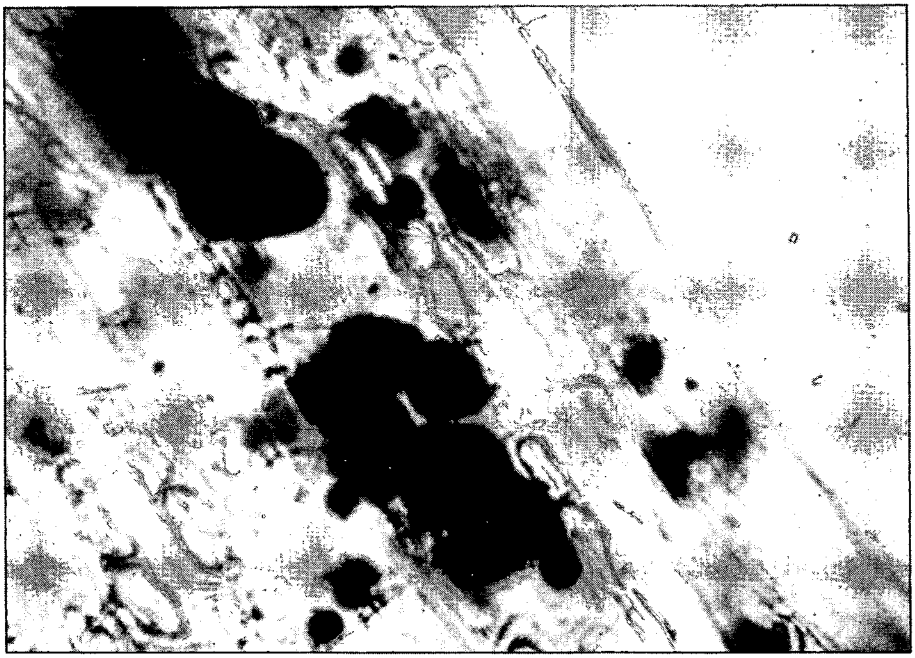

Figure 6 Frambiodal pyrite particles inside plant debris (Phangnga Province, 50-80 cm) 400 x

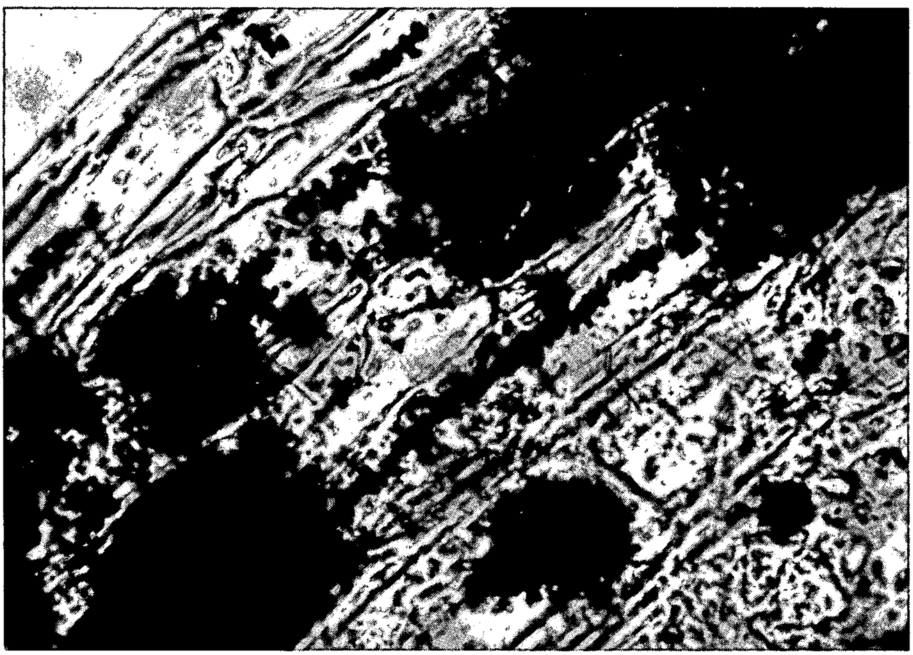

Figure 7 Filaments of pyrite particles connecting clusters of pyrite particles (Phangnga Province, 50-80 cm) 400 x

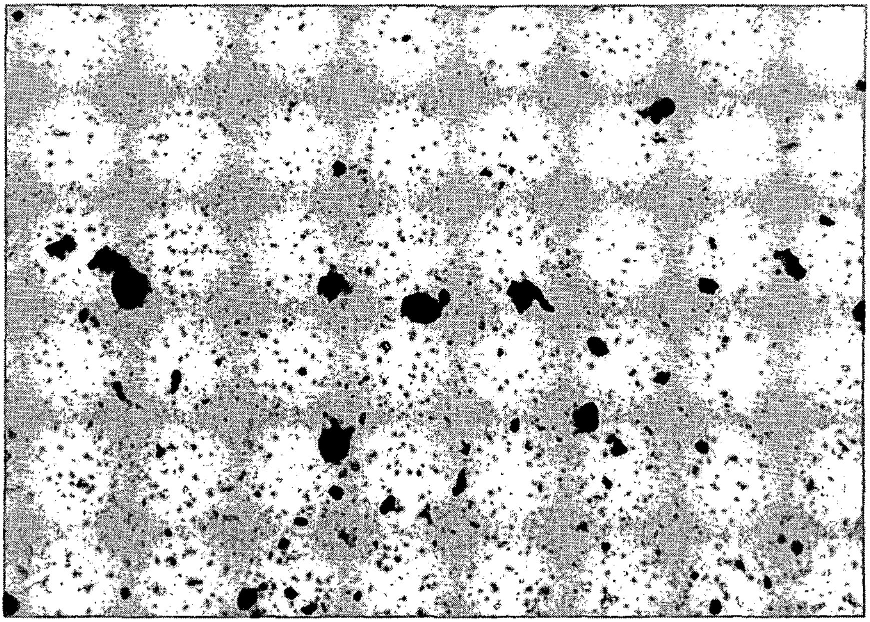

Figure 8 Framboidal pyrite particles with fragments of filaments of pyrite particles (Phangnga Province, 50-80 cm) 200 x

A few crystals were sometimes found to stick out from the surface of the detached framboids, suggesting that the framboidal spheres might grow by newformation of tiny cristals on their surface.

Under a scanning electron microscope, the pyrite clusters were found to be completely composed of tiny cubic crystals of pyrite which in the case of framboids are about the same size and neatly arranged in the convex surface of the spherical clusters (Figure 9). The combination of framboidal spheres and their interconnecting filaments strongly resemble the shape of the sporangia and hyphae of some aquatic fungi that are contributing to the decomposition of plant debris in wet soils (Figure 10). This resemblance intimates the possibility that such fungi be instrumental in the formation of micro cristalline pyrite.

As mentioned above, pyrite particles were rarely found in samples of the upper horizons. Instead, plant debris in these horizons contained reddish or brownish stains of various shapes among which spherical shapes were predominating. When Na-thioglycolate solution was added to the plant debris, at first a purple color developed but then faded out. After this treatment, the reddish or brownish stains had disappeared from the plant debris. This result indicates that the reddish or brownish stains are composed of ferric compounds.

In the upper horizons, some plant debris contained both framboidal pyritic and ferric spheres of similar size. In this plant debris, some of the spherical particles showed intermediate color between phyrite and ferric compounds.

These observations suggest that the spheres of ferric compounds are formed at first which then are converted into pyritic framboidal spheres.

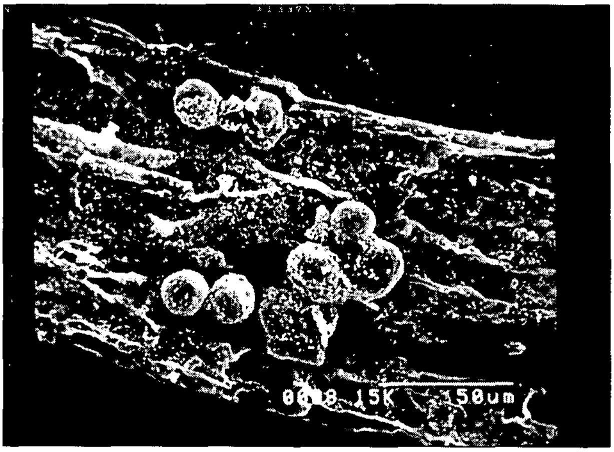

Figure 9a Framboidal pyrite particles inside plant debris (Phangnga Province, 50-80 cm)

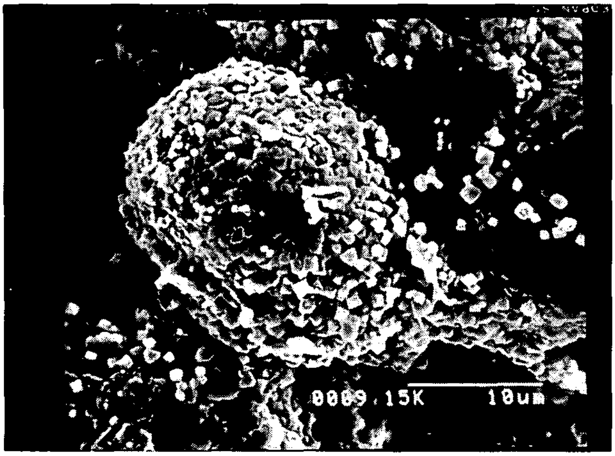

Figure 9b A framboidal pyrite accumulation composed of tiny crystals of pyrite (Phangnga Province, 50-80 cm)

4.3 A hypothesis of pyrite formation in mangrove soils

On the basis of the presented observational results, we can propose the following hypothesis of pyrite formation in mangrove soils.

Upper horizons of mangrove soils are heterogenous in regard to oxidation-reduction state. Tunnels of burrowing animals and young active roots of mangrove trees will supply O_2 to the upper horizons and oxidize their surroundings. Organic debris, especially debris of fine roots, is abundantly supplied to the upper horizons by the standing mangrove trees. When this organic debris is still fresh and rapidly decomposing, it will enhance the reduced state of the soil. However, once the debris is already

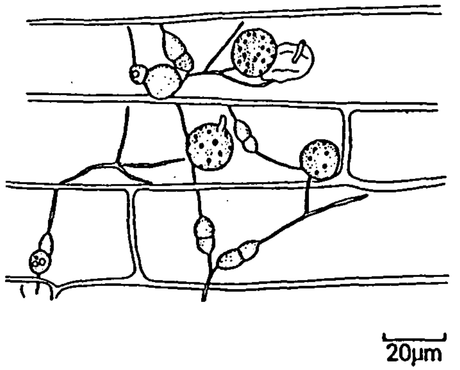

Figure 10 Cladochytrium replicatum. Rhizomycelium within the epidermis of an aquatic plant. From Webster, J. 1980. Introduction to Fungi. Cambridge University Press

fairly well decomposed, it will not contribute much more to further the reduced state of the soil. Agents of decomposition of the organic debris are zymogenous bacteria in the initial stage of decomposition and autotrophic bacteria and aquatic fungi in the later stage of decomposition.

In the upper horizons Fe^{2+} is formed in the reduced parts of the soil and is deposited as ferric compounds in the oxidized parts of the soil. The dying microorganisms in the well decomposed plant debris are favorable sites for this iron deposition.

In the lower horizons, the soil remains strongly reduced throughout and a part of the H_2S formed in these horizons will rise to the upper horizons.

At the boundary zone between the upper horizons and the lower horizons, the H_2S will react with the ferric compounds of the well decomposed plant debris to form at first FeS and S^0 (or S_n^{2-}). The FeS and S^0 (or S_n^{2-}) thus formed side by side will react to form pyrite. Accordingly, this boundary zone can be called the zone of pyrite formation (Figure 11). Where sedimentation continues slowly, the zone of active pyrite formation will gradually be raised with the surface level of the mangrove soil and the pyritic horizon below built up at the same rate.

The newly formed pyrite cristals occupy predominantly the sites of the microorganisms that have been active in decomposing plant tissue, e.i.: sites inside the cell and tissue structure of the debris. When the plant debris is decomposed further, the pyrite particles become free from the plant debris (Figure 4). When pyritic horizons are eroded; their plant debris and pyrite particles are transported and sedimented separately and give rise in other places to respectively allochthonous plant debris and deposits of 'free pyrite particles'.

With this hypothesis a plausible explanation can be offered for many problematic occurrencies of pyrite in mangrove soils. E.g. accumulation of pyrite particles on the surface of cleavage planes free from plant debris (Van Dam and Pons 1973). Probably, at some early period, this soil was drained to form cracks the walls of which became coated with ferric compounds. In a later period, H_2S coming up from lower horizons reacted with the ferric compounds, resulting in pyrite.

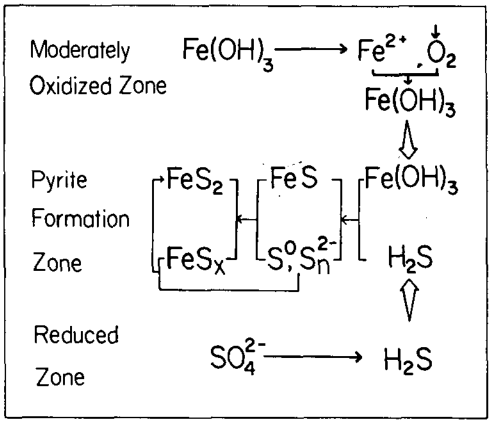

Figure 11 The process of pyrite formation in mangrove soils

The proposed hypothesis takes in the following ideas previously reported:

1. The sulphidication of ferric hydroxides is particularly important because S^0 is produced spatially near FeS (Rickard 1973);
2. Framboidal pyrite accumulations may be pseudomorphs of organic spherules (probably pyritoshpera barbaria) (Love 1962);
3. Pyrite is mainly formed just below the oxidized layer (Rickard 1973).

Acknowledgments

We thank Mr. Y. Satoi (Chiba University) for analyzing pyrite by X-ray diffraction. We are also grateful to Mr. Y. He (Institute of Academia Sinica, Ch'eng-tu, China) for taking photographs and to the Cambridge University Press for their kind permission to reproduce Figure 10.

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Annex I
Description of representative soil profile

Date	23/4/83
Soil name	Thakua Thung series
Classification	fine-silty, mixed, isohyperthermic Typic Sulfaquents
Latitude	8°20′45″N
Longitude	98°26′50″E
Location	Ban Khao Po, Amphoe Tha Kua Thung, Phang-nga province
Physiographic position	Mangrove swamp on intertidal flat
Topography	Flat
Slope and Aspect	0%
Elevation	< 1 m. MSL
Drainage	Very poorly drained
Vegetation	Mangrove forest: Rhizophora sp, Sylocarpus sp, Avicenia sp.
Parent material	Marine deposit
Sampled by	P. Vijarnsorn W. Sirichuaychoo
Remarks	1. Ground water table level about 20 cm from the soil surface 2. Common mud lobster mounds

Depth (cm)	Horizon	Description
0-10	A_1	Mixed dark gray (10YR 4/1) and very dark grayish brown (10YR 3/2) clay; common fine distinct brown to dark brown (7.5 YR 4/4) mottles; massive; slightly sticky, slightly plastic; common fine roots; overwash material as polluted in stream by tin mining; moderately alkaline (field pH 8.0)
10-50	C_{1g}	Mixed very dark grayish brown (10YR 3/2) and dark gray (10YR 4/1) peaty clay loam; half ripe; common fine distinct yellowish brown (10YR 5/6) mottles; massive; slightly sticky, slightly plastic; many roots and

		woody fragments (partially decayed); moderately alkaline (field pH 8.0)
50-100	C_{2g}	Mixed dark grayish brown (10YR 4/2) and dark gray (2.5Y 4/0) peaty silt loam; nearly unripe; massive; slightly sticky, slightly plastic; many roots and woody fragments (partially decayed); moderately alkaline (field pH 8.0)
100-150	C_{3g}	Mixed dark grayish brown (10YR 4/2) and dark gray (2.5Y 4/0) peaty silt clay loam; nearly unripe; massive; slightly sticky, slightly plastic; common roots and woody fragments (partially decayed); moderately alkaline (field pH 8.0)
150-200	C_{3g}	Mixed dark grayish brown (10YR 4/2) and very dark grayish brown (10YR 3/2) silty clay; unripe; massive; slightly sticky, slightly plastic; fine roots and woody fragments (partially decayed); moderately alkaline (field pH 8.0)

Evidence of eluviation-illuviation of sulfur and heavy metals in sulfaquepts in recent Baltimore Harbor (MD) dredged materials

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1 Summary

Studies of the distribution of sulfur and various heavy metals (Cd, Cr, Cu, Mn, Ni, Pb and Zn) with depth in young (less than 10 year old) Sulfaquepts developed in Baltimore Harbor dredged materials were made. The heavy metals and S were examined in two profiles varying in age and degree of development in 1982 and the distribution of Zn and Eh with depths were examined in 4 profiles of the younger soils again in 1985. The dregded materials were shown to be elevated in content of all the heavy metals relative to the amounts found in typical Maryland agricultural soils. Sulfuricization processes appear to have caused or to be causing the loss of a large part of all the heavy metals from the sulfuric horizons of the soils and also of a large part of the S, at least from the upper parts of the horizons. Lower in the profiles there appears to be a bulge in the distribution of heavy metals and also in some instances of S. This bulge appears to be in the transitional horizons, between the sulfuric horizon and the underlying sulfidic material that have been little affected by oxidation processes. This zone has a pH intermediate between the low pH of the sulfuric horizons (about 3 measured in water at an approximate 1:1 by weight dilution in water) and the neutral pH of underlying sulfidic materials and a low Eh relative to the sulfuric horizon based on 4 profiles examined in 1985. Implications are that the heavy metals may be tied up in the dredged materials largely as sulfides. They apparently are made mobile by oxidation processes and some of them are eluviated to deeper horizons where they are illuviated, perhaps by reprecipitation as sulfides. The processes taking place and their consequences have important environmental implications. Acid sulfate soils like those in the dredged materials examined in this study, which were of fine texture and low bulk density, apparently are cleansed of heavy metals by the sulfuricization associated with ripening processes. Some of these metals apparently are held in lower parts of the profiles, which may prevent them from contaminating ground water at deeper depths.

Résumé

Des études concernant la distribution en profondeur du soufre et des différents métaux lourds (Cd, Cr, Cu, Mn, Ni, Pb et Zn) ont été effectuées dans les Sulfaquepts récents (de moins de 10 ans) développés dans les matériaux dragués au Port de Baltimore.

Les métaux lourds et le soufre ont été étudiés en deux profils, differents comme âge et degré de développement.

Le premier, formé dans les matériaux dragués déposités en 1978, avait un horizon sulfurique de 34 cm à la surface et n'était pas couvert de végétation. Le jarosite, présent à la surface des agrégats structuraux, pénétrait jusqu'à 50 cm de profondeur et les oxydes de fer, jusqu'à 125 cm. La nappe d'eau au moment de l'échantillonnage (Juin 1982) se trouvait à 50 cm.

Le deuxième profil, formé dans les matériaux dragués déposités en 1974, présentait à la surface un horizon sulfurique d'une épaisseur de 75 cm, des taches de jarosite jusqu'à 128 cm et des taches d'oxydes de fer jusqu'à 146 cm. Au moment de l'échantillonnage (Juin 1982) la nappe d'eau se trouvait à 75 cm et le sol était couvert d'une végétation dense de Phragmites australis.

Les deux profils ont une texture argileuse, une densité apparente d'environs 0,7 Mg m-3, une capacité d'eau au champ élevée. Le kaolinite et le mica sont les minéraux argileux dominants.

La distribution du Zn et le Eh a été examinée encore dans quatre autres profils, en 1985. Sauf l'épaisseur plus grande de l'horizon sulfurique, ces profils étaient identiques aux premiers.

Les analyses effectuées, ont montrées que les matériaux dragués ont une teneur plus élevée en métaux lourds que les sols agricoles de Maryland. Pourtant, le processus de sulfurisation semble avoir causé l'éluviation d'une grande partie d'eux, ainsi que d'une grande partie du soufre, de l'horizon sulfurique vers les horizons sous-jacents. Leur accumulation apparaît dans la zone de transition entre l'horizon sulfurique à pH bas et le matériau sulfuré à pH neutre. Apparemment les métaux lourds devient mobiles suite à l'oxydation, et la plupart d'entre eux sont éluviés vers la profondeur où ils sont illuviés probablement comme sulfures. La détente de l'illuviation peut augmenter le pH, diminuer l'Eh ou les deux à la fois.

Ces processus peuvent avoir des importants implications pratiques, car si les métaux lourds peuvent être éluviés de la rhizosphère des principales cultures agricoles et illuviés dans les horizons inférieurs sans danger qu'ils contaminent la nappe, la mise en culture de ces sols peut-être très valable.

2 Introduction

Some materials dredged from harbors tend to be elevated in heavy metals, relative to amounts found in most soils, and also to be high enough in sulfides that active acid sulfate soils form on them when they are exposed at land-based deposition sites. The soils described in this paper are examples of such soils. As part of other studies of these soils (Snow et al. 1983; Fanning et al. 1983), we examined the distribution of sulfur and a number of heavy metals with depth in two profiles. The data indicated loss of sulfur and heavy metals from the sulfuric horizons that had formed at the surface of the soils. The data also suggested that the elements were being illuviated in the top of the underlying sulfidic materials. As part of ongoing research, data have been collected from some additional profiles in regard to the distribution of Zn with depth that tend to confirm the earlier findings for the heavy metals. The purpose of this paper is to report these findings so that they may be considered by the international community of scientists interested in acid sulfate soils.

3 Materials and methods

Soil profiles were described and sampled in June, 1982, on two of the five diked dredged material deposition areas at Masonville in Baltimore, MD. A description of the younger of the two profiles (S-82-MD-510-2) is given by Witty et al. (1986, this symposium proceedings). This profile was developed in conveyor belt deposited dredged materials that were deposited in 1978. This soil had a 34 cm thick sulfuric horizon at its surface when sampled and was unvegetated. Jarosite was present on ped faces to a depth of 50 cm and free iron oxides (as evidenced by red mottles) were present to a depth of 125 cm. The water table at time of sampling was at 50 cm.

An older and more deeply developed soil (S-82-MD-510-1) in dredged materials deposited by truck in 1974 was described and sampled at the same time. This soil had a 75 cm thick sulfuric horizon at its surface and was heavily vegetated with common reed, Phragmites australis, when sampled. Jarosite was present on ped faced to a depth of 128 cm and free iron oxides were present to a depth of 146 cm. The water table was at a depth of 75 cm at sampling time, which was at the end of a rainy period. A description of this soil has been given by Fanning et al. (1983).

The profiles were characterized in regard to several chemical characteristics. Physical and mineralogical characteristics were determined for selected horizons. These data have been and/or will be reported elsewhere (e.g. Fanning et al. 1983; Cheng 1986; additional manuscripts in progress). In general the soils are fine in texture, with little sand and about 40% clay in 510-2 and about 60% clay in 510-1. They were texturally uniform with depth, except for some sandy strata in the lowermost horizon of 510-1. The soils have low bulk density throughout, about 0.7 Mg m-3. The soils have high field water contents and associated low bearing capacities (Fanning et al. 1983). Kaolinite and mica are the main clay minerals based on X-ray diffraction patterns (Cheng 1986).

The characteristics reported in this paper for the soils sampled in 1982 are pH, total S, and total amounts of several heavy metals (Table 1). The pH was determined on fresh samples with a glass electrode using an approximately 1:1 by weight ratio of air dry soil (quantity estimated based on water content) to deionized water. Total S was measured by the method of Snow (1981). Samples by this method are put into solution by digestion with nitric, perchloric and hydrofluoric acids and ammonium vanadate in the presence of added Cu to prevent S volatilization. The digestate after going to dryness is redigested to dryness with HCl, then taken up with a few ml of water and absorbed on microcrystalline cellulose, freeze-dried and then pelletized for determination of S by X-ray spectroscopy. Standards are made from sodium sulfate run through the same procedure. The method has been shown to give accurate S analyses on a variety of kinds of samples (Snow 1981). The heavy metals were run by a method like the method for S, except that no Cu was employed in the digestion and determination was by atomic absorption on solutions diluted to a known volume with deionized water following the HCl digestion. For comparison, concentrations of heavy metals were also determined for samples from Ap horizons from two comparison Maryland agricultural soils (Table 1). These samples had silt loam textures and the soil series were considered to be Mattapex (a fine silty, mixed, mesic, Aquic Hapludult) and Beltsville (a fine loamy, or probably fine silty where sampled, mixed, mesic, Typic Fragiudult).

Table 1 Total heavy metals, pH (~ 1:1 by weight in H_2O for fresh samples and total S in soil profiles developed on dredged materials from areas 2 & 4 at the Masonville Research Site, and heavy metals for selected agricultural soils. Heavy metals and S are expressed on an air-dry weight basis

Horizon	Depth (cm)	Profile ≠ S82 Md 510-2 (Area 2) ppm total							pH	Total S(%)
		Zn	Cd	Cu	Ni	Mn	Cr	Pb		
Bw(j)1	0-3	388	1.2	360	51	438	489	203	3.46	0.86
Bw(j)2	3-8	204	0.1	268	47	303	463	253	3.45	0.61
Bw(j)3	8-18	221	0.3	230	47	357	477	240	3.26	0.63
Bw(j)4	18-34	257	0.4	224	50	369	440	246	3.30	0.66
BC(j)	34-50	763	3.6	355	66	603	375	208	6.39	1.05
Cg1	50-65	616	3.3	436	62	624	452	220	7.14	1.32
Cg2	65-80	590	3.0	396	58	597	513	198	7.13	1.26
Cg2	80-95	569	3.0	422	58	576	482	210	7.13	1.20
Cg2	95-110	511	2.8	406	58	582	439	208	7.10	1.10
Cg2	110-125	510	2.6	399	58	564	399	212	7.10	1.20
Cg3	125-140	485	2.6	398	60	549	397	202	7.10	1.30
Cg3	140-155	491	2.6	404	59	570	358	197	7.10	1.27
Cg3	155-170	481	2.5	391	58	588	367	192	7.10	1.31

Horizon	Depth (cm)	Profile ≠ S82 MD 510-1 (Area 4) ppm total							pH	Total S(%)
		Zn	Cd	Cu	Ni	Mn	Cr	Pb		
A(j)	0-6	107	0.1	54	29	240	149	50	3.28	0.91
Bw(j)1	6-13	107	0.1	44	29	273	122	36	3.12	0.91
Bw(j)2	13-28	110	0.1	47	28	282	128	23	2.84	0.97
Bw(j)3	28-53	95	0.1	53	28	288	135	24	2.80	1.15
Bw(j)4	53-75	133	0.8	59	35	378	150	27	2.80	1.91
Bw(j)5	75-88	210	1.1	60	46	501	126	28	4.95	2.31
Bw(j)5	88-98	157	0.4	52	40	504	99	19	4.95	2.19
Bw(j)5	98-113	136	0.2	45	39	486	97	18	4.95	2.22
Bw(j)5	113-128	310	1.1	107	52	705	255	163	4.95	2.22
Cg1	128-146	464	2.3	184	59	828	476	391	7.16	0.93
Cg2	146-162	510	2.8	231	59	708	700	422	7.16	0.83
Cg2	162-190	604	3.4	273	68	744	790	534	7.16	0.66
Cg2	190-202	523	2.8	236	54	609	789	383	7.16	0.95

Horizon	Selected agricultural soils ppm total						
	Zn	Cd	Cu	Ni	Mn	Cr	Pb
Mattapex Ap 1*	37	0.1	7	11	291	54	13
2	47	0.1	8	11	372	36	14
Beltsvelle Ap 1*	34	0.1	10	10	159	41	19
2	32	2.2	9	9	183	42	17

* Two locations at Wye Agricultural Research Center (Queen Anne's County, MD) for Mattapex and two locations at Plant Research Farm (Montgomery County, MD) for Beltsville

Table 2. Eh values at time of sampling for horizons from 4 profiles from Area 2 at Masonville, sampled during the summer of 1985. The three values for each horizon of each profile represent 3 platinum electrodes inserted in different spots in the horizon. The bulges in Zn concentration (Figure 2) generally correspond depthwise to the BC(j) horizons shown here

Horizon		Eh (millivolts)			
		Profile ≠2	Profile ≠3_0	Profile ≠4	Profile ≠5
Bw(j)1		+410	+578	+585	+523
		+559	+600	+602	+616
		+428	+492	+574	+609
	Average	+466	+557	+587	+583
Bw(j)2		+482	+618	+590	+597
		+589	+650	+648	+646
		+420	+626	+623	+636
	Average	+497	+631	+620	+627
Bw(j)3		+ 58	+383	+486	+595
		+131	+520	+544	+649
		+158	+441	+509	+632
	Average	+116	+448	+513	+627
BC(j)		+ 10	+ 95	+116	+130
		+ 45	+ 75	+ 74	+190
		+ 34	+ 51	+102	+225
	Average	+ 30	+ 74	+ 97	+182
Cg		+125	+ 98	+ 52	+ 84
		+104	+ 87	+ 7	− 20
		+ 76	+ 82	+ 8	+259
	Average	+102	+ 89	+ 22	+108

Eight additional profiles from the Area 2 dredged material deposition area at Masonville (where profile S-82-MD-510-2 was collected in 1982) were sampled in 1985. These profiles were from randomly selected locations in alleyways of a former field plot experiment, all from within about 100 meters of the 1982 profile. Samples from 4 of these profiles were analyzed for total Zn by a ground powder X-ray spectroscopy technique. Samples from profile S-82-MD-510-2 as analyzed for Zn earlier by atomic absorption (Table 1) were used as standards. The R^2 (coefficient of determination) value for counts per second vs. Zn content for these standards was 0.988, showing that the method should give reasonably accurate analyses for Zn.

The pH was also measured on the fresh samples collected in 1985 and the Eh was measured in the field for selected horizons of the soils collected in 1985 at the time of sampling using a LDC digital multimeter and platinum electrodes and a calomel reference electrode. The readings were made using 3 electrodes in each of the horizons recognized in profile descriptions and the values were corrected by adding 244 millivolts to the readings taken with the calomel electrode to give Eh values (Table 2). The Bwj horizons represented the sulfuric horizon, at least the upper 2. The Cg horizons represented the upper part of the underlying sulfidic materials, where the pH was close to neutral. The BCj horizon represented a transitional horizon that had usually black and/or very dark gray prism interiors, but with prism faces with free iron 'oxides' and jarosite. The morphology of these profiles was generally similar to that of S-82-MD-510-2, for which a description is given in this book by Witty et al. (1986), but the Bwj horizons (sulfuric horizon) were somewhat deeper in most of these profiles (by perhaps 20 cm) than in that profile sampled in 1982.

4 Results and discussion

4.1 Data for soils collected in 1982

The data for pH, total S and total quantities of heavy metals for the soils sampled in 1982 are presented in Table 1 along with data for heavy metals for the selected agricultural soils.

The S content for most of the deeper horizons was high enough for them to be recognized as sulfidic materials by Soil Taxonomy (Soil Survey Staff 1975). The soils had sulfuric horizons at their surfaces and would be classified as Sulfaquepts by the proposals presented by Witty et al. (1986). Jarosite was present on ped faces (shown by j subscripts on horizon symbols in Table 1) for horizons below the zone having a pH < 3.5, probably because of mixing of ped faces with lower pH with ped interiors with higher pH before pH measurement or because of pH increase in these horizons, following a lower pH at an earlier time, because of high water tables at the time of sampling. The presence of free iron 'oxides' (apparently occurring on ped faces) indicated that some degree of oxidation had taken place to a depth of about 125 cm in 510-2 and 146 cm in 510-1.

The heavy metal analyses showed that the soils in dredged materials were elevated in content of heavy metals relative to the levels found in the agricultural soils (Table 1), particularly for profile 510-2 and the deeper horizons of profile 510-1. The upper horizons of profile 510-1 appear to have been depleted in all heavy metals examined relative to the deeper horizons if one assumes an original uniform distribution with depth. The upper horizons of profile 510-2 appear depleted in Zn, Cd, Cu, Ni, and Mn relative to underlying Cg horizons, but Cr and Pb were not depleted as in profile 510-1. The zone of depletion appears to correspond with the sulfuric horizon (zone with pH < 3.5) in profile 510-2 and with the zone having jarosite present in profile 510-1.

Profile 510-2 had more of each of the heavy metals, except for Pb, in the surface-most horizon, Bw(j)1, 0-3 cm, than in horizons just below. It is thought that the higher amounts at the surface relate to wicking of metal salts to the surface of the soil during dry seasons. Salt efflorescences have been found at the surface of the soils at the dredged material deposition site in dry seasons. By X-ray diffraction, iron sulfate salts as well as small amounts of halite have been identified in some of these efflorescences. Studies of the EC (electrical conductivity of extracts equivalent to saturation extracts) of the surficial soils as a function of time near the 510-2 profile showed conductivity values up to 20 dS m-1 in the summer of 1982, as opposed to EC values of about 2 dS m-1 during winter months (McMullen 1984). If part of the metals are present in the sulfidic dredged materials as metal sulfides, as has been shown for harbor sediments from other harbors (Lee and Kittrick 1984a and 1984b), they would likely be converted to metal sulfates during sulfuricization (Carson et al., 1982) processes. As soluble sulfates they could be transported to the soil surface by wicking as well as be leached to deeper horizons or laterally in the soil. Iron and sulfur obviously move laterally in the soil to ped surfaces, perhaps largely by diffusion and/or wicking, where they are converted to iron 'oxide' minerals and jarosite, apparently by the oxidation and hydrolysis of the iron at ped surfaces, where the Eh is apparently high enough for the iron to be oxidized from FeII to FeIII.

Below the sulfuric horizons of the soils, in the zone where the pH of the soils was transitional between the low pH of the sulfuric horizons and the neutral pH of the deeper, Cg, horizons, there appears to be a bulge with depth in the content of various heavy metals and S (Table 1). This is illustrated for Cd in Figure 1. Actually, Profile 510-1 appears to have two bulges in heavy metals, one in the Bw(j)4 horizon at a depth of from 75 to 88 cm and another in the Cg horizon at a depth of from 162 to 190 cm. The first bulge coincided with the top of the water table at the time that the soil was sampled. The second bulge was within the reduced zone and, in this instance, coincided with a minimum value in the profile for S content, although the profile description for this soil showed this horizon to be black with monosulfides apparently present. To explain the bulges in heavy metal, and S in the case of profile 510-2 and the upper bulge in 510-1, it is hypothesized that illuviation of products of oxidation and eluviation from overlying horizons is taking place. The trigger for illuviation may be rising pH or decreased Eh or both. Perhaps the metals are being reprecipitated as sulfides. Alternatively, some of the metals may be incorporated into jarosite or iron oxides. However, if this were the main mechanism then the elements should as well have been illuviated in the sulfuric horizons because there is a considerable quantity of iron 'oxides' and jarosite in these horizons as well as in the horizons below.

4.2 Data for the profiles collected in 1985

To see if the bulge in heavy metals in the lower B horizons was reproducible, additional profiles were collected in late summer of 1985 from Area 2, where the dredged materials were deposited in 1978. The dredged materials in this area were quite uniform in texture and color and it was thought that this would be a good place to subject the hypothesised eluviation-illuviation model to further testing. Eight profiles were sampled but to date only the Zn distribution with depth for 4 of the profiles has been determined (Figure 2). The pH distribution with depth for these soils is presented in Figure 3 and Eh data for selected horizons for these soils is presented in Table 2.

The distribution of Zn with depth again shows the bulge in Zn content near the base of the sulfuric B horizons where the pH is transitional between the low pH of the sulfuric horizons and the neutral pH of the deeper horizons (Figures 2 and 3). The Eh also increases dramatically in this part of the profiles. These observations corroborate other data in indicating that the oxidation of sulfides is a primary mechan-

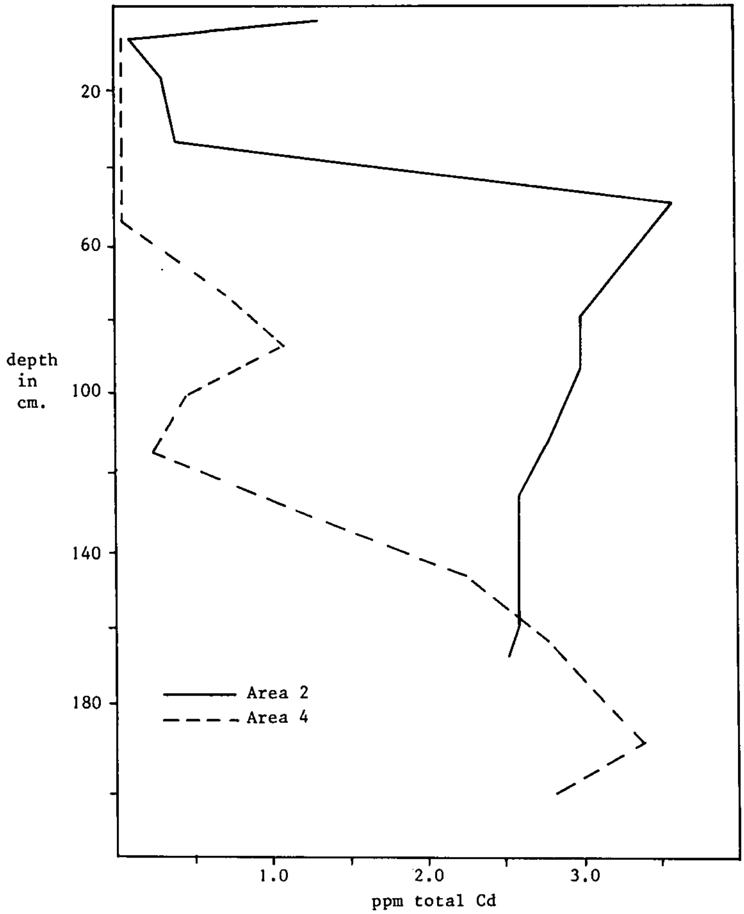

Figure 1 Graph of total Cd (air-dry basis) distribution with depth for profiles from Area 2 (4 year old soil, S-82-MD-510-2) and Area 4 (8 year old soil, S-82-MD-510-1) at Masonville dredged material deposition site in Baltimore

ism in promoting the eluviation of heavy metals in these acid sulfate soils and they further imply that decreasing Eh and increasing pH trigger the reprecipitation of the metals deeper in the profiles, probably again as sulfides. While some of the Zn remaining in the sulfuric horizons may be bound in iron 'oxides' and jarosite, or possibly even remain in sulfides, it is thought that it is probably mainly present within the structures of silicate clays. All of these relationships need further study.

Cadmium, which would not be expected to occur in the structures of silicate clay minerals because of its large ionic size, was shown in the data collected earlier (Table 1) to apparently have been reduced in the sulfuric horizon of the older soil (Area 4, profile S-MD-510-1) to levels about the same as found in most agricultural soils (see Korcak and Fanning 1985, for more background levels of heavy metals in Maryland soils).

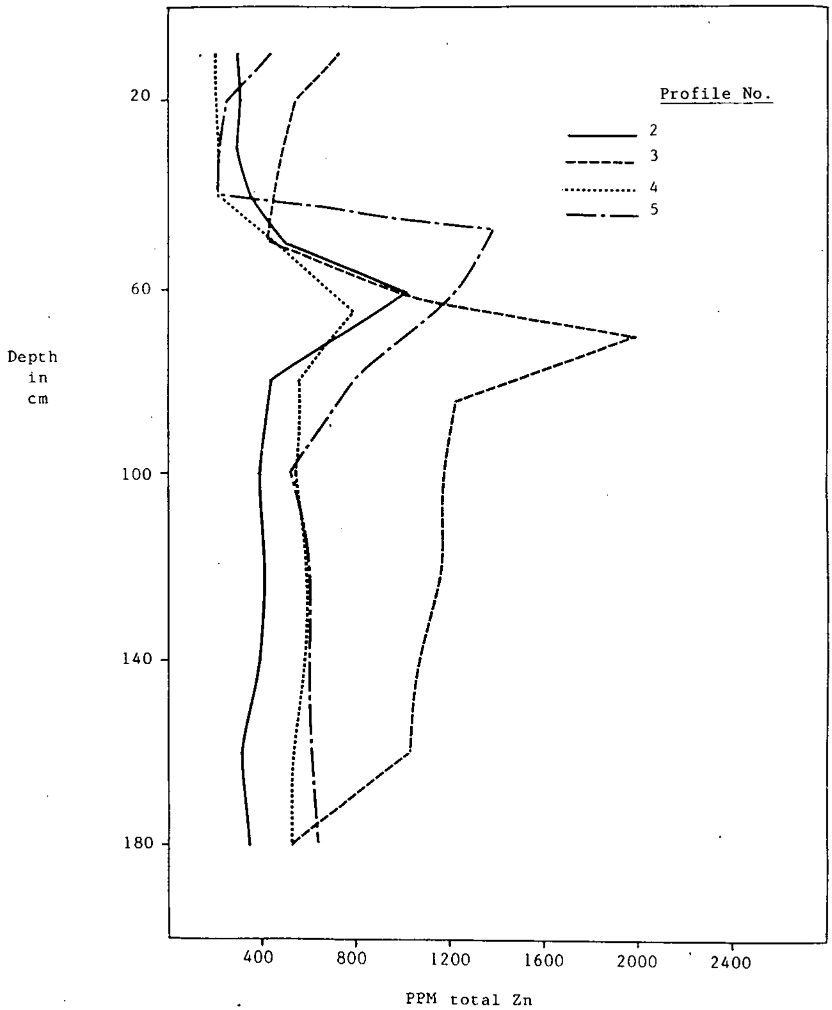

Figure 2 Graph of total Zn (air-dry basis) distribution with depth for 4 profiles from Area 2 (S-85-MD-510-2 thru 510-5) at Masonville dredged material deposition site in Baltimore that were sampled in 1985

4.3 Additional discussion

The loss of sulfur from soils during sulfuricization has been observed in several other studies (e.g. Wagner 1982; Wagner et al. 1982; Fleming and Alexander 1961). That some of this sulfur might be illuviated again deeper in the profiles of acid sulfate soils has also been suggested based on an apparent bulge in S content (Fleming and Alexander 1961).

The flushing of heavy metals from soils during acid sulfate ripening of soils appear to have received little attention in the past. If heavy metals are taken out of the root zone of most crops and possibly held within the lower horizons of acid sulfate soils, so that they do not contaminate ground water as much as they otherwise might do, this may have significant benefits from an environmental quality point of view. Other studies, of crops grown on the acid sulfate soils developed on the dredged materials from Baltimore Harbor, both in the greenhouse (Fanning 1983) and in the field (Snow et al. 1983) have shown that plant tissues can be produced on the more thoroughly ripened (Area 4 at Masonville) soils that are not elevated in heavy metals relative to those grown on 'normal' agricultural soils if the pH is adjusted to levels close to 6.5.

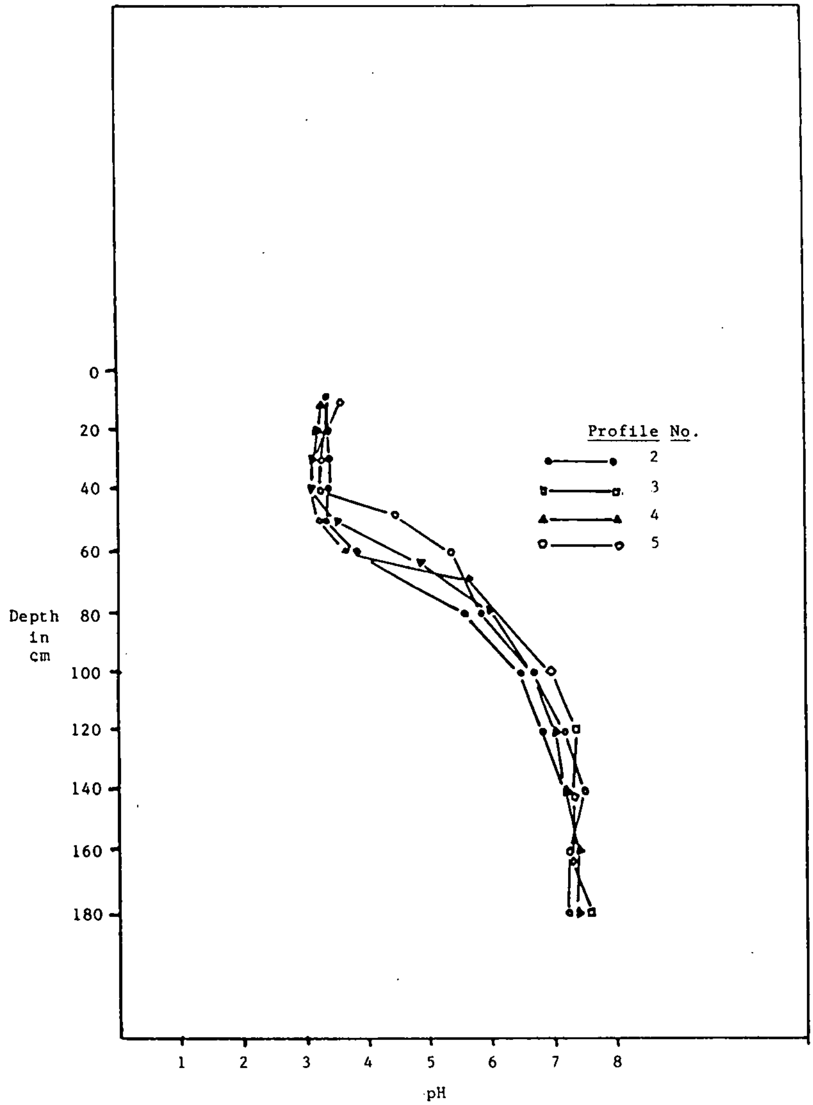

Figure 3 Graph of pH (1:1 by weight in water) with depth for 4 profiles from Area 2 (S-85-MD-510-2 thru 510-5) at Masonville dredged material deposition site in Baltimore that were sampled in 1985

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Engineering impacts of acid sulfate deposits in California, U.S.A.

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1 Summary

Three genetically different types of acid sulfate deposits in California are:

1. 'Common' acid sulfate deposits in reclaimed tidal marshes;
2. In-place and reworked products of past sulfide mining operations;
3. Acidic deposits associated with seepages of methane through gypsiferous deposits.

The last two of these three types of acid sulfate deposits have created costly engineering-geologic and environmental hazards and required remedial actions.

Résumé

Trois différents types génétiques de dépôts sulfaté-acides sont présents en Californie:

1. Les dépôts sulfaté-acides 'normaux' situés sur la côte nord de la baie de San Pablo (une extension de la baie de San Francisco), qui après l'amélioration des marécages côtiers à influence tidale ont développé des sols sulfaté-acides (Figure 2) à pH 3-3,5 (Lynn, 1964). Ils occupent une superficie restreinte de seulement quelques km^2.
2. Les dépôts sulfaté-acides résultant des opérations minières dont les plus importants sont ceux de la Vallée Centrale de Californie au voisinage de la ville de Redding (Figure 1) et ceux de Sierra Nevada. Ils présentent une acidité élevée et sont en même temps une source de pollution de Cu, Zn et d'autres métaux, résultant ici de l'oxydation de la pyrite (Prokopovich 1965). Le pH des pâtes saturées des déchets miniers est parfois de 0,7. Les déchets replacés, érodés et redéposés ont causé par endroits la mort des poissons et des sauvagins, et ont provoqué des sédimentations excessives. Les valeurs du pH des ruissellements miniers ont été par endroits 1,4-1,6, pendant que celles des alluvions associées étaient de 2,3-3,8.
3. Les dépôts sulfaté-acides associés au suintement de méthane (CH_4) à travers les dépôts gypseux. Ils ont une apparition ponctuelle dans les barrages de San Luis et O'Neill de la bordure-ouest de la Vallée San Joaquin et ont été étudiés lors des recherches géologiques concernant la construction du projet géant d'irrigation de la Vallée Centrale de Californie (Anonymous 1981). Les valeurs pH de ces dépôts varient entre 0,7 et 3,7 et descendent parfois à 0,5.

Les deux derniers dépôts ont produit des dégâts importants tant pour l'environnement que pour les travaux de géologie technique et de construction, et les mésures de restauration sont extrêmement coûteuses.

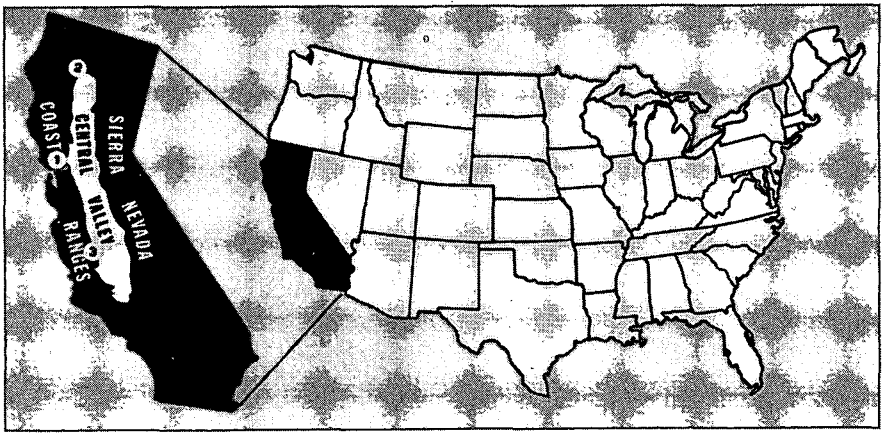

Figure 1. Maps of the continental USA and the State of California showing locations of the described acid sulfate area: (1) Tidal marshes north of San Francisco, (2) old sulfide mining area near Redding, (3) gas seepages in areas of San Luis and O'Neill Dams.

2 Introduction

The following text is a brief description of three genetically different types of acid sulfate deposits known to be present in the State of California (Figure 1) and their engineering and environmental impacts. The fourth type of such deposits associated with volcanic and postvolcanic processes (for example, hot springs in the Lasson Volcanic National Park, etc.) is not included in the discussion. The data used in the text were collected by the author for the Mid-Pacific Region of the U.S. Bureau of Reclamation in connection with design, construction, and operation of the giant irrigation Central Valley Project (Anonymous 1981, p. 165-232). The ideas expressed in this paper are, however, those of the author and may not represent the official view of the Bureau.

3 Acid sulfate deposits in California

The following three genetically different types of acid sulfate deposits are known in the State of California in the USA (Figure 1):

3.1 Tidal acid sulfate deposits

The first type – the 'common' acid sulfate deposit – covers several square kilometers on the northern shore of the San Pablo Bay (an extension of the San Francisco Bay). The lowest pH values of soils are in the order of 3.0 to 3.5. The soils here, studied in detail by Lynn (1964) are developed over reclaimed tidal marshes (Figure 2).

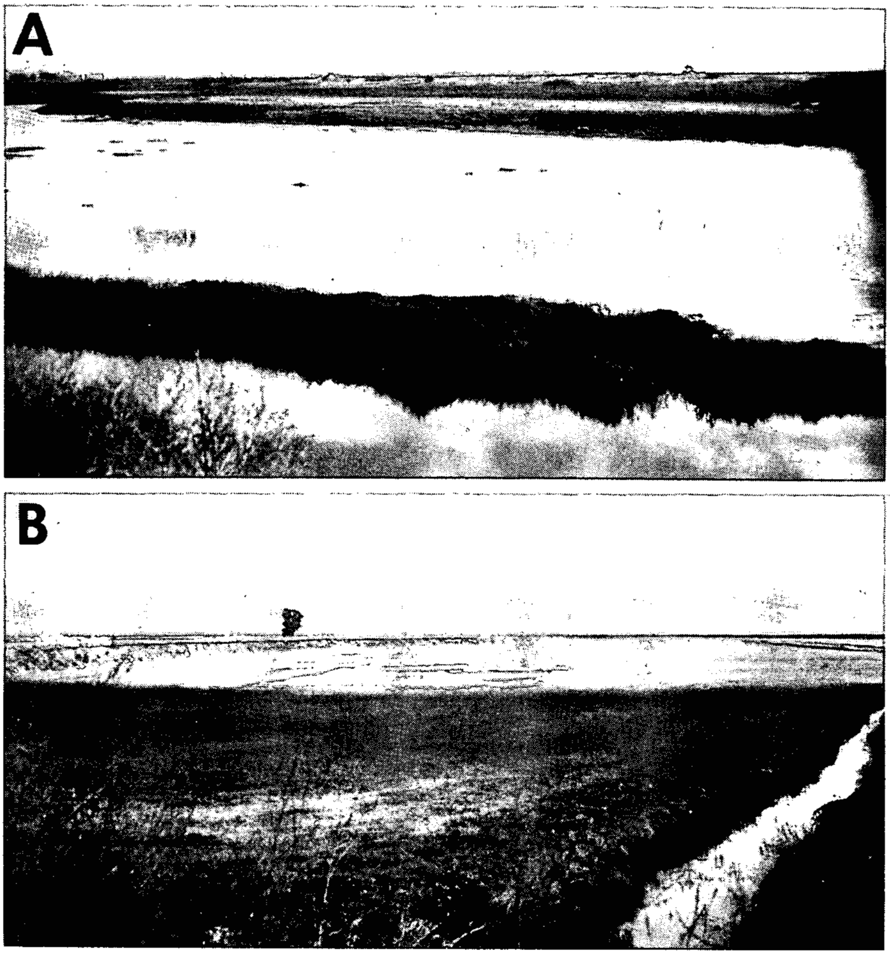

Figure 2. Photographs of the unreclaimed (A) and reclaimed (B) tidal marshland on the northern shore of San Pablo Bay north of the city of San Francisco

3.2 Pyritic mining tailings

The second type of acid sulfate deposit is associated with past mining activities. The best-developed deposits of this type occur at the northern end of California's Central Valley in the vicinity of the City of Redding (Figure 1). Similar deposits are also known in the Sierra Nevada and elsewhere. High acidity and pollution by metals such as copper, zinc and others is caused here by an oxidation of sulfide or minerals (mostly pyrite) in underground workings and in old mining dumps (Prokopovich 1965). The pH values of saturated pastes of some pyritic mining tailings is locally as low as 0.7. Reworked, eroded and redeposited tailings polluted some local streams killing fish and other wildlife and causing excessive sedimentation (Figure 3). The pH values of

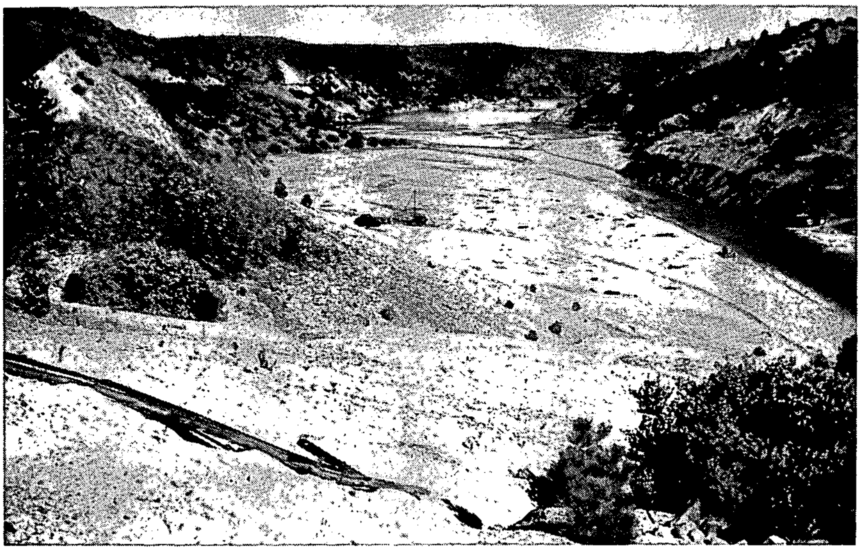

Figure 3. Downstream view of the 10 years old, 0.8 km long, Spring Creek Delta in Keswick Reservoir. The thickness of highly acidic sandy alluvium was locally over 12 m

some local surface mine runoff were 1.4-1.6 and lower while the field pH value of associated alluvium was on the order of 2.3-3.8. Additional damages to local vegetation were done in the past by acidic smelter fumes.

3.3 Acid sulfate deposits associated with seepage of methane

The third type of acid sulfate deposits is associated with local seepage of methane (CH_4) through sulfate (mostly gypsum)-bearing sediments. This rather unusual type of acid sulfate deposits has 'spotty' occurrence at the San Luis and, particularly, O'Neill Dams in the Coast Range foothills on the western edge of the San Joaquin Valley (Figure 1). The phenomenon was studied in connection with geologic investigations for the San Luis Unit of the Central Valley Project (Anonymous 1981, p. 209-216) and was described in the literature (Prokopovich et al. 1971).

The location of main acidic 'spots' is shown in Figure 4. 'Petroleum methane' associated with the Upper Cretaceous marine beds seeps through overlying, usually gypsiferous continental fluvial and lake deposits. Bubbling methane was noted both in several flooded areas and in test holes. The gas always had strong hydrogen sulfide odor. Chemical analysis of four samples of gas is as shown on Table 1.

Isotopic composition of two gas samples indicate their 'petroleum' character. In dumped or wet media, bacterial reactions between methane and gypsum create hydrogen sulfide and reactions between the hydrogen sulfide and the limonitic pigment of sediments create black, fine-grained iron-sulfides. Typical black coloration of normally buff-colored alluvium was noted here in preconstruction test holes in several areas in the O'Neill Reservoir and along O'Neill Dam. Oxidation of both hydrogen and

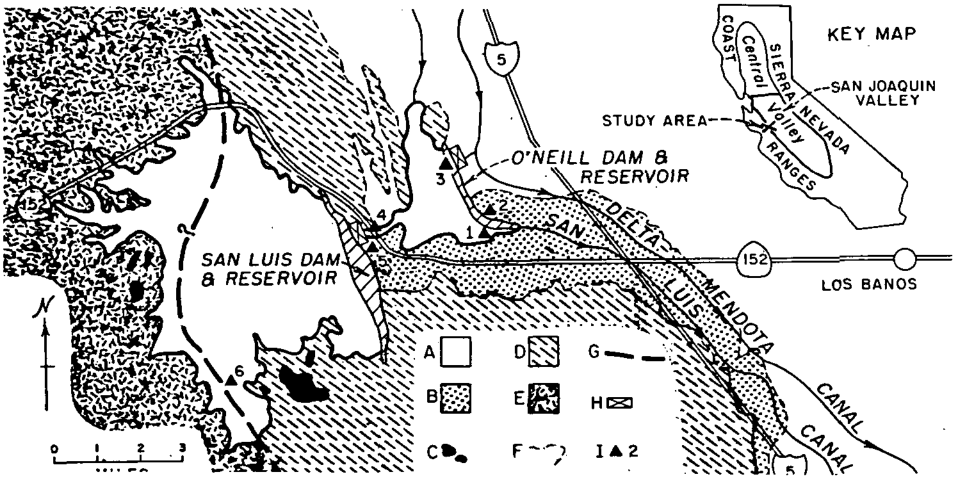

Figure 4. Regional geology of San Luis area. A, young alluvium. B, older alluvium and lake beds. C, Tertiary basalt. D, Upper Cretaceous marine sediments. E, Franciscan complex. F, Geologic contacts. G, Ortigalita fault zone. H, pumping plant. I, acidic areas: (1) Madeiros area, (2) southeastern part of O'Neill Dam, (3) O'Neill Pumping Plant, (4) San Luis Pumping-generating Plant intake channel, (5) Switchyard, and (6) 'Harper Line Road'

Table 1. O'Neill Dam and Reservoir chemical composition of gas samples

	A	B	C	D
Methane	27.1	40.8	1.1	37.2
Ethane		0.1	0.1	0.4
Propane		Trace	Trace	Trace
Normal Butane		0.0	Trace	0.0
Isobutane		0.0	0.1	0.0
Normal Pentane		0.0	Trace	0.0
Cyclopentane		0.0	Trace	0.0
Hexanes Plus		0.0	0.1	0.0
Nitrogen	69.6**	54.8	94.7	3.2
Oxygen	0.4	0.0	0.0	0.5
Argon		0.7	0.8	0.1
Hydrogen	0.7	0.0	0.0	57.7
H_2S*	0.7	0.0	0.0	0.0
CO_2	2.2	3.6	3.0	0.9
Helium		Trace	0.01	Trace

Where:

A = January 1967: gas flowing from the test hole 'C' at Madeiros Recreation Area, O'Neill Reservoir

B = August 1979: gas bubbles collected beneath a shallow water cover for a boat ramp, Madeiros Recreation Area, O'Neill Reservoir

C = May 1980: gas bubbles in pipeline trench at east toe of O'Neill Dam

D = May 1985: gas bubbling from slope indicator test hole SI-6, southwest corner of O'Neill Pumping Plant

* Due to the sorption and oxidation of H_2S during storage, the data are not reliable

** Including all inert and trace gases

iron sulfides resulted in development of very low pH, native sulfur, jarosite and alunite. Some pH values were as low as 0.5. pH values of 0.7 to 3.7 were more common (Prokopovich et al. 1971).

4 Engineering impact

Engineering and economic impacts of the 'common' acid sulfate deposits in California appear to be relatively small.

Runoff from old mining areas with field pH values as low as 1.4 and 1.6 is carrying large amounts of toxic metals such as copper, zinc and others. The pollution and associated erosion in tributary streams has caused several fishkills and an accelerated sedimentation in large streams and reservoirs (Figure 3). Revegetation in some areas was particularly slow because of soil poisoning by fumes from old smelters. In order to control sedimentation and pollution in one of the polluted streams, a special debris and pollution control dam (Figure 5) was built at a cost of over $ 4 million (1964 values) (Prokopovich 1965). Severe corrosion of drilling equipment by acidic stream water occurred at the damsite during preconstruction investigations (Figure 6). Similar corrosion of steel and concrete used in the dam occurred after the construction.

More surprising are two cases of engineering impacts of acidity related to the migration of natural gas in the San Luis area. In one of these cases, a section of shore of O'Neill Reservoir initially designated as a public recreational area and having highly acidic soils (pH 0.5-3.7) was riprapped to prevent body contact with acidic deposits (Figure 7).

In the second case, in April 1985 a routine inspection of one of the buried discharge pipes of O'Neill Pumping Plant (Figure 8) revealed a 7.5x15 cm-hole in the 1 cm-thick, 3 m-diameter steel pipe (Figure 9). Following excavation of all six discharge pipes

Figure 5. An upstream view of the 60 m high Spring Creek Debris Dam during rainy season (During summer-fall seasons the reservoir is nearly dry)

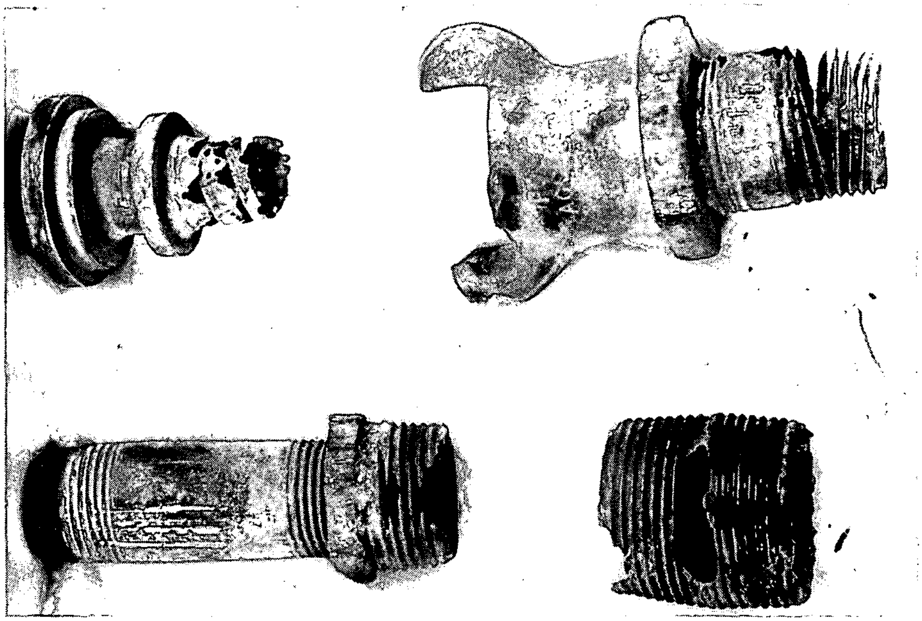

Figure 6. Corrosion of drilling equipment used in studies of the Spring Creek Dam

(only partially accomplished at the present time) revealed some 40 'through' holes and about 100 corroded cavities up to 0.5 cm deep on the outside surface of all pipes. Corrosion of steel pipes is believed to be caused by sulfuric acid associated with seepages of natural gas from the bedrock into backfill surrounding the pipes. Bacterial reactions between gas and gypsum created hydrogen sulfide, and oxidation of the hydrogen sulfide and other associated sulfides created H_2SO_4, which corroded the steel pipes. Local, 5-8 millimeter thick, black discolored stringers of originally buff clayey gypsiferous backfill were noted next to the pipes. This black colored clay reacted strongly with hydrochoric acid releasing H_2S.

Remedial action included removal of the backfill, patching the holes, and backfilling of excavated areas with clean gravel (Figure 10). This gravelly, nongypsiferous fill will permit an easy escape of natural gas without generation of hydrogen sulfide. The total cost of this rehabilitation is estimated to be \$ 80,000 – \$ 100,000.

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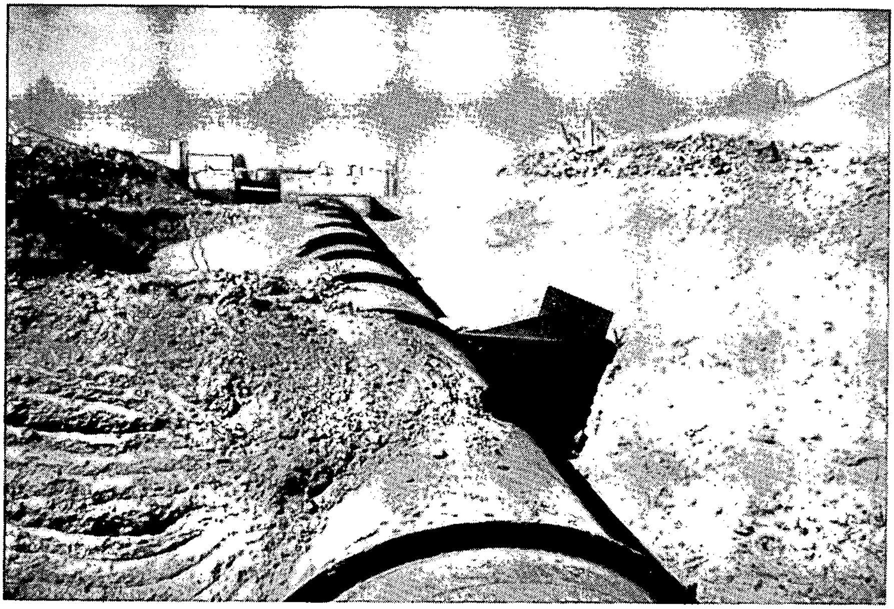

Figure 10. An excavation around a discharge pipe of the O'Neill Pumping Plant partially backfilled with gravel

Inhibition of pyrite oxidation in coal mine waste

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1 Summary

Acidification of reclaimed coal mine waste is a problem in the coalfields of Central Scotland and Northern England. Acid patches, often below pH 3, develop on areas of high pyrite content, killing off any established vegetation. The usual method for controlling acidity on these sites is to add high levels of lime. Estimation of a lime treatment which would neutralize all the potential acidity is difficult due to the uneven distribution of pyrite. Such a liming policy often results in a massive overliming of most of the site. Thus a management option which inhibits acid production would be an advantage.

The crucial step in the oxidation of pyrite is the conversion of ferrous to ferric iron. In high pyrite systems this is the rate determining step, whereas in low pyrite systems the oxidation of pyrite by ferric ions is rate determining. So any factor which can complex or precipitate iron could inhibit pyrite oxidation.

Inhibition of pyrite oxidation has been shown to be possible in model systems using a complexing agent specific for ferrous ions (1:10 phenanthroline) or by using a bacteriacide to prevent oxidation of ferrous ions by Thiobacillus ferrooxidans. Treatments which complex or precipitate ferric ions also had an inhibitory effect on pyrite oxidation. Phosphate, silicate, citrate and EDDHA (ethylenediamine di-orthohydroxyphenylacetic acid) were examined. All of these treatments inhibited the release of acid and iron from pyritic mine waste. As a practical treatment it would be advantageous to use materials which are themselves wastes, or which have some amendment value, e.g. supply nutrients, wood waste, chicken manure and pulverized fuel ash (PFA) all resulted in a decrease in the release of acid and iron from pyritic waste.

Résumé

L'acidification des surfaces améliorées après la déposition des déchets miniers est un problème sérieux des champs charboniers de l'Ecosse Centrale et de l'Angleterre du Nord. Des taches acides à pH inférieur à 3 se développent dans les superficies à haute teneur en pyrite et tuent toute végétation. La méthode usuelle pour contrôler l'acidité dans ces sites, était le chaulage. Comme l'estimation de quantités nécessaires à neutraliser toute l'acidité potentielle est très difficile à cause de la distribution inégale de la pyrite, cette méthode a menée souvent à un surchaulage de la plus grande partie du site. C'est ainsi que de recherches ont été entreprises pour trouver une méthode d'amélioration qui pourrait inhiber la production des acides.

L'étape critique dans l'oxydation de la pyrite est la conversion des ions ferreux en ions ferriques. Donc tout facteur qui peut complexer ou précipiter la fer peut inhiber l'oxydation de la pyrite et par conséquence le développement de l'acidité.

1:10 phenantroline, agent complexant spécifique pour les ions ferreux, un bactéricide (Panacide –2,2' dihydroxy 5,5' dichlorophenylmethane) dans un concentration de 0,5 mg l^{-1}, pour prévenir l'oxydation des ions ferreux par Thiobacillus ferrooxidans et des traitements qui complexent ou précipitent les ions ferriques et ont un effet inhibitoire sur l'oxydation de la pyrite (phosphates, silicates, citrates et EDDHA-ethylenediamine di-orthohydroxyphenyl – acide acetique) ont été utilisés.

Les résultats des essais montrent que tous ces traitements ont inhibés la libération des acides et du fer des déblais miniers pyritiques.

D'autres expériences, utilisant des matériaux, eux même déchets, ont conduit aux mêmes résultats.

La cendre de charbon (des thermocentrales), la fumure de volailles, les déchets de bois se sont montrés efficaces. Dans le cas de déchets organiques l'inhibition de la libération des acides et du fer a été probablement due à la chélation du fer, tandis que la cendre (contenant $\pm 50\%$ SiO_2) a réagit par précipitation.

Pour rendre avantageuse l'application au champ de ces traitements, les niveaux et les méthodes d'incorporation doivent être attentivement examinées, ainsi que la distance de la source d'amendaments du site à améliorer.

2 Introduction

Coal mine waste is a collective description for the unwanted material brought to the surface during coal mining and then separated from the marketable coal. This material comprises mainly shales, with some sandstones, ironstones, limestones and low-grade coal. It is usually tipped into large mounds on the surface. Such mounds, known also as tips, heaps or bings, are common in the coal mining areas of the U.K., resulting mainly from mining activities over the last 100 years. As land has been used up, especially for building in the industrial areas, there has developed a demand to reclaim coal waste tips for other uses. Along with this requirement for the reuse of the land, there has been an increasing awareness of environmental quality over the last 20 – 30 years which has also resulted in pressure to reclaim such sites. In Scotland alone the expenditure on land reclamation, much of it coal waste tips, is currently some £ 20 – £ 25 million per annum.

As more land is reclaimed the costs of management increase, and become a greater proportion of the total budget. On coal waste tips the production of acid due to pyrite oxidation is a particular problem. Acid production is usually counteracted by addition of lime, but the variation in pyrite content across a site means that estimation of the amount of lime needed to neutralize all existing and potential acidity is difficult. Thus any management option which would allow prevention of acid production by inhibiting pyrite oxidation would be advantageous.

Oxidation of pyrite can be due to the action of either oxygen or ferric ions. The overall reactions can be represented respectively as

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 8H_2SO_4 \tag{1}$$

and

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \tag{2}$$

If the pH is maintained above about 3.5 then the oxidation of ferrous ions by oxygen is the important step, and this is controlled by the rate of diffusion of oxygen into the spoil (Van Breemen 1973). Thus the overall rate of oxidation of pyrite is low, and this is the control obtained by liming to a higher pH. If on the other hand the spoil pH falls below about 3.5 then the oxidation of ferrous ions is catalysed by Thiobacillus ferrooxidans, which can increase the rate of oxidation by a factor of 10 or more (Singer and Stumm 1970). In acidic coal waste ferrous ions released from pyrite are oxidized bacterially to ferric ions, which can then act as oxidizing agents on pyrite. This leads to a large amount of acid being released, which can neutralize any added lime and natural buffering capacity in the waste. The result is very acid waste of pH 3 or less and a killing off of any established vegetation. On many sites, acid patches such as these appear 2 to 3 years after reclamation and prove difficult to ameliorate.

The crucial step in the oxidation pathway is the conversion of ferrous to ferric ions. In high pyrite systems this is the rate determining step, whereas in low pyrite systems the oxidation of pyrite by ferric ions is rate determining (Backes 1984). In either case any factor which inhibits or slows down the ferrous to ferric oxidation could result in a decrease in acid production. This inhibition could be brought about by various means: reducing conditions could be maintained, either by waterlogging or by physically sealing off the subsoil from the surface layers; bacterial activity could be stopped by the use of a bacteriacide; chemical complexing or precipitation of iron would confine the oxidation pathway to one in which oxygen was the oxidizing agent (reaction (1)). The work described here used chemical methods to inhibit the oxidation of pyrite.

3 Inhibition of pyrite oxidation

Having shown that the ferrous to ferric oxidation was the important step in the oxidation of pyrite, attention was paid to methods of slowing down or completely inhibiting this reaction (Backes 1984; Backes et al. in press). Suspensions of pyritic coal waste in water were incubated and treatments used which would specifically interfere with the oxidation of ferrous to ferric ions, or the oxidation of pyrite by ferric ions. The feasibility of this approach was tested initially by using a bacteriacide to prevent the oxidation being catalysed by Thiobacillus ferrooxidans, and by using 1:10 phenanthroline which is a chelating agent specific for ferrous ions. These treatments were to prevent the oxidation of ferrous to ferric ions. Subsequent treatments attacked the ferric ion, preventing oxidation by it of the pyrite. Phosphate, citrate, silicate and EDDHA (ethylenediamine di-orthohydroxyphenylacetic acid) were all chosen to complex or precipitate ferric ions. As the use of such treatments would be unlikely on a practical basis, with the exception of phosphate and silicate, other materials were tested which had properties which could affect the ferrous or ferric ions in solution. These materials were also amendments used in land reclamation for other reasons, i.e. as suppliers of nutrients or as neutralizing agents. The amendments used were chicken manure, wood waste and pulverized fuel ash.

3.1 Use of a bacteriacide

Under very acid conditions the oxidation of ferrous to ferric ions is catalysed by Thio-

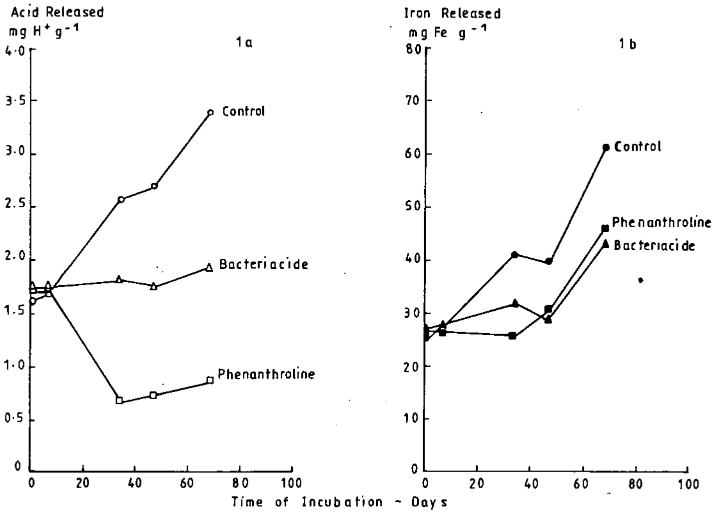

Figure 1. Effect of a bacteriacide and a chelating agent for ferrous iron (1:10 phenanthroline) on the release of a) acid and b) iron from pyritic coal mine waste

bacillus ferrooxidans, considerably increasing the rate of acid production. A bacteriacide should therefore prevent this catalytic effect. Kleinmann et al. (1981) and Dugan & Apel (1983) have used detergents to inhibit the bacteria and control acid production. The bacteriacide used here was Panacide (2,2′ dihydroxy 5,5′ dichlorophenylmethane) (BDH Chemicals) at a concentration of 0.5 mg l^{-1}. This inhibited the release of acid and iron compared to an untreated control (Figures 1a and 1b). That this was due to prevention of oxidation of ferrous ions by inhibiting bacterial action was shown by isolating a ferrous containing sample of acid mine water. The concentration of ferrous ions in this was 90 mg l^{-1}. In the untreatedcontrol solution ferrous ion concentration rapidly decreased, even under the very acid conditions, to zero at 35 days. Treatment with the bacteriacide stabilized the ferrous concentration at a constant 85 mg Fe^{2+} l^{-1} (Figure 2).

3.2 Use of a chelating agent specific for ferrous ions

1:10 phenanthroline is a chelating agent which reacts specifically with ferrous ions. Treatment of the pyritic coal waste with this resulted in inhibition of acid release and stabilization of ferrous ions in solution in a similar manner to that found with the use of the bacteriacide (Figure 1a, 1b and 2).

3.3 Chelation or precipitation of ferric iron

If the oxidation of ferrous to ferric iron is not prevented it should still be possible to inhibit acid production by chelating or precipitating the ferric ions, so preventing

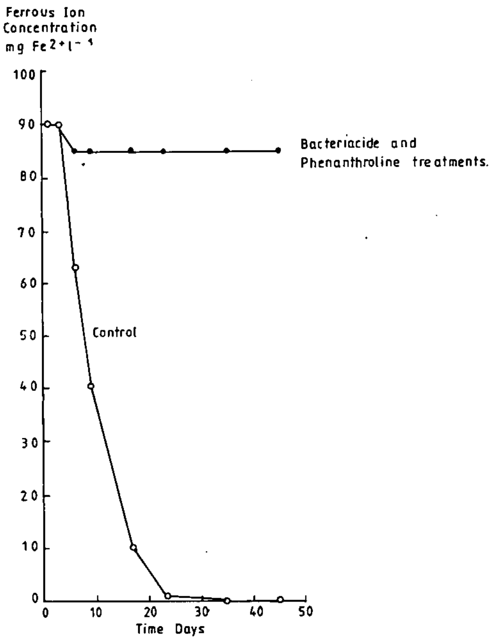

Figure 2. Effect of a bacteriacide and 1:10 phenanthroline on the oxidation of ferrous iron

them acting as oxidizing agents on pyrite. Four compounds known to react with ferric ions were studied for this purpose; phosphate, citrate, silicate and EDDHA (ethylene-diamine di-orthohydroxyphenylacetic acid). All inhibited acid production in suspensions of pyritic coal waste compared to the untreated control (Figure 3a and 4a). Although all four also resulted in a decrease in iron in solution, the pattern of release differed between treatments (Figures 3b and 4b). Citrate and EDDHA are both known to complex ferric iron. In the suspensions treated with citrate the level of iron in solution was only slightly below that in the controls. Most of this iron was in the ferric form (the ratio of Fe^{3+}: Fe^{2+} being 3:1), suggesting that a soluble ferric citrate complex was formed. The iron concentration in the EDDHA treated suspensions was initially not different to the controls, only after about 50 days incubation was there a significant decrease in iron concentration in solution. Although both citrate and EDDHA showed an effect in decreasing acid production they are unlikely to provide practical treatments to the problem.

Phosphate and silicate are both more practical possible treatments which have both been previously considered as treatments for pyritic spoil (Watkin and Watkin 1983). Phospate is known to react with ferric iron to produce a precipitate of ferric phosphate, which is stable under acid conditions. Early work on the reclamation of the Dutch polder soils showed that pyrite oxidation was inhibited by the presence of phosphate (Quispel et al. 1952).

Treatment with phosphate caused the iron concentration in solution to decline almost to zero (Figure 3b), suggesting that phosphate was acting by precipitating iron out of solution. The use of phosphate as a means of inhibiting pyrite oxidation is

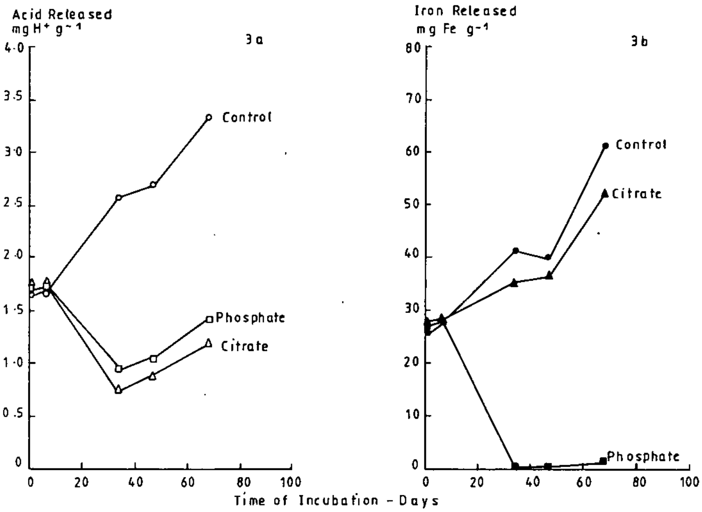

Figure 3. Effect of phosphate and citrate on the release of a) acid and b) iron from pyritic coal mine waste

attractive as it is used routinely as a fertilizer treatment, although cost may be a prohibitive factor. Silicates have been used in the past to control acid mine drainage, but usually in the form of a silica gel which effectively acts as a seal preventing the influx of air into the mine waste (Tyco 1971). Silicate can however react with iron, forming either a soluble complex or a precipitate depending on pH and iron concentration (Weber and Stumm 1985; Olson and O'Melia 1973). In the incubation of pyritic suspensions, silicate decreased the release of acid and iron (Figures 4a and 4b). Further studies showed that the concentration of Si was important (Figure 5). There was only little effect on acid release at 0.015% Si, and initially no effect on iron concentration in solution. Only in the later stages of the incubation did the iron concentration fall significantly below the control. At this stage a yellow precipitate was observed, suggesting that initially a soluble iron silicate complex was formed which precipitated above a certain iron concentration. Increasing the Si concentration to 0.15% gave complete control over the release of acid and iron.

3.4 Use of waste materials

Pulverized fuel ash (PFA) is the waste product of coalfired electricity generating stations. Its disposal is a problem to the electricity supply industry, some 10-12 million tonnes being produced per.annum in the U.K. Silicon is a major component of PFA, a typical figure being 50% SiO_2. In suspensions containing a ratio of 2:1 coal waste: PFA, there was virtually complete control of acid and iron release (Figures 5a and 5b). Although some adsorption of hydrogen ions and ferrous or ferric ions on to the surface of the PFA may have taken place, the presence of a yellow precipitate indicated that iron was also being removed from solution, probably as a ferric silicate. Analysis of the water for Si showed that silicon was being released from the PFA over the

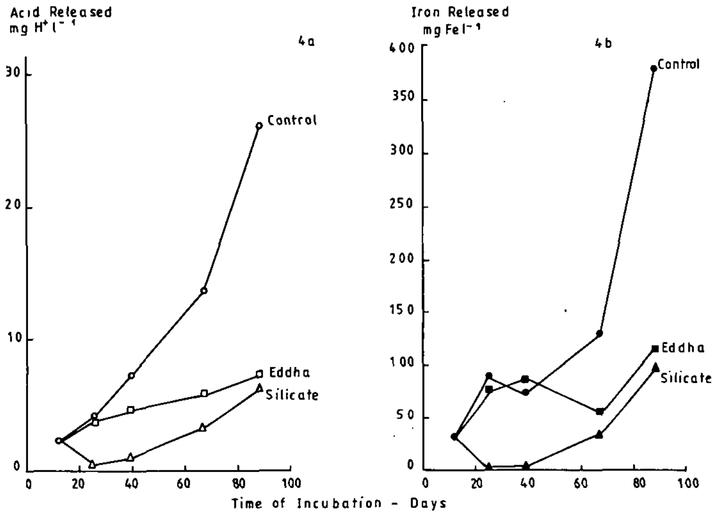

Figure 4. Effect of silicate and EDDHA (ethylenediamine di-orthohydroxy phenylacetic acid) on the release of a) acid and b) iron from pyritic coal mine waste

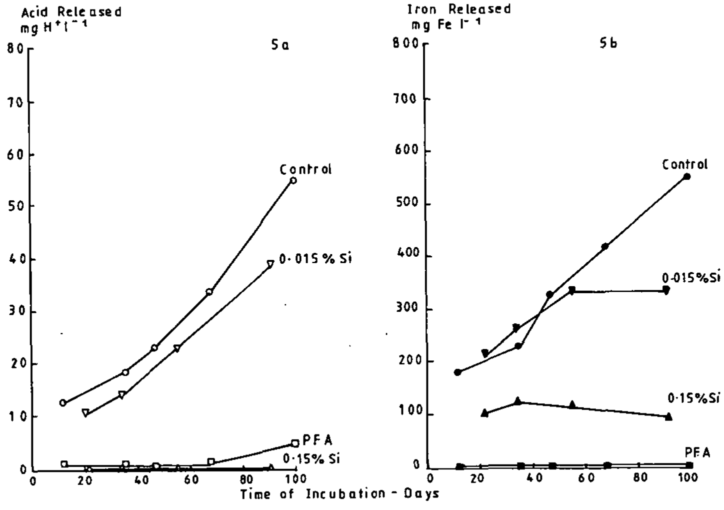

Figure 5. Effect of pulverized fuel ash (PFA) and solutions of varying Si concentration on the release of a) acid and b) iron from pyritic coal mine waste

course of the incubation (from 10 to 60 mg Si l^{-1} over 100 days). The two organic wastes used, chicken manure and wood waste, both inhibited the release of acid and iron from the pyritic coal waste (Figures 6a and 6b). This was probably due to chelation of ferrous or ferric ions by functional groups on the organic waste, or in soluble material released from the organic waste. Other studies suggested that iron was held on the solid component of the manure, but by soluble material released from the wood

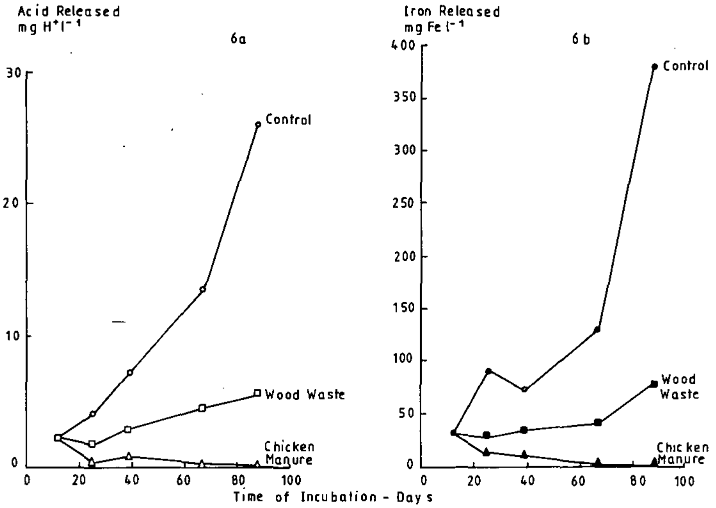

Figure 6. Effect of wood waste and chicken manure on the release of a) acid and b) iron from pyritic coal mine waste

waste (Backes 1984). Both chicken manure and wood waste have been used as amendments for coal mine waste. Their ability to inhibit pyrite oxidation is an additional reason why such materials should be incorporated into reclamation treatments.

4 Conclusions

There is evidence from the results described here that the oxidation of pyrite can be inhibited by treatments which interfere with the oxidation of ferrous to ferric ions, or which complex iron, so preventing ferric ions acting as an oxidizing agent on pyrite. Such treatments have yet to be shown to be effective in the field. Two main factors would have to be taken into consideration. Firstly, the degree to which the oxidation can be controlled could depend on the mechanism of the inhibition. In some cases good contact between pyrite and inhibitor may be essential, which could be difficult to obtain in the field. So levels and methods of application will have to be examined. The second factor is the availability of a material. The use of an amendment is feasible only if a plentiful supply is available close to the reclamation site. Otherwise transport costs become too great for the treatment to be economic. However, given the variety of waste materials which could have suitable properties for inhibiting pyrite oxidation, this type of treatment could be a useful management option for the reclamation of pyritic coal waste.

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Spatial analysis as a reconnaissance survey technique: an example from acid sulphate soil regions of the Mekong Delta, Viet Nam

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1 Summary

In the Mekong Delta, Viet Nam, a study was carried out to determine the spatial variability of soil properties in acid sulfate areas, with the joint aims of selecting the most suitable soil properties for distinguishing between soil units and the best scales for soil survey. The method chosen used nested sampling and nested analysis of variance. Results showed, that in these acid sulfate soils, EC (and consequently soluble sulfate) was a useless attribute for distinguishing between soil units. Depth to jarosite was a reasonably reliable criterion for distinguishing between soil units at various scales in areas of acid sulfate soils having jarosite mottles in the profile, but short range variability of this property was also large. In areas having acid sulfate soils without jarosite mottles, the presence/absence of jarosite is a useful characteristic for mapping at semi-detailed and reconnaissance scales.

Résumé

Une étude permettant de déterminer la variabilité spatiale des sols sulfaté-acides, avec le but de choisir les propriétés des sols les plus appropriées pour séparer les unités des sols, ainsi que les échelles aux quelles ces propriétés varient, a été réalisée.

La ferme de Lang-Bien située dans la Plaine des joncs (avec des SSA sur matériau originel pauvre en matière organique, généralement oxydés jusqu'à une profondeur de plus d'un mètre) et la ferme 85B située dans la partie occidentale de la Plaine de Ha Tien (avec des SSA issus d'un matériau originel argilo-tourbeux, généralement oxydés sur moins d'un mètre de profondeur), ont été choisies comme superficies d'étude.

Pour séparer les unités des sols sulfaté-acides, les propriétés suivantes ont été enregistrées:
- altitude relative;
- utilisation des terres (1 = sans végétation; 2 = inondé; 3 = joncs; 4 = autre végétation naturelle; 5 = riz submergé; 6 = forêt);
- topographie (1 = plat; 2 = faiblement ondulé);
- classe de drainage (1 = très pauvre: plus de 6 mois d'inondation par année; 2 = pauvre: 3 à 6 mois; 3 = modére: < 3 mois; 4 = bon: pas d'inondation);

- matériau originel (1 = argile fluviatile; 2 = sable fluviatile; 3 = sédiment argileux d'eau saumâtre (vasière pyritique potentiellement acide);
- efflorescences de sels à la surface du sol (0 = non; 1 = oui);
- profondeur de la nappe d'eau en cm;
- profondeur de l'apparition du jarosite en cm;
- profondeur de l'apparition de la pyrite en cm;
- nomenclature des horizons conformément à la FAO;
- épaisseur de chaque horizon;
- classe d'argile en % (1 = 10%, 2 = 10-20%; 3 = 20-40%; 4 = > 40%);
- couleur d'après Munsell (teinte, valeur et chroma de la matrice de sol de chaque horizon);
- pH de la couche supérieure du sol;
- Ec de la surface du sol en extrait sol-eau 1:5;
- état de maturation de chaque horizon (1 = non maturé; 2 = demi-maturé; 3 = maturé, test au champ);
- présence de taches de jarosite dans chaque horizon (0 = néant; 1 = rares; 2 = frequentes; 3 = abondantes);
- présence de taches oranges ou bruns dans chaque horizon (rares, fréquentes, abondantes = comme pour le jarosite);
- présence de taches rouges dans chaque horizon (rares, fréquentes, abondantes = comme pour le jarosite);
- estimation au champ de la matière organique dans la partie supérieure du sol ainsi que dans le sous-sol réduit (1 = 0-10%; 2 = 10-20%; 3 = 20-30% et 4 = > 30% du volume).

Pour la détermination de l'échelle à la quelle ces propriétés varient, on a utilisé la technique d'échantillonnage en nids (Figure 3) et l'analyse de la variabilité des propriétés (Figures 5 et 6).

Les résultats montrent que dans les superficies à SSA, le EC (et par conséquence aussi le sulfate soluble) n'est pas un paramètre utile pour la séparation des unités des sols. Par contre, la profondeur de l'apparition du jarosite est un critère valable et stable durant de longues périodes (différemment du pH par exemple, qui varie beaucoup au cours des saisons). La profondeur de l'apparition du jarosite peut être utilisée pour la séparation des unités des sols à différentes échelles, dans les superficies à SSA à taches de jarosite, tout en tenant compte de la variation sur courte distance. Dans les superficies à SSA sans taches de jarosite, la présence/absence du jarosite est un critère utile pour la cartographie de reconnaisance ou à moyenne échelle.

2 Introduction

The aim of soil mapping is to discover and record the pattern of variation of soil within a given area. Because the kind of soil present at any given place on the earth's surface is strongly affected by its geology, landform, climate, hydrology and vegetation, these phenomena can give a good indication of the nature of the soil and how and where it changes. In many landscapes, the sampling density necessary to characterize the soil can be inferred from reconnaissance studies using stereo aerial photographs that allow the scale of the soil pattern to be deduced from the textures, three-dimensional views and the tones present on the imagery. It is well known that both aerial photo interpretation and 'free' ground soil survey are most effective when the soil pattern is strongly related to the patterns of landform, vegetation and hydrology. These conditions prevail in terrain with a clear relief, and in situations where the natural patterns of drainage and vegetation have been little disturbed.

There are many situations, however, particularly in plain lands, or in areas that have been cleared of the natural vegetation, where the soil pattern cannot easily be interpreted from the external expression of landscape differences. In these situations, aerial photo interpretation and other reconnaissance techniques are likely to be unsatisfactory for exploratory studies prior to detailed soil survey work.

In soil mapping using only field sampling, there is a direct relation between sample spacing, the size of the individual soil units that can be mapped, and the scale of the soil map used to display the results. By the sampling theorem (a rule of thumb from signal theory), it is impossible to recognise a pattern unit if it has been sampled only once; consequently an absolute minimum of two samples are needed to distinguish a pattern unit in one direction. By analogy, a minimum of four observations are needed to recognise a block of land belonging to a given kind of soil. Mapping conventions (see Vink 1961) relate sampling density to map scale through the number of samples or observations per cm of map. So, using a map of scale 1:10.000, four samples on a square grid would be able to resolve a minimum pattern unit of 1 ha; at a scale of 1:1.000.000 four samples would resolve a unit of 10 × 10 km.

Many soil survey organizations determine sample spacing from map scales, assuming a priori, that standard topographic map sheet scales will allow soil pattern to be resolved as far as required, with external evidence from landforms etc. being used to support regular sampling. In many cases there is no reason to expect that an a priori choice of map scale, and hence sampling interval, will be the most appropriate for any given area. In fact, in areas with large, simple soil patterns, this approach will result in a waste of survey effort. In complex, highly variable areas, the chosen sample spacing may be completely inadequate. So, in situations where the size of the soil patterns cannot be deduced from the external aspects of the landscape, or for soil properties having a distribution that is unlikely to be directly related to landform or vegetation, it is sensible to first undertake pre-survey reconnaissance studies in order to determine the size and complexity of the patterns to be mapped. These pre-survey studies should ensure that the most appropriate soil properties and sampling intervals are used for any given area, thus maximizing survey efficiency.

In 1982 the need for pre-survey reconnaissance studies arose in the context of a project of collaboration between the agricultural universities of Wageningen, the Netherlands and Can Tho, Vietnam.

The aim of this project was to carry out research for management of acid sulfate soils. One of the components of the research was to describe and map the occurrences of actual and potential acid sulfate soils in the Mekong delta. Because of the unavailability of aerial photographs it was not possible to undertake a reconnaissance study of the size of the patterns of soil variation prior to the field work. Also, in the field, a quick appraisal of the pattern size of soil variation was not possible because of a) the extent of the area to be covered, b) the almost total lack of perceptible relief, c) the removal of the original vegetation, now replaced by an obscuring reeds vegetation and d) the strong disturbance of the natural drainage pattern by an intricate system of man-made canals. Moreover, because the survey personnel had only a limited experience in the area and the total time available was only a few weeks, it was essential to find a reconnaissance technique that would allow a quick and effective appraisal of the scale of the soil variation.

The results of such a study, it was hoped, would permit subsequent soil survey activities to be better planned. To this end it was necessary to find out which soil properties would be most useful for mapping actual and potential acid sulfate soils, and to discover their spatial scales of variation. It was also necessary to find out if the same properties could be used over the other parts of the Mekong delta, where other surveys would be carried out later.

The problem was approached by using a technique of spatial analysis: nested sampling and nested analysis of variance. The nested method was used in two study areas. The aim of this paper is to describe how this method was used in the Mekong Delta, to present some of the results achieved, and to discuss the practical advantages and disadvantages of this technique in the context of a short-term study with limited budgets and manpower.

3 The study areas

3.1 Description of the Mekong Delta

The Mekong Delta, situated at the most southern tip of Vietnam between 9 and 11° N and 105 and 107° E. covers an area of roughly 4 million hectares. Except for a narrow strip in the border area with Kampuchea, where some old granite and limestone outcrops and Pleistocene Mekong river terraces are found, the entire delta is built up of Holocene fluviatile, brackish water and marine sediments.

The fluviatile sediments are found in the central part of the delta, along and in between the river streams. The marine sediments are found in a broad strip along the south-eastern coastline, and in a narrow strip along the north-western shore.

The brackish water sediments are found in the backswamps to the north-east and the west of the river streams. Here, during sedimentation, all conditions for the formation of acid sulfate soils were fulfilled (Van Breemen & Pons 1978); the presence of an iron containing sediment, sulfate-containing seawater, Fe and S reducing bacteria, a dense vegetation, tidal movement and slow sedimentation. Two large uninterrupted areas of actual acid sulfate soils can be distinguished. East of the river the Plain of Reeds, and in the north-west corner of the delta the Ha Tien Plain. The acid sulfate soils in the Plain of Reeds are generally derived from heavy clay sediments with a low organic matter content, and are mostly deeply oxidized; the pyritic subsoil occurs at a depth of 1.5 to 2 meters. In the Ha Tien Plain, especially in the western part, the acid sulfate soils are for the major part derived from peaty clay sediments with the pyritic subsoil at a depth roughly between 70 and 150 cm. Although these soils have most properties associated with acid sulfate soils, they usually do not show jarosite mottles. The morphology of these soils is discussed by van Mensvoort and Tri (1986).

In the southern part of the delta scattered low lying areas with actual and potential acid sulfate soils are found, mostly derived from clay sediments with low organic matter (Brinkman et al. 1986).

Extensive areas of potential acid sulfate soils have been found only in the most south-western tip of the delta, and in the delta of the Saigon river, south of Ho Chi Minh City. In both areas the formation of potential acid sulfate soils is still continuing.

3.2 Description of the two areas chosen for study

For our study, two areas were selected: I) Lang Bien Farm, situated in the Plain of Reeds (acid sulfate soils with parent material low in organic matter, generally oxidized to more than one meter depth), and II) Farm 85B, situated in the western part of the Ha Tien Plain (acid sulfate soils derived from peaty clay parent material generally oxidized to less than one meter depth).

The farms were chosen because they are situated in places considered to be representative for large areas of acid sulfate soils. Furthermore, the farms supplied transportation, lodging and labour for the survey teams.

The field work was carried out in the dry season. Lang Bien farm in March 1982 (4 days), 85B in March/April 1983 (one week).

3.2.1 Lang Bien farm

Lang Bien farm, covering 300 ha, is situated in the Plain of Reeds, about 20 km east of Sa Dec town in the Dong Thap Province (Figure 1).

The soils of the farm range from acid sulfate soils with the sulfuric horizon within 50 cm depth (Sulfaquepts) to acid sulfate soils with the sulfuric horizon at greater depth (sulfic and palesulfic Tropaquepts, Pons et al. 1986) and non acid soils (Tropaquepts). The farm is subjected to deep flooding (0.5 – 1.5 m) in the rainy season. Tidal movement is absent in the rainy season, and is only a few decimeters in the dry season. In the early part of the rainy season (April – May – June) water in the canals turns very acid as a result of acid being washed out from the dikes of recently dug canals. On the deeply developed acid sulfate soils and the non-acid soils the farm cultivates deep water rice. The area with Sulfaquepts is partly covered by Melaleuca leucadendron forest, partly covered with reeds (mainly Xiris indica, a short, unusable reed and in some places Cyperus spp and Eleocharis spp).

3.2.2 Farm 85B

Farm 85B is situated in the centre of the Ha Tien Plain (Figure 1), halfway along canal 8000, which connects the town of Tri Ton with the Rach Gia – Ha Tien Canal. The farm covers an area of 3800 ha, 1900 ha on either side of canal 8000. Besides a few creekbeds, which are filled with peat, the entire area consists of Sulfaquepts, dominated by acid sulfate soils that show no jarosite mottles in the oxidized horizons. The farm is subjected to a 0.5 – 0.8 m flood in the rainy season. In that season tidal movement is absent. In the dry season the difference between high tide and low tide is about 30 cm. In the 85B area many excavation works have been undertaken in recent years. Acidity washes from the dikes and raised beds in the early rainy season,

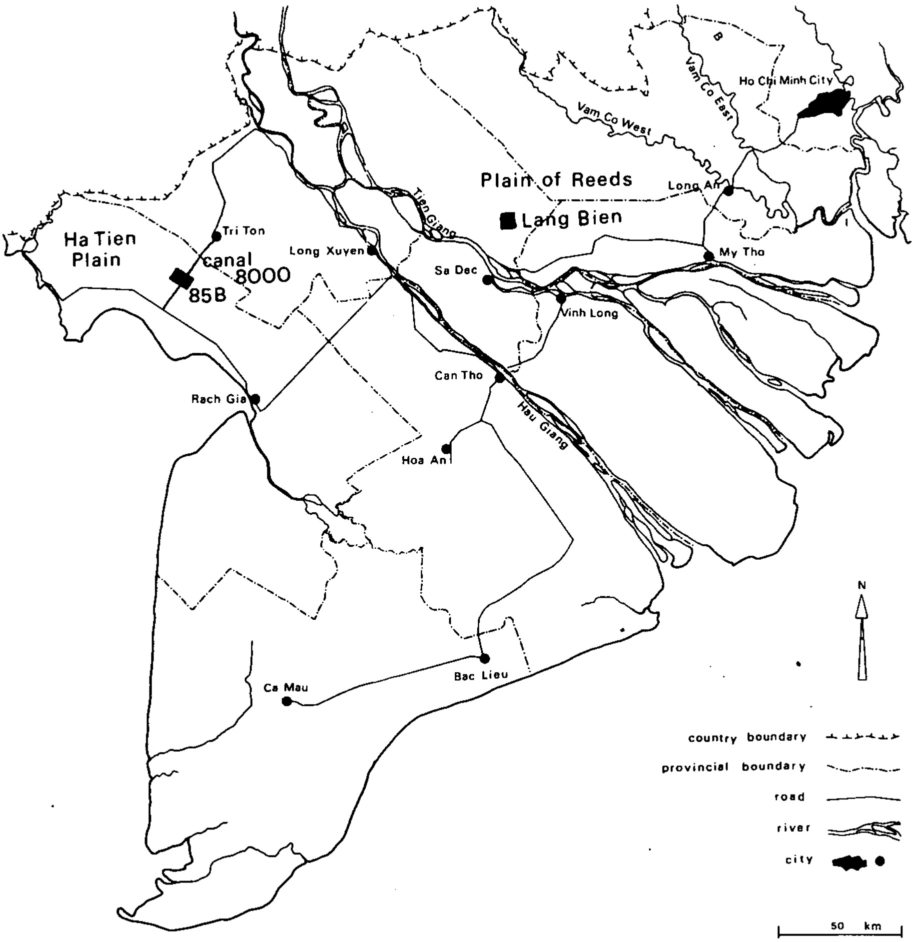

Figure 1 Location of the study areas Lang Bien and 85B

when surface water becomes extremely acid. 85B has tried to grow deep water rice on an area of 1500 ha with discouraging results. Rice performed better on acid sulfate soils with jarosite than on those without. Except for some 300 ha, which are still in use for deep water rice, most of the farmland is covered with reeds: Cyperus spp, Eleocharis spp, Scleria peaformis and Imperata cylindrica. Melaleuca leucadendron is destined to be the main crop, and has been planted on part of the land where deep water rice failed.

4 Methods and procedures
4.1 Soil properties recorded

The main aim of this study was to determine which soil properties were most suitable for distinguishing between different types of soil, and the scales at which these properties could best be mapped. The latter aspect determines the most efficient sampling spacing for mapping and the reliability of the soil maps.

Until recently, the most widely used method of distinguishing between different acid sulfate soils in Vietnam was based on measurement of pH and sulfate content of the surface soil (Moormann 1961; van Breemen and van Mensvoort 1982).

The following criteria were used:

	SO_4^{--}	pH
slightly acid	0.05 – 0.1%	> 4.2
moderately acid	0.1 – 0.15%	3.5 – 4.2
strongly acid	> 0.15%	< 3.5

In this study we recorded as wide a range of properties from soil augerings and simple field laboratory measurements (pH and EC) as was practically feasible.

In Lang Bien the following properties were observed:

- Relative altitiude compared to a chosen base level (m);
- Land use (1 = bare, 2 = inundated, 3 = reeds, 4 = other natural vegetation, 5 = floating rices, 6 = forest);
- Topography (1 = flat, 2 = slightly undulating);
- Drainage class (1 = very poor: inundation > 6 months per year; 2 = poor: 3 – 6 months; 3 = moderate: < 3 months; 4 = good: no inundation);
- Parent material (1 = river clay, 2 = river sand, 3 = clayey brackish water sediment (potentially acid, pyritic mud);
- Salt efflorescence on the soil surface 0 = no; 1 = yes;
- Ground water level in cm below surface;
- Depth to jarosite in cm below surface;
- Depth to pyrite in cm below surface.
- Horizon nomenclature according to FAO;
- Begin and end depth of each horizon;
- % clay class (1 = < 10%; 2 = 10-20%; 3 = 20-40%; 4 = > 40%); Munsell hue, value and chroma of the soil matrix in each horizon;
- Field pH of the surface soil;
- EC of the surface soil in a 1:5 soil: water extract;
- Ripening stage of each horizon (1 = unripe, 2 = halfripe, 3 = ripe, field test by squeezing);
- Presence of jarosite mottles in each horizon (0 = none, 1 = few, 2 = common, 3 = many);
- Presence of orange or brown mottles in each horizon (few, common or many as with jarosite);
- Presence of red mottles in each horizon (few, common or many as with jarosite);
- Field estimate of % organic matter in the surface soil and in the reduced subsoil (1 = 0-10%; 2 = 10-20%; 3 = 20-30% and 4 = > 30% by volume);

The same properties were observed in the 85B region with the following exception:

air dry pH of the surface soil was determined as well as field pH.

4.2 The nested sampling technique and analysis of variance

4.2.1 The theory and method of nested sampling

In order to determine the most efficient sampling interval for soil mapping, it is necessary to know the sizes of the patterns of soil variation. In the absence of clear external information (from landform, vegetation, etc.), these scales can be estimated using the technique of nested sampling (Webster 1977, Nortcliff 1978).

In conventional soil survey, the landscape is divided into mapping units. In terms of the analysis of variance, this means that the variation of the soil in the landscape is partitioned into variation between, and variation within classes. No account is taken of the spatial extents of the mapping units. The model used is:

$$Z(x) = \mu + \alpha_i + E \qquad (1)$$

where $Z(x)$ is the value of soil property Z at location x in class i, μ is the general mean of the property over study area, α_i is the difference between the mean of class i and μ, and E is a random variable, with mean 0 and variance δ^2.

When an area that has been mapped at a reconnaissance scale is remapped at a detailed scale, the original mapping units are often redivided. The subdivision is based on soil taxonomy (e.g. series within families) so that with every successive division there is a nested set of soil classes within larger classes and so on. The one-way analysis of variance can easily be extended to this hierarchical situation so that it is possible to estimate the amount of variation associated with each level in the classification hierarchy.

A corollary to refining the classification with increasing map scale, is that sampling intervals decrease, so smaller areas of land are delineated (Burrough 1983). The analysis of variance can then be used to indicate the improvement in map quality brought about by increasing the mapping scale (Beckett and Burrough 1971).

The analysis of variance technique can be used to estimate how map quality varies with sampling spacing as follows. Sample observations are arranged in clusters over several well defined sampling distances. The analysis of variance is used to estimate the amount of variation that occurs over each sampling distance. A plot of cumulative variance against sampling distance will then yield information about the average sizes of the soil patterns. For example, in Figure 2, property A shows little increase in variance up to a sampling distance of 20 m. Thereafter, the variance increases rapidly. The conclusion to be drawn is that property A varies little within 20m and to sample at a spacing closer than 20m reveals nothing extra. Property B shows similar behaviour over the range 2-20m, though the residual variation is much greater. Almost all the variation of B occurs within 200 m.

Consequently attempting to map B using a sample spacing of greater than 200m would be a waste of effort; the interpretation is that B has a pattern of variation that can best be mapped by an observation net having a spacing between 20 and 200 m. Property C has most of its variation present at the shortest sampling distance. The interpretation is that the variation of C occurs over such short distances that it cannot be mapped.

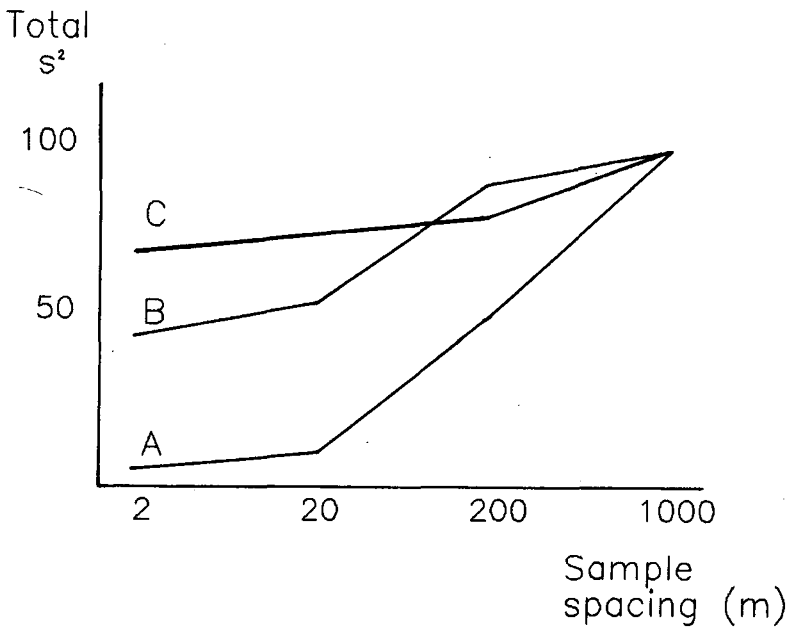

Figure 2 Examples of 3 variograms: cumulative variance (%) against sample spacing

4.2.2 The procedure for nested sampling

The procedure for nested sampling is as follows. Before fieldwork, the area to be surveyed is covered by a grid of squares, the actual dimensions of which reflect the size of the area.

A number of these squares are chosen at random, subject to the condition that the average distance between squares corresponds to the largest sampling distance thought to be worthwile. These squares are then further subdivided into sub-squares (usually by a 5 × 5 square grid) and a set of sub-squares is chosen as before. The centre of each sub-square serves as the reference point for a set of observations located at random orientations but at nested sampling distances (example: Figure 3). The resulting sampling scheme has the structure shown in Figure 4. In the field, it is only necessary to locate the centre of each sub-square, the actual sampling points can be determined by pacing along previously determined, random directions, indicated by a compass.

If g is the number of levels in the hierarchy, and n_g is the number of subdivisions at each stage, the components of variance at each stage δ_g^2 can be estimated as shown in table 1.

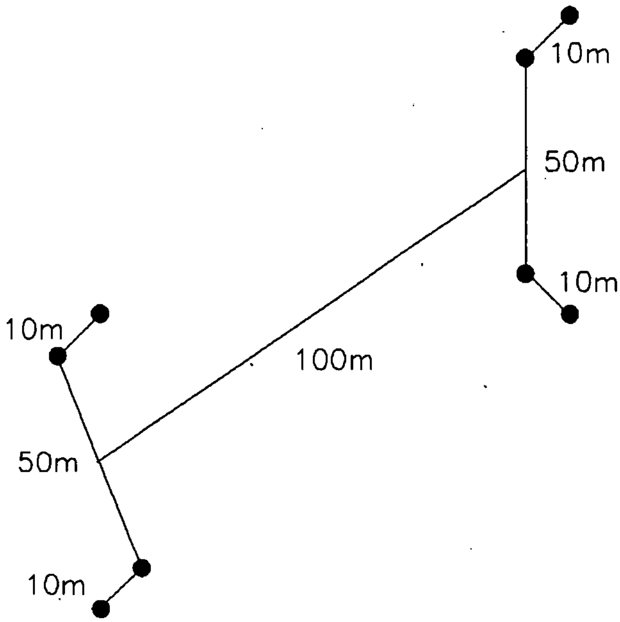

Figure 3 Examples of 8 soil observations at nested sampling distances 10m, 50m, 100m

4.3 Nested sampling in practise

4.3.1 Lang Bien area

From a 1:10.000 field map the farm was divided into squares each 1000 × 1000 m; four of these were chosen with centres at a distance of 2000 m. Each of these squares was then divided into 25 sub-squares, each 200 × 200 m; two sub-squares were chosen at random, subject to the condition that their centres were 500 m apart. This resulted in 8 points on the map, each the centre of 8 soil borings; these were located along random orientations in pairs at 10, 50 and 100m apart. An example of such a cluster of 8 borings is shown in Figure 3.

Sixty-four borings were carried out, and the results were entered on a field sheet, an example of which is given in Table 2. The 64 points were located accurately by a land survey team. The soil surveyors followed to carry out the borings and observations.

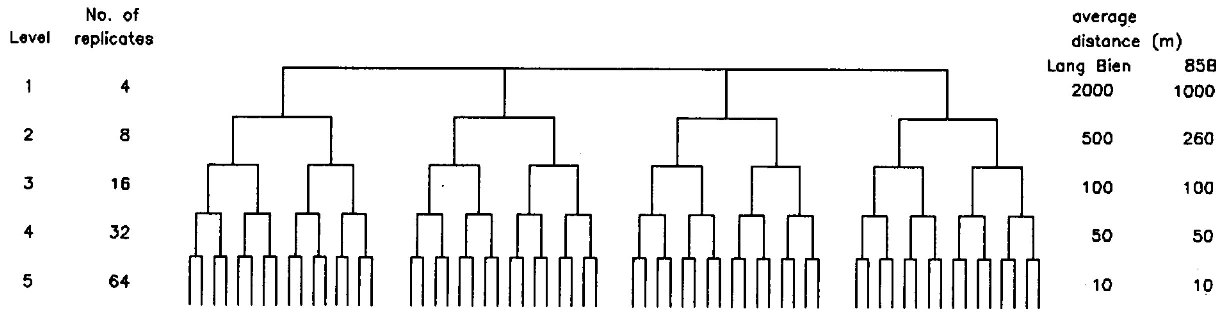

Figure 4 Structure of the sampling scheme for 64 soil observations

Table 1 Analysis of variance for hierarchial classification with five levels (stages)

Source	Degrees of freedom	Sums of squares	Estimated components in mean squares
Stage 1	f_1-1	$\sum_{i=1}^{f_1} m_i(\bar{x}_i-\bar{x})^2$	$U_{11}\sigma_1^2 + U_{12}\sigma_2^2 + U_{13}\sigma_3^2 + U_{14}\sigma_4^2 + \sigma_5^2$
Stage 2	f_2-f_1	$\sum_{i=1}^{f_1}\sum_{j=1}^{n_i} m_{ij}(\bar{x}_{ij}-\bar{x}_i)^2$	$U_{22}\sigma_2^2 + U_{23}\sigma_3^2 + U_{24}\sigma_4^2 + \sigma_5^2$
Stage 3	f_3-f_2	$\sum_{i=1}^{f_1}\sum_{j=1}^{n_i}\sum_{k=1}^{n_{ij}} m_{ijk}(\bar{x}_{ijk}-\bar{x}_{ij})^2$	$U_{33}\sigma_3^2 + U_{34}\sigma_4^2 + \sigma_5^2$
Stage 4	f_4-f_3	$\sum_{i=1}^{f_1}\sum_{j=1}^{n_i}\sum_{k=1}^{n_{ij}}\sum_{l=1}^{n_{ijk}} m_{ijkl}(\bar{x}_{ijkl}-\bar{x}_{ijk})^2$	$U_{44}\sigma_4^2 + \sigma_5^2$
Stage 5	η-f_4	$\sum_{i=1}^{f_1}\sum_{j=1}^{n_i}\sum_{k=1}^{n_{ij}}\sum_{l=1}^{n_{ijk}}\sum_{m=1}^{n_{ijkl}} m_{ijklm}(\bar{x}_{ijklm}-\bar{x}_{ijkl})^2$	σ_5^2
Total	n-1	$\sum_{i=1}^{n_i}\sum_{j=1}^{n_j}\sum_{k=1}^{n_k}\sum_{l=1}^{n_l}\sum_{m=1}^{n_m} (\bar{x}_{ijklm}-x)^2$	

f_g is the number of classes at the stage
n_i, n_{ij}, are the numbers of classes at the 2nd, 3rd stage
m_i, m_{ij}, are the numbers of observation in the ith, ijth, class at the 1st, 2nd, stages

Table 2 Example of a completed field sheet from Lang Bien area

Profile number	Date	Surv. name	Grid ref.	Alti-tude	Land use	Topo-graph.	Drain. class.	Parent mat.	Salt efflor.	Groundw. table	cm to jarosite	cm to pyrite	Perdysic horizon	Class. code	EC topsoil
X 10	11/3/82			1.241	4.2	0	1	3	1	82	60	110		tSuTp	0.725

Horizon	Begin depth	End depth	% clay	Hue	Value	Chroma	pH field	pH airdry	Ripening	Mottles jarosite	Brown mottles	Red mottles	Organic matter
Ah	0	8	4				4.0	3.7	3	0	0	0	2
Bg1	8	40	4						3	0	1	0	0
Bg2	40	60	4						3	0	1	0	0
Bgj3	60	110	4						2	1	1	0	0
Cr	110	200	4	5Y	4	1			2	0	0	0	0

4.3.2 85B area

From a 1:10.000 field map, 8 adjacent (4 × 2) squares of 1000 × 1000 m were chosen. As in Lang Bien each of these squares was divided into 25 sub-squares of 200 × 200 m; two were chosen at random with midpoints at 250m distance. Each midpoint was, again, the centre of a cluster of 8 borings in pairs at 10, 50 and 100 m.
A total of 128 borings was carried out. By choosing 8 adjacent blocks,the statistical analysis could be carried out for 3 adjacent areas, each comprising 4 squares, 8 sub-squares and 64 borings. These areas will be called 1, 1/2 and 2 from now on.

5 Results and discussion

5.1 Correlations between properties

Tabulated summaries of the results for Lang Bien and 85B are given in table 3 and table 4, respectively.

As can be seen from the field sheet (Table 2) all properties have been recorded as numbers on ratio scale. These data were analysed using correlation matrices and nested analysis of variance.

Correlation analysis showed that there were few large correlations between soil properties in the two areas. The large correlations found are rather obvious: depth to the C horizon and depth to pyrite have a correlation coefficient of 0.815 in Lang Bien and 0.861 in 85B area. Moderate correlation coefficients (0.5 – 0.7) were found between some properties in Lang Bien: e.g. relative altitude and groundwater table, depth to jarosite and groundwater table, depth to pyrite and groundwater table, depth to pyrite and depth to jarosite, depth to jarosite and depth to the C horizon. These high correlations are not very surprising, all these properties are relief-associated.

5.2 Variance of properties

The nested analysis of variance for all properties in Lang Bien is presented in Figures 5a, 5b and 5c and for some properties in 85B in figure 6a to 6f. The cumulative percentage of variance at each sampling level has been plotted against sample spacing. The complexity of the figures reflects the presence of several overlapping scales of variation in the soil pattern. The following interpretations can be made:

5.2.1 In Lang Bien

The short-range variance of EC (74% at 10 m distance) is so large that for all practical purposes it is a useless attribute for distinguishing between soil units at any scale.

The large percentage short-range variance of most properties of the C horizon (Hue, Value, texture, ripening stage, organic matter content) reflects the spatial uniformity of the subsoil in the area. The variance of texture of the C horizon only changes between 50 and 100 m, which suggests that variation of soil texture is caused by infilling

Table 3 Summary of Lang Bien properties

Property	Mean	Minimum	Maximum	Nr misses	Cv%
Altitude (m)	1.33	1.05	1.74	0	13.83
Groundwater (cm)	62	17	130	1	33.96
Depth jar. (cm)	66	24	145	12	34.59
Depth pyr. (cm)	106	67	169	12	22.41
Thickness A (cm)	19	6	50	0	56.22
pH field	4.4	3.3	6	1	13.18
EC mS/cm	0.54	0.1	1.05	9	42.59
Depth C (cm)	123	60	181	0	19.17
Value C	4.7	3	6	1	14.52
Chroma C	1	0	2	1	58.2

Land use	: Reeds 39.1%; other natural vagetation 10.9%; floating rice 29.7%; floating rice mixed with other natural vegetation 17.2%; Melaleuca 3.1%
Drainage	: Very poor 9.4%; poor 82.8%; moderate 7.8%
Salt efflorescence	: 23% of observations with salt efflorescence on the surface
Org. matter	: 0-10% Org. matter: 25%; 10-20% Org. matter: 75%
Texture C	: Class 1: 3.1%; class 2: 0%; class 3: 7.8%; class 4: 89.1%
Hue C	: 5YR: 1.6%; 5YR: 4.8%; 10YR: 12.7%; 5Y: 52.4%; N: 23.8%; 5GY: 1.6%; 5bg/3.2%
Org. matter C	: 0-10% Org. matter: 85.7%; 10-20% Org. matter: 12.7%; 20-30% Org. matter: 1.6%
Ripening C	: Unripe: 42.2%; halfripe: 50.8%; ripe: 7.9%

Table 4 Summary of 85B properties

Property	Mean	Minimum	Maximum	Nr misses	Cv%
Altitude (m)	0.54	0.13	0.99	0	39.08
Groundwater (cm)	137	89	187	27	15.34
Depth jar. (cm)	55	20	95	53	33.55
Depth pyr. (cm)	76	10	112	2	23.44
EC mS/cm	0.44	0.1	1.6	7	60.49
Thickness A (cm)	17	5	46	2	44.93
pH field A	3.4	2.5	4.4	9	10
ph airdry A	3.4	2.7	4.9	6	9.55
Value C	4.5	2	6	2	16.91
Chroma C	1.3	0	4	2	43.41
Depth C	84	10	133	2	25.48

Topography	: Slightly undulating: 9%; flat plain: 91%
Drainage	: 100% flooded 3-6 months per year
Brown mottles A	: None: 11%; few: 64%; common: 25%
Ripening C	: Ripe: 3%; halfripe: 86%; unripe: 11%
Org. matter C	: 0-10% Org.matter: 39%; 10-20% Org.matter: 52%; 20-30% Org.matter: 86%; > 30% Org. matter: 2%
Org. Mottles C1	: None: 19%; few: 56%; common: 25%
Org. Mottles Ctotal	: None: 15%; few: 57%; common: 28%
Hue C	: 5YR: 2%; 7.5YR: 4%; 10YR: 49%; 2.5Y: 2%; 2.5Y: 2%; N: 1%; 5GY: 2%

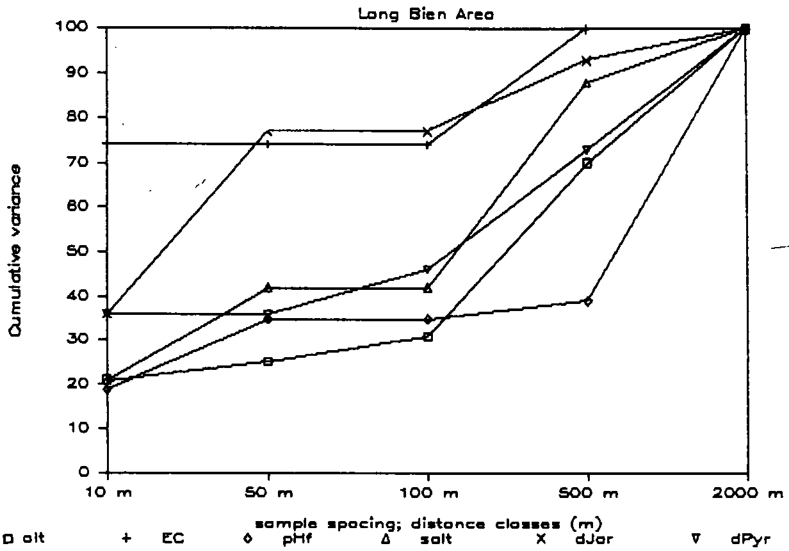

Figure 5a Variogram of 6 properties

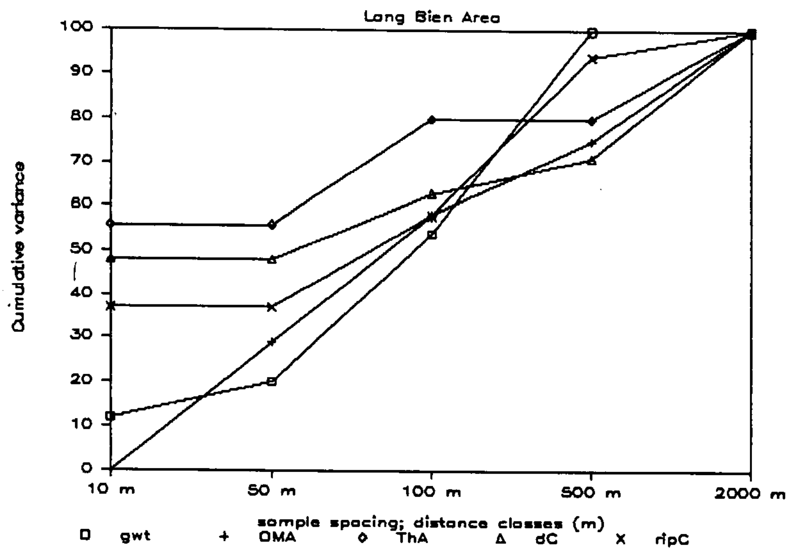

Figure 5b Variogram of 5 properties

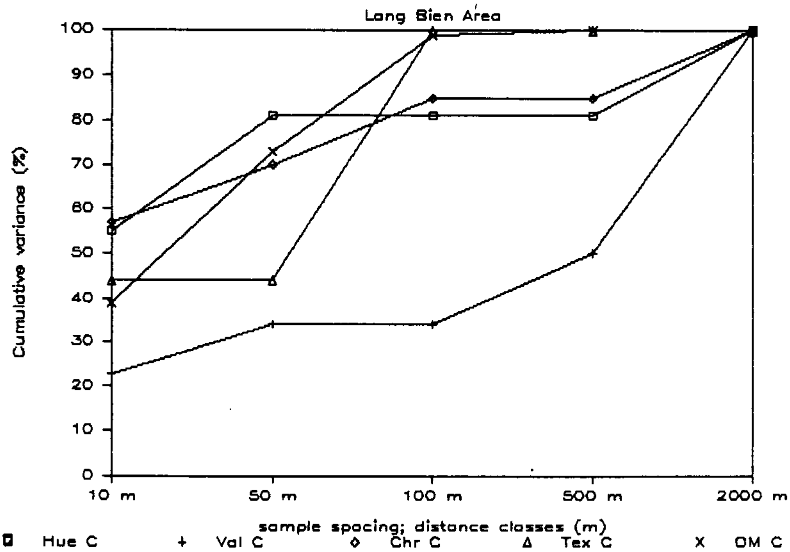

Figure 5c Variogram of 5 properties

of small gullies with lighter textured material in a predominantly heavy clay area.

The variation in the thickness of the A horizon, with a jump between 50 and 100 m may be attributed to land use (ploughing).

The variance of depth to jarosite (an important characteristic in distinguishing types of acid sulfate soils according to Soil Taxonomy) has jumps between 10 m and 50 m, and between 100 m and 500 m. So this property can be mapped by surveys at various scales with sampling distances somewhere between 100 and 500 m (leading to maps of scales 1:20,000 to 1:100,000). To reduce the confusion caused by the short range variance, for mapping it would be advisable to use average values from multiple observations within a small area (bulked samples) rather than single borings.

Properties with clear jumps in the variance occurring at distances between 500 and 2000 m can best be used for mapping at small scales, for example field pH.

5.2.2 85B

In 85B most properties have a large percentage short-range variance (variance within 10 m), and reach more than 70% of the total cumulative variance within 100 m. This reflects the general uniformity of the soil properties in the area: exceptions are elevation (see Figure 6a) and topography.

Depth to jarosite (see Figure 6b) also shows a large shortrange variance,and a general upward trend without jumps, making this property of little use for distinguishing soil units in the 85B area. A complicating factor is that in many cases no jarosite is found in the area. The original nested analysis of variance regards such observations as missing values, assuming that jarosite is present in every boring. Of the 64 borings in each of the three areas the number of missing values was 31, 22 and 36 respectively. Because these were too large to be ignored, the nested analysis of variance was applied to data indicating the presence and absence of jarosite (see Figure 6d). The outcome was very surprising: about half the variance was reached within 50 m, but between 50 and 280 m, for two out of three areas, no further rise occurred, and a large rise was found between 280 and 1000 m.

This indicates that, in this area, the presence or absence of jarosite is a useful characteristic for surveys at mapping scales varying between 1:56.000 and 1:200.000.

Relative altitude shows a similar large jump between 280 and 1000 m, but unfortunately correlation analysis shows that this property bears no relation to any of the other properties thought important for mapping acid sulfate soils.

6 Conclusions

a. How useful is a reconnaissance study of spatial variability? In a very limited amount of time (for Lang Bien four, for 85B six days) a large number of data were collected from which the sizes of the main scales of the soil patterns were found. This was important for choosing the scale at which a reliable soil map could be made. The study also quickly indicated the most suitable attributes that could be used for distinguishing between soil units. This is important information in an area such as the Mekong delta, where only a limited amount of surveys have been executed.
b. The Lang Bien study showed the uselessness of EC for distinguishing between soil units. It should be remembered, that outside the zone with sea water intrusion, EC has a direct relationship to the sulfate content in soil moisture.
c. Depth to jarosite, which is a stable characteristic of acid sulfate soils (contrary to pH for example, which changes with every season), is a reasonably reliable criterion for surveys at various scales. Short range variation should be suppressed by using average values from multiple augerings within small areas (bulk sampling).
d. Properties associated with relief (elevation, depth to jarosite, depth to pyrite, ground water table, depth to the C horizon, drainage class) show a reasonable degree of correlation in the Lang Bien area.
e. In areas such as 85B, where acid sulfate soils with and without jarosite occur, the presence or absence of jarosite is a reliable characteristic for distinguishing mapping units at scales between 1:50.000 and 1:200.000. Field information indicated that soils with jarosite have a somewhat higher agricultural potential, emphasizing the importance of this characteristic.

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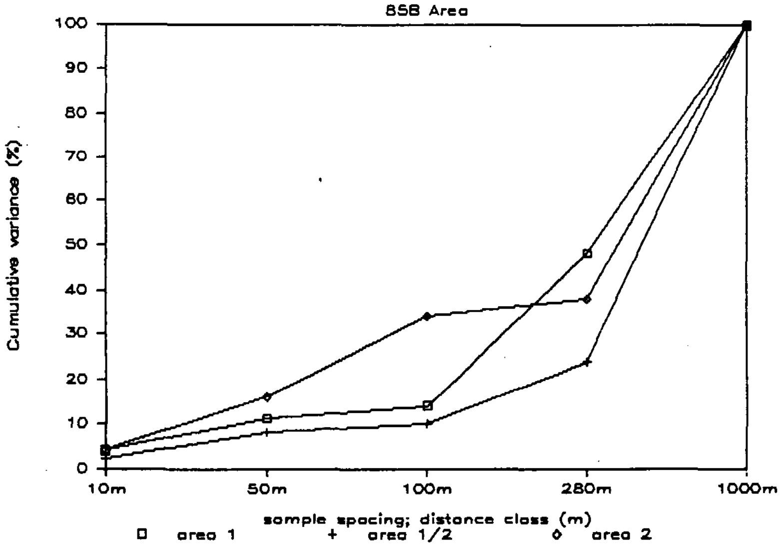

Figure 6a Variogram of altitude

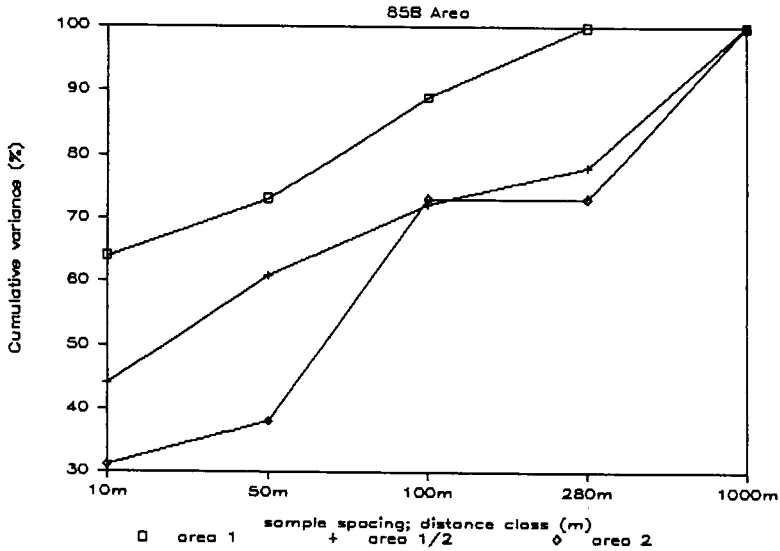

Figure 6b Variogram of depth to jarosite

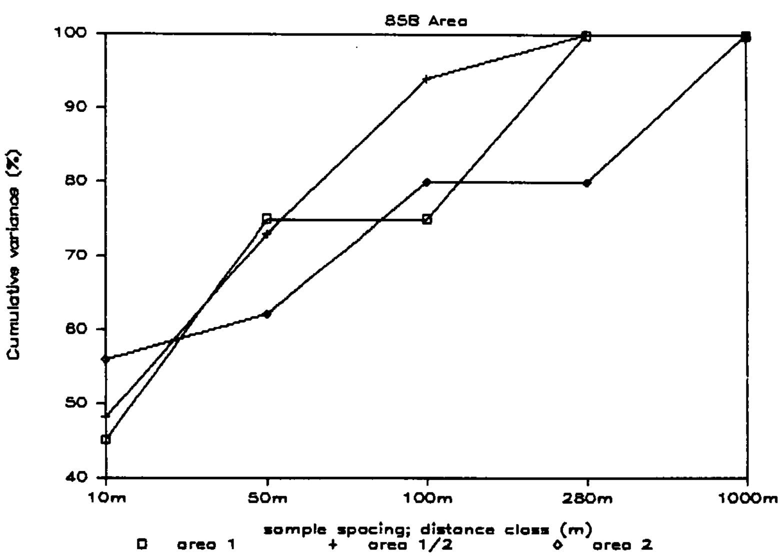

Figure 6c Variogram of org.matter C-hor.

Should acid sulfate soils be classified among the inceptisols or the entisols?

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1 Summary

In Non Acid Alluvial Soil Materials, physical, chemical and mostly also biological ripening are proceeding about simultaneously, stimulating each other. When sulfidic muds develop into Acid Sulfate Soils, physical ripening will start, but soon stagnates while chemical ripening proceeds very rapidly, producing 'sulfuric' materials. Only very old 'Acid Sulfate Soils' are physically more or less ripe, but most of them have deacidified 'sulfuric' materials that are not longer meeting the pH requirements. Arguments are brought together to classify the physically unripe soils with 'sulfuric' materials with the Aquents (as a different great group) and the physically ripe ones, forming a minority, with the Aquepts as Sulfaquepts.

Résumé

Dans les vasières des sols alluviaux non acides, la maturation physique, chimique et biologique se développent presque simultanément en se stimulant réciproquement. Des sols alluviaux bien développés peuvent se former à court temps après l'introduction d'un bon drainage.

Dans les vasières sulfurées, la maturation physique est très lente, tandis que celle chimique avance rapidement menant à la formation de l'horizon sulfurique et par conséquent aux sols sulfatés acides. Due â l'intense acidité, l'activité biologique dans ces sols est très maigre, car seulement un nombre limité de plantes et d'animaux peuvent supporter un taux élevé d'acidité. Etant pauvres en espèces floristiques et faunistiques, ces sols ne sont pas brassés et homogenisés ce que fait que la maturation physique et biologique se déroulent très lentement.

C'est ainsi que seulement les sols sulfatés acides très anciens, sont plus ou moins maturé physiquement toutefois rarement plus profondément de 50 cm, tandis que les plus jeunes, sont ou maturés ou semi-maturés, même dans les conditions d'un bon drainage. A cause de l'imperméabilité du sous-sol non-maturé, la dé-acidification ne peut pas avancer et le processus de maturation est stagné.

Une grande partie des sols sulfatés acides anciens ont subi une dé-acidification et leur horizon sulfurique ne satisfait plus à l'exigence d'un pH bas (> 3,5).

En ajoutant des arguments de nature pratique aux principes de classification, l'auteur propose de classifier les sols sulfatés acides physiquement non-maturés dans les Aquents (Entisols) et ceux maturés dans les Aquepts (Inceptisols).

2 Introduction

One of the main principles on which the differentiation of the orders of Soil Taxonomy are based, are the results of pedogenetic processes. Entisols are considered to lack or nearly lack soil development, whereas Inceptisols show a certain measurable effect of pedogenesis. Pedogenetical processes, however, are known to be complicate and composed of a number of different soil forming processes acting more or less simultaneously with different intensities and speeds, making soil classification possible as well as complicate.

Considering the initial soil forming processes, physical, chemical and biological ripening (Pons and Zonneveld 1965) in soft sulfidic muds developing into Acid Sulfate Soils, observations have learned that chemical ripening may proceed rapidly and intensely, while both physical and biological ripening are slow and retarded. In 'normal' muds, without potential acidity, however, physical, chemical and biological ripening are developing about simultaneously, producing a cambic horizon, which fits the soils smoothly into the Inceptisols.

The doubt, wheather to choose between the results of physical or of chemical ripening makes it difficult to classify these soils with the Entisols or with the Inceptisols.

This short note will deal with the difficulties to classify the Acid Sulphate Soils in relation with these unequally developing kinds of initial soil formation and will give suggestions to solve the problem.

3 The sulfuric horizon

Under rapid dehydrating conditions, e.g. artificial drainage, a soft sulfidic mud will dry out superficially, forming shallow cracks (physical ripening). Air will penetrate into the soil and very soon, pyrite starts to oxidize (chemical ripening), forming sulfuric acid and jarosite mottles and the pH (water) drops below 3.5. When 'the mineral or organic soil material of the horizon has both a pH < 3.5 (1:1 in water) and jarosite', Soil Taxonomy (USDA 1975) recognises the sulfuric horizon. Inceptisols, defined as 'physically ripe soils' (n-factor < 0.7 to a depth of at least 50 cm), with a sulfuric horizon beginning within a depth of 125 cm have to be classified with the great group of Sulfaquepts, according to the present Soil Taxonomy (USDA 1973).

On 'normal' muds, after some superficially drying up, plants start to grow and penetrate the soil with their roots, accelerating the dehydration of the mud and causing shrinking, stiffer consistencies, deeper cracks, better permeability and development of soil structure. Immediately after, the chemical ripening is following with oxidation, improving the environment for further root development, which accelerates new physical ripening and so on. At the same time the biological ripening starts and is contributing both to the physical as well as to the chemical ripening (Pons and Zonneveld 1965).

In Acid Sulfate Soils, to the contrary, physical and biological ripening are absent or very poor because plant growth is prevented by the toxic environment with the extremely low pH, the high Al-ion concentration and several other adverse conditions. As dehydration by roots is by far the most important way of attracting water, promoting the physical ripening (Zuur, 1961), sulfuric horizons are not ripening and the soils are only developing superficially ripe to half ripe upper horizons. These soils show well pronounced chemical ripening processes. The development of favourable land qualities as waterholding capacity, absence of toxicity, drainage and reasonable burying capacity stagnates as well, giving the soils a 'juvenile' character. Leaching, which would evacuate the acids, permitting a further physical ripening, is also strongly hampered by the adverse chemical and physical conditions, as e.g. the poor developed permeability.

Only after a very long time, when the excess of acids is evacuated by slow leaching, diffusion into floodwater or neutralisation by slowly weathering minerals on a low pH level, the pH will gradually increase to between 3.5 and 4.0 (Figure 1A). Then the roots are beginning to penetrate the 'sulfuric horizon' and the process of physical ripening slowly proceeds. On this moment, however, most 'sulfuric horizons' are not longer meeting the pH requirements of < 3.5 and in fact have vanished. Jarosite mottles may yet be visible, buť they lack the bright yellow colours.

4 Acid sulfate soils and non acid marine soils of different age

In the Bangkok plain fine textured, very young Acid Sulfate Soils, as well as Non Acid Marine Soils are present next to developed and deeply developed old ones (Pons and Van de Keevie 1968; Van de Keevie and Yanmanas 1969; Van Breemen 1976). The last author is given a lot of analytical data, including n-factors. In Figures 1A and B we are presenting some characteristic data of 4 groups of soils respectively: A: Very young, saline Acid Sulfate Soils; B: Young, saline to rather old, fresh Acid Sulfate Soils (Figure 1A); C: Medium old to old, fresh Acid Sulfate Soils and D: Young to medium old, fresh Non Acid Marine Soils (Figure 1B). In these figures the physically ripe soils can be distinguished from the unripe soils by the n-factor at 50 cm depth, the value of which is less than 0.7 for the ripe and more than 0.7 for the unripe soils. The profile morphology and the pH values are also shown.

Group A (Figure 1A) includes soils which are physically unripe. Only the upper soil surface layer of some of them are half ripe. They are undeveloped, saline muds (Bp-1) or very young, saline Acid Sulfate Soils, of which Kd-1 and Ch-1 are possessing a well developed surfuric horizon.

The soils of group B (Figure 1B) are also physically unripe, including young (Ca-1) to rather old (0-1), acid sulfate soils, both with surfuric horizons and 0-1 even red mottled.

Group C (Figure 1A) are old Acid Sulfate Soils with (Ra-1; Ra-2) and without (Ra-3) red mottles. All three soils show sulfuric horizons, which are on the boundary of meeting the pH requirements (< 3.5) of the sulfuric horizon and also on the boundary between physically ripe and unripe.

In group D (Figure 1B) the really physically ripe soils are brought together. Bk-1 and T-1 are well developed Non Acid Marine Soils without sulfuric horizons. Na-2 is a very deep, well ripened river levee soil on top of an old Acid Sulfate Soil.

From the numerous data of Marius (1984) may be concluded that Acid Sulfate Soils in Senegal with a well developed sulfuric horizon never are physically ripe. In Guinea-Bissau, only very old Acid Sulfate Soils of the Estuary Terraces are sufficiently ripe to meet the requirements of ripe soils (Pons, these Proceedings; Pons et al, item).

For most of them it is questionable if their sulfuric horizons are meeting the pH requirements.

It may be concluded that the majority of the soils with a sulfuric horizon are 'unripe'. Most of the old, red mottled Acid Sulfate Soils which are definitely ripe, are possessing questionable sulfuric horizons that are on the boundary of the pH requirements. Only very few old Acid Sulfate Soils are 'ripe' and at the same time meeting the pH requirements.

5 Discussion

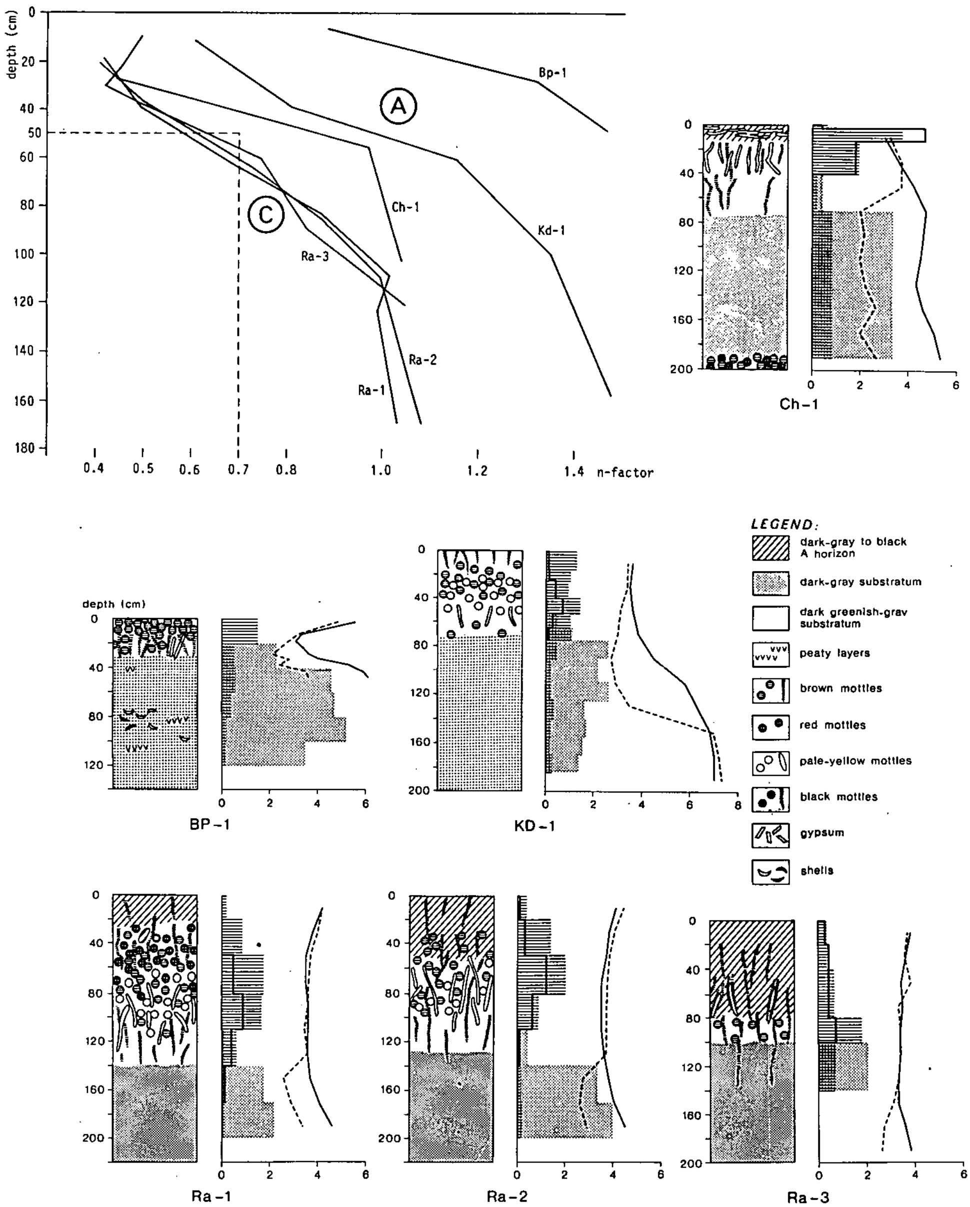
To my feeling the subprocess of physical ripening of soft muds, represents the very beginning of ripening or initial soil formation, and is also the most characteristic subprocess, on which the other depends. Unripe, half ripe and shallow ripe soils with unripe subsoils naturally are at home in the Suborder of Aquents as, no doubt, most soil scientists will agree upon.

According to the present definition of Soil Taxonomy 'Soils with aquic moisture regimes having a sulfuric horizon whose upper boundary is within 125 cm of the mineral soil surface' are excluded from the Entisols and classified as Sulfaquepts. The sulfuric horizon is not a diagnostic criterium in the suborder of the Aquents.

The underlaying thoughts are of course, that a sulfuric horizon is a diagnostic one, which is chemically strongly developed, differing in such an important way from the original sulfidic material, that it meets easily the requirements of altering and losses of bases, comparable to cambic horizons. Soils having chemically so strongly changed must be included in the Inceptisols.

Fortunately the sulfuric horizon is not considered as a kind of cambic horizon. So we are free to handle this horizon apart from the cambic horizon, eventually to consider only sulfuric materials.

As we have seen, most of the real sulfuric horizons don't meet the requirements of physical ripening, which are bringing all other soils in the Entisols. Therefore, classifying them with the Inceptisols seems unnaturally and we propose to bring these soils under the Entisols. We propose further to use 'sulfuric' materials as a diagnostic criterium in the Aquents to distinguish the Acid Sulfate Soils as a subgroup in the Sulfaquents, or, preferably as a new great group, apart from the present Sulfaquents, under the Aquents. 'Sulfuric' materials may be defined in the same way as a sulfuric horizon with the addition 'unripe'. We are getting then Hydraquents, Sulfaquents (both physically and chemically unripe) and the new Aquents-great group with the sulfuric material (chemically developed, but physically unripe). Probably, some Acid Sulfate Soils developed from marine muds, will stay in the Aquepts, together with the ripe Acid Sulfate Soils derived from acid mine spoil materials. This Aquept-great group will then include the physically and chemically ripe Acid Sulfate Soils, a much better solution, not only better adopted to the feelings of most Acid Sulfate Soils specialists, but also better fitted in the concept of Inceptisols as physically ripe soils. In this way the physically unripe 'acid sulphate' Aquents and the physically ripe Sulfaquepts, very different soils will clearly be distinguished, which is favourable because of their strongly different land qualities (bearing capacity, chemical behaviour, permeability, etc.).



Figures 1A and B The physical ripening, expressed as the n-figure, and profile diagrammes showing morphology, distribution of iron and sulphur compounds and pH (both fresh and after incubation) of some marine alluvial soils from Thailand (according to Figure 11, Van Breemen 1976). (The horizontal scale from 0-6 refers to pH, values on it have to be halved for mass fractions of S and doubled for FeO).

Figure 1A A: Unripe, saline sulphidic muds; C: Well developed, old Holocene Acid Sulphate Soils with sulfuric horizons

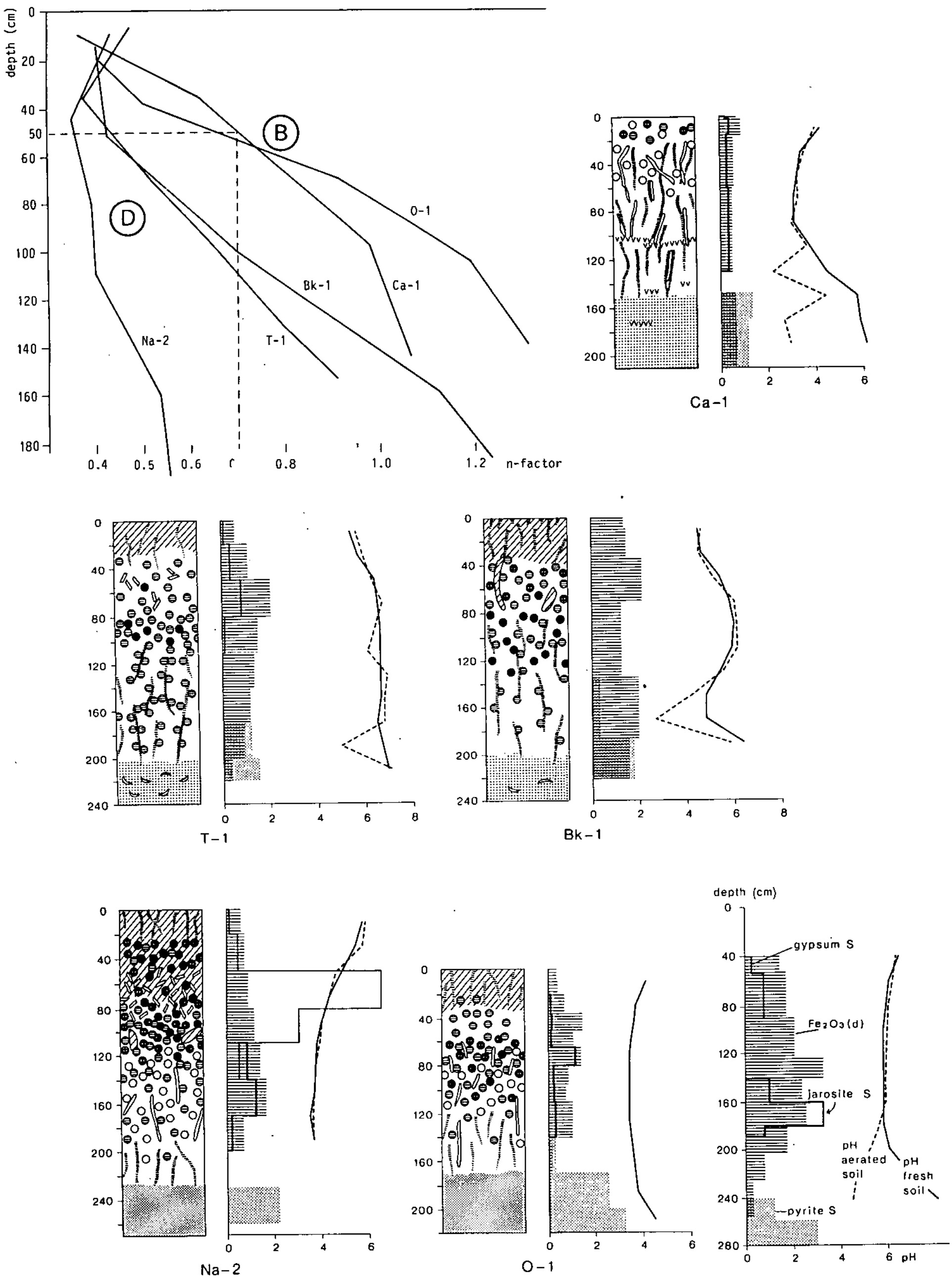


Figure 1B B: Unripe, young to rather old, desalinized Acid Sulphate Soils with sulfuric horizons; D: Ripe, Non Acid Alluvial Soils

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Using morphological data for the simulation of water regimes in clay soils

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1 Summary

Formation of acid sulphate clays involves ripening processes that are often associated with formation of both vertical and horizontal cracks (planar voids) in clayey soil materials. Crack formation complicates the physical characterization of soil water regimes because vertical cracks induce bypass flow which is defined as vertical flow of free water through macropores in an unsaturated soil matrix. Horizontal cracks impede vertical unsaturated flow of water, particularly in the upward direction. Use of computer simulation techniques to characterize flow processes and the associated transport of dissolved chemical compounds, is not possible in cracked clay soils when using existing models that are based on Darcy-type flow theory. A new procedure is presented in this paper that allows simulation of water regimes in clay soils with cracks or other continuous macropores, such as channels. The model used consists of three submodels that describe: (1) Vertical infiltration at the soil surface in peds between cracks; (2) Surface ponding and flow into the cracks (bypass flow); (3) Lateral absorption of water from the partly or completely filled cracks into the unsaturated soil matrix, and (4) Upward unsaturated flow from the water table to the rootzone in soil with horizontal cracks. Soil morphological descriptions, using staining techniques, form a key element of the model. Simulation results for a Dutch heavy clay soil will be discussed to illustrate the potential of the method. Implementation of the method requires measurement of hydraulic conductivity and moisture retention curves with existing methods and use of several new macromorphological field techniques.

Résumé

La formation d'argiles sulfaté-acides implique de processus de maturation souvent associés à la formation de fentes verticales et horizontales dans les matériaux des sols argileux. La formation de fentes complique la caractérisation physique des régime hydriques des sols, en ce sens que les fentes verticales entraînent des dérivations dans l'écoulement de l'eau. On parle alors d'écoulement vertical par les macropores se trouvant dans une matrice de sol non-saturée. Les fentes horizontals empêchent l'ecoulement vertical non-saturé de l'eau surtout vers le haut. L'utilisation de techniques informatiques de simulation, en vue de caractériser les processus d'écoulement et de transport des composants chimiques dissous, n'est pas possible dans le cas des sols argileux fissurés lorsqu'on fait appel aux modèles existants, lesquels sont basés sur des théories d'écoulement de type Darcy.

La présente étude, propose une nouvelle procédure qui prévoit la simulation des régimes hydriques dans les sols argileux fissurés ou présentant d'autres macropores

continus tels que les canaux. Le modèle utilisé consiste en trois sous-modèles qui décrivent:

1. L'infiltration verticale se produisant à la surface du sol dans les agrégats entre les fentes;
2. La formation de mares en surface et l'ecoulement de l'eau par les fentes (écoulement par dérivation);
3. l'absorbtion latérale de l'eau des fentes partiellement ou entièrement remplies dans la matrice du sol non-saturé; et
4. l'écoulement ascendant non-saturé de la nappe aquifère jusqu'à la rhizosphère dans les sols présentant des fentes horizontales.

Les descriptions morfologiques des sols constituent un élément clé du modèle; se sont:

a. Le microrelief de la surface supérieure des agrégats;
b. La longueur des fentes (ou le nombre de pores tubulaires ouverts) au niveau de la coupe transversale du sol;
c. La zone de fentes verticales qui permette une infiltration latérale; et
d. La zone relative de fentes horizontales dans le sous-sol qui est remplie d'air, comme fonction de la pression hydrostatique.

Des techniques de coloration pour utilisation in situ ont été mises au point afin de déterminer les données morphologiques mentionnées dans les deux derniers points.

L'article présente les résultats des essais de simulation d'un sol argileux lourd de Pays-Bas. L'application de cette méthode nécessite la mesure de la conductivité hydraulique et des courbes de rétention de l'humidité à l'aide des méthodes existentes, ainsi que l'utilisation de plusieurs techniques macromorphologiques de terrain comme indiqué ci-dessus.

2 Introduction

Computer simulation models are well established tools to characterize actual and potential soil water regimes in the context of land evaluation (e.g. Belmans et al. 1984 and references therein). Special problems occur, however, when these models are applied to cracked clay soils where flow patterns are strongly influenced by both vertical and horizontal cracks (planar voids). Many acid sulphate soils have been formed in clay soils and use of traditional simulation models, assuming presence of isotropic soil, may therefore raise problems. Two approaches are being followed now in trying to model water movement in cracking clay soils: (1) varying hydraulic characteristics of the soil matrix are measured as a function of swelling and shrinkage processes. In this approach, size and continuity of planar voids are considered to be the result of these processes. (2) Morphometric characterization of both vertical and horizontal planar voids is emphasized. In this approach, the soil matrix is considered to be 'soil between the cracks'. The second approach will be discussed in this paper. A case study from the Netherlands will be presented to explain the procedures involved. Particular emphasis will be placed on water storage in cracked soil; lateral infiltration from planar voids into the soil matrix; and upward, unsaturated flow from the water table to the soil surface in clay soils with horizontal planar voids.

3 Defining subsystems of flow

Complex flow processes in clay soils with macropores can be better understood when submodels are distinguished, which can be defined by using soil morphological data for the entire soil and soil physical data for the soil matrix. Three submodels are distinguished in Figure 1:

1. Vertical infiltration at the upper soil surface between the planar voids (i_1), and downward vertical movement through the soil matrix;
2. Flow of water from the surface into the planar voids, after filling of microdepressions at the soil surface. The process of vertical movement of free water along cracks in an unsaturated soil matrix is referred to as 'bypass flow' (Bouma 1984);
3. Partial or complete filling of the macropores and lateral infiltration into the (unsaturated) soil matrix (i_2), to be characterized by flow equations (Hoogmoed and Bouma 1980; Bouma and Wösten 1984).

A separate submodel for upward unsaturated flow (i_3 in Figure 1) is needed when hydraulic gradients induce upward flow. Vertical and lateral infiltration can be characterized by Darcy's equation in combination with the continuity equation. The reader is referred to any current soil physics textbook for specific details. Computer simulation, using CSMP or other user friendly subroutines, is attractive for the applications being discussed here.

4 Methods

4.1 Bypass flow

Bypass flow can be measured by using large undisturbed cores of dry soil (Bouma et al. 1981). For Dutch conditions in heavy clay soils, cylinders have been used with a height and diameter of 20 cm. Cores include the soil surface with grass, which is closely cropped. The cores are placed in the path of a spraying gun in the field which

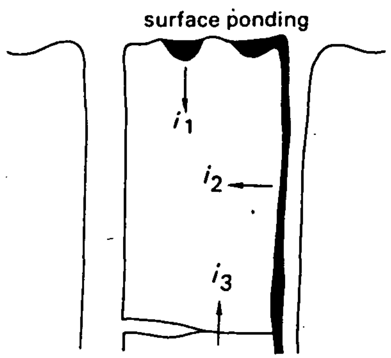


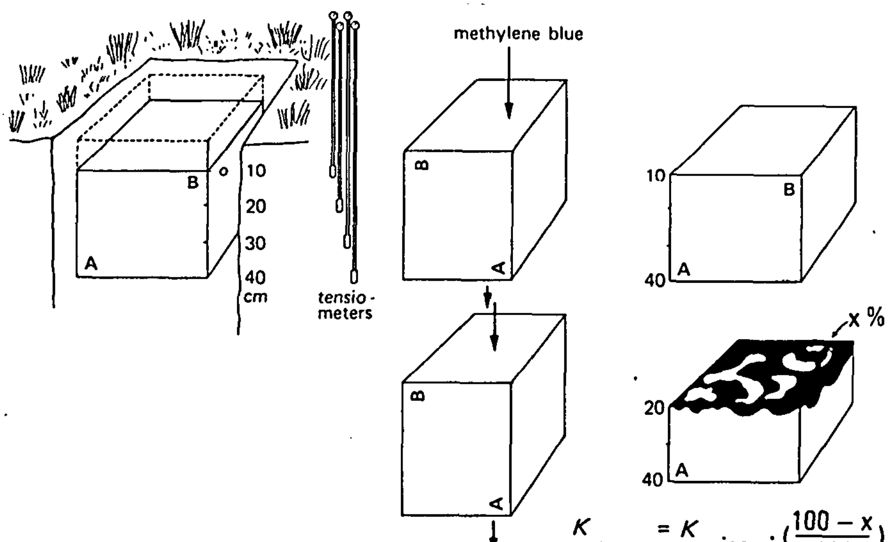
Figure 1 Schematic representation of water infiltration into cracked clay soils, showing surface ponding of water, vertical infiltration (i_1), lateral infiltration from ped faces into the peds (i_2) and upward flow (i_3).

is commonly used for sprinkling irrigation. In general, sprinkling conditions should correspond to local practices. The mass of the soil filled cylinder is determined before and after sprinkling and the stove dry mass is measured at the end, thus allowing calculation of physical constants such as bulk density and moisture contents. Sprinkling intensities and duration should be measured independently. The volume of water that leaves the column is measured as a function of time, thus allowing an estimate of bypass flow which can be expressed as a percentage of the applied quantity of water. Many measurements can be made in a short time and the effects of using different durations can be easily evaluated. Thus, irrigation efficiencies can be improved because movement of water beyond the root zone often presents a loss of precious irrigation water and surface applied chemicals (Dekker and Bouma 1984).

4.2 Horizontal cracking

Vertical planar voids may result in bypass flow. However, soil shrinkage also causes the formation of horizontal cracks which strongly impede upward flow of water in unsaturated soil (Bouma and De Laat 1981). A method was devised to stain air filled horizontal cracks at different moisture contents and corresponding (negative) pressure heads. A cube of soil (30 cm × 30 cm × 30 cm) is carved out in situ (Figure 2). The cube is encased in gypsum and is turned on its side.

The upper and lower surfaces are opened and two sidewalls of the turned cube are closed. Methylene blue in water is poured into the cube and will stain the air filled cracks. The surface area of these stained cracks is counted after returning the cube



$$K_{macro} = K_{micro} \cdot \left(\frac{100 - x}{100}\right)$$

Figure 2 Schematic representation of the method for measuring the area of air-filled horizontal cracks as a function of the pressure head.

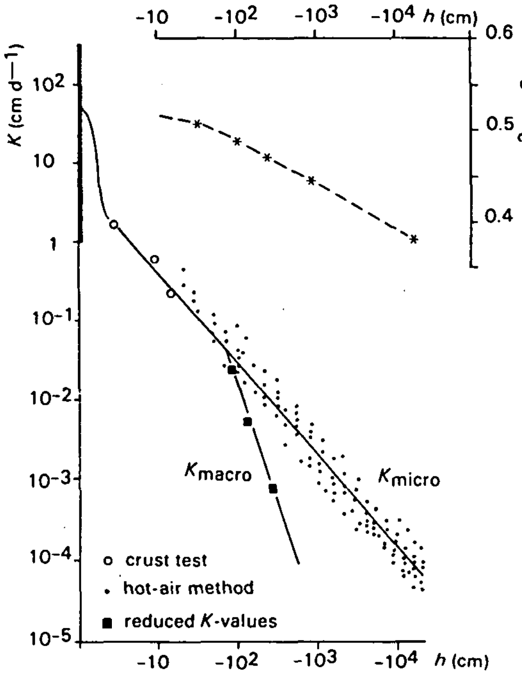


Figure 3 K curve for a heavy clay consisting of the regular curve (k_{micro}) which defines water movement in the peds and a K_{macro} curve which is used to define upward, unsaturated flow from the water-table. Three cubes of soil were used to obtain the three reduced K values that are indicated.

to its original position. A separate cube is needed for each (negative) pressure head. The K-curve for the peds (Figure 3) is 'reduced' for each pressure head measured in a cube. When, for example, 50% of the horizontal cross sectional area is stained, K_{unsat} for upward flow is 50% of the K_{unsat} at the same pressure head in the peds.

5 Results

Two types of results will be discussed: (1) Simulation of the water regime in the growing season, and (2) Simulation of infiltration during sprinkling irrigation or ponding in dry or slightly moist clay soil.

5.1 Seasonal water regime

Using weather data for 1979, a simulation run was made for the summer period July 1 – September 1 for a heavy clay soil in the Netherlands. The soil had 55% clay and was classified as a very fine, mixed mesic Typic Haplaquept. Vertical cracks were continuous and ponding of water inside cracks did not occur under natural conditions (Bouma and De Laat 1981). Independent measurements of bypass flow as a function of natural rainfall duration and intensity, were used to estimate fractions of natural rainfall that were likely to contribute towards bypass flow. These fractions turned out to be 20% for the period indicated (Bouma and De Laat 1981). Natural quantities of rainfall, that were used in the model for weekly periods, were therefore reduced by 20% to account for bypass flow. The assumption was made, in fact, that the fraction of rain that contributed towards bypass flow could be ignored. Upward unsaturated flow was characterized by the K_{macro} curve as shown in Figure 3.

Results are presented in Figure 4. Field measurements agreed well with simulations that considered both bypass flow and the effect of horizontal cracks, while the latter aspect had the largest impact. The significant effect of horizontal cracks on the upward flux of water is further illustrated in Figure 5 which shows the height (Z) above the water table to which a steady flux (q_c) of 2 mm day^{-1} can be maintained. The Z_{micro}-curve is based on the hydraulic conductivity curve of the peds and shows, for example, a Z value of 65 cm when the pressure head at 65 cm above the zero pressure level is –1000 cm. The corresponding Z value, when considering horizontal cracking, is only 35 cm. These results are important when considering possible upward movement of acid water by, unsaturated flow.

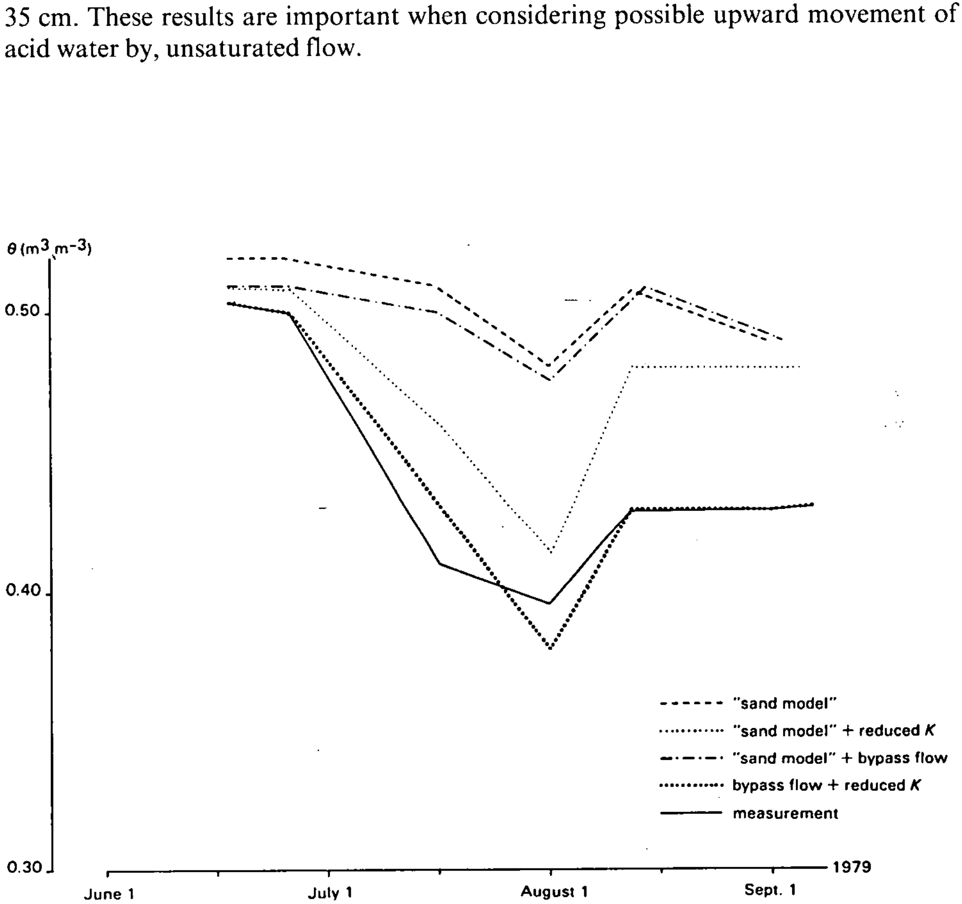


Figure 4 Measured and simulated moisture contents for a depth of 30 cm below surface in a Dutch heavy clay soil, showing the effects of bypass flow and horizontal cracking.

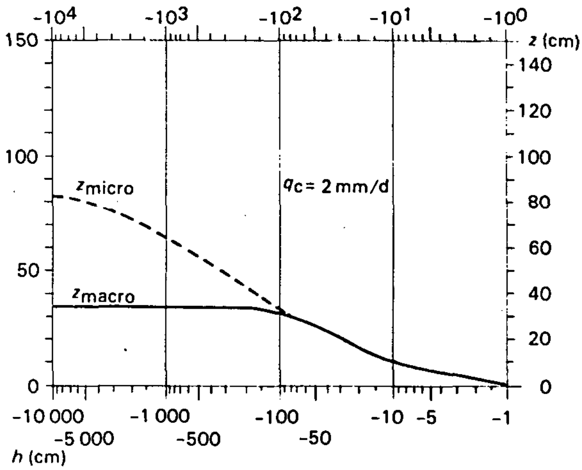


Figure 5 Curves that show the height (z) to which a steady upward flux of 2 mm d^{-1} can be sustained at defined negative pressure heads at the upper part of the flow system. The z_{micro} curve was derived from the k_{unsat} curve of the soil matrix. The z_{macro} curve reflects the effect of horizontal cracks (see Figure 3).

5.2 Irrigation or ponding

A model, composed of three submodels as explained in Section 3, was used to predict infiltration of water during sprinkling irrigation in a dry, cracked clay soil (Hoogmoed and Bouma 1980). Measured hydraulic conductivity (Figure 3, the regular curve) and moisture retention data were used. The model correctly predicted reduced wetting of surface soil due to bypass flow. Lateral infiltration of free water from the walls of the cracks into the dry matrix was very low, due to the presence of cutans and very rapid downward movement of free water along air filled planar voids.

Planar voids were not filled with water here as water moved downwards as narrow bands on the vertical walls of air filled planar voids. On the contrary, continuous ponding of water at the soil surface results in filling of the planar voids. Their number per unit surface area, and their width and depth determine the available volume for storage. Infiltration occurs into the upper soil surface, and laterally from the filled planar voids. A field study was made in which these various flow processes were combined (Bouma and Wösten 1984). The volume of air filled planar voids, available for storage of water, could be reliably estimated by making counts of gypsum filled voids in horizontal cross section. Lateral infiltration into the peds was simulated by using a measured D-θ function in a simulation model (subsystem 3, as defined in Section 3), which also needed the total length of planar voids within a given horizontal cross sectional area (D-θ stands for the Diffusivity as a function of the moisture content). Measured and calculated data agreed well in terms of the depth of penetration along the planar voids and the total volume of laterally absorbed water which is a function of the total length of the planar voids in horizontal cross section. This length can only be obtained by morphometric techniques (Figure 6). Thus, the process of lateral infiltration from planar voids can be described in quantitative terms, when a $D(\theta)$ relation is known.

6 Discussion

Formation of acid sulphate clays and transport of acid water is, of course, governed by patterns of water and air movement in the soil. Water and air movement in clay soils is highly influenced by planar voids and other macropores. The morphometric techniques, described in this paper, allow realistic predictions of patterns of water movement using existing simulation models. Emphasis is placed on the characterization of planar voids in terms of length per unit cross sectional area, (through which lateral infiltration has to occur) and vertical and horizontal continuity (which governs up-and downward fluxes).

Methods described are independent and quantitative. Matrix properties are expressed in terms of a singly hydraulic conductivity, diffusivity and moisture retention function. This is allowed when effects of swelling and shrinkage are expressed in terms of volume fractions of water of the soil matrix only, excluding the volume of the planar

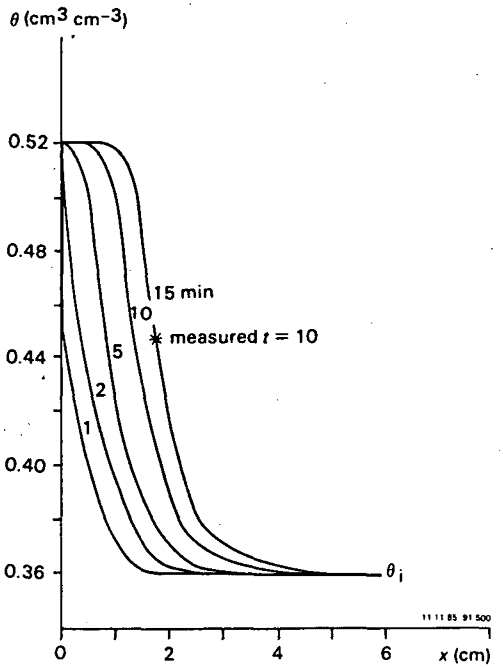


Figure 6 Calculated moisture distributions as a function of time and distance from surface of infiltration in a dry clay soil per unit surface area. The numbers 1, 2 etc. indicate the duration of infiltration (min).

voids. Planar void continuity is much more important than void width.

The method presented implies exclusive use of soil morphometric data, which could not have been obtained by physical methods. These data include: (1) The length of horizontal planar voids in horizontal cross section; (2) The vertical area of planar voids that is available for lateral infiltration, and (3) the area of air filled horizontal cracks in the subsoil.

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A field laboratory method to determine total potential and actual acidity in acid sulphate soils

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1 Summary

A new quantitative method is presented for the determination, in a field laboratory, of total potential and actual acidity of acid sulphate soils. The method is based on the fast titration of the total acidity of the soil sample with sodium hydroxide. For the determination of the 'total actual acidity' a soil sample is suspended in a 1 molar sodium chloride solution and titrated subsequently. The 'total potential acidity' is determined by oxidation, with 30% H_2O_2, of a soil sample suspended in a 1 molar sodium chloride solution. After the oxidation has been completed, the sample is titrated with NaOH as well. The total acidity thus determined, gives a quantitative measure of the maximal actual or potential acidity which has to be neutralized or leached to permit the soil pH to rise to 5.5 under actual circumstances (actual acidity) or after the reduced soil is completely aerated (= potential acidity).

The method has been tested on some 60 samples of actual, potential and non acid sulphate soils from Vietnam and Indonesia, ranging from clay to peat. The potential acidity determined by way of the proposed method was closely related to the total content of sulphur species. The relation with pyrite was poor because sulphur species other than pyrite were found to be important sources of acidity, especially organic sulphur. pH after oxidation by H_2O_2 turned out to be a very poor parameter for the potential acidity. Total potential acidity varied manifold at a certain pH, especially below pH 2.5.

Guidelines are given for the application of the method in a field laboratory. Two simple volumetric soil sampling devices are proposed which enable a direct determination of actual and potential acidity per hectare of soil over a certain depth.

Résumé

Une nouvelle méthode quantitative de détermination au champ de l'acidité actuelle et potentielle des Sols Sulfaté-Acides a été mise au point.

La méthode est basée sur la titration rapide de l'acidité totale d'échantillons des sols avec l'hydroxyde de sodium. Pour la détermination de l'acidité actuelle, l'échantillon du sol est apporté en suspension dans une solution de chlorure de sodium 1 molar, et titré par la suite. L'acidité potentielle est déterminée par l'oxydation de l'échantillon de sol apporté en suspension dans une solution de chlorure de sodium 1 molar, avec 30% H_2O_2. Après que l'oxydation est achevée, l'échantillon est titré encore avec NaOH.

L'acidité ainsi déterminée, donne la mésure quantitative de l'acidité maximale actuelle et potentielle qui doit être neutralisée ou lessivée, pour permettre au pH du sol d'augmenter jusqu'à 5,5 dans les conditions actuelles (= acidité actuelle) ou après que le sol a été drainé (= acidité potentielle).

La méthode a été testée sur 61 échantillons des Sols Sulfaté-Acides (actuels et potentiels) et Sols Non Sulfaté-Acides du Delta du Mekong, Vietnam et de la partie orientale de Sumatra, Indonésie, formés sur une gamme large de sédiments, d'argile à tourbe.

L'acidité potentielle déterminée d'après la méthode proposée, a été étroitement liée à la teneur totale de sulfures réduites. Par contre, la relation avec la pyrite n'a pas été significative, car d'autres formes de sulfures réduites que la pyrite, celles organiques particulièrement, ont été aussi d'importantes sources d'acidité. Egalement, le pH après l'oxydation à H_2O_2 n'est qu'un vague paramètre, car l'acidité potentielle totale varie considérablement à certains pH, surtout inférieurs à 2,5.

Il en découle, que quoique de nombreuses méthodes et études préconisent la mesure du pH comme moyen de détermination de l'acidité potentielle, la titration après l'oxydation à H_2O_2, c'est la meilleure.

Des indications sont données pour l'application de la méthode dans le laboratoire de terrain.

Deux procédés simples d'échantillonnage volumétrique sont proposés, qui permettent la détermination dirécte de l'acidité actuelle et potentielle par ha de sol sur une certaine profondeur.

2 Introduction

Acid sulphate soils as defined by Pons (1973) are materials and soils in which, as a result of soil formation, sulphuric acid either will be produced, is being produced or has been produced in amounts that have a lasting effect on main soil characteristics. Sulphuric acid is produced by oxidation of unripe soil material containing reduced sulphur species. These soils have conditions unfavourable for plant growth: they often contain free acid, Al^{3+}, Fe^{2+}, Mn^{2+}, H_2S and CO_2 in amounts which are toxic for plants, have low nutrient status and often a high salinity (Coulter 1973; Ponnamperuma et al. 1973).

Acid sulphate soils have a worldwide distribution. They occur under widely different climatic conditions, from the tropics to permafrost areas (Kawalec 1973). They are found not only in recent marine deposits, but also in older inland areas (Poelman 1973). Throughout the world their extension is estimated at 12 – 14 million ha (Beek et al. 1980).

Acid sulphate soils have a low potential for agricultural use and their management often requires high technology. Therefore, areas in which these soils occur are still uncultivated or they have been abandoned after agricultural use failed. With increasing population, however, the pressure on these areas is growing, especially in densely populated coastal areas of southeast Asia and western Africa. In fact, these areas have a climate favourable for food production and are suitable for agriculture but for the potential or actual acidity of their soils. Decisions on their development for food production depend, apart from social and economic factors and possibilities of water control, mainly on the content of potential and actual acid substances of these soils.

Total actual acidity is defined here as the total amount of acidity which exists in a soil at present. Total potential acidity of a soil is the maximal amount of acidity which a partly or totally reduced soil may contain after it has been completely oxidized. Thus the total potential acidity comprises eventually present actual acidity and the amount of acidity which developes upon complete oxidation of the soil.

Identification of developed acid sulphate soils in the field is relatively easy: they have a low pH, usually below 4, they contain water-soluble sulphate and most of them have pale yellow jarosite mottles (compare the 'sulphuric horizon' of USDA, 1975 and FAO/Unesco, 1974). Potential acid sulphate soils, however, are not easily recognized in the field. As is sometimes done in soil survey, actual and potential acidity are determined in a laboratory and related to visual properties of the soil, like soil colour and organic matter content, or to physiography or vegetation (Brinkman and Pons 1973; Thomas and Varley 1982). These relations, however, can only be used within the limits of a certain climatic, sedimentary and vegetational system and their assessment requires intensive integrated surveys of soil, landscape genesis, vegetation, hydrology and land-use history (Pons 1973).

Several field or field laboratory methods for rapid identification of pyrite or potential acidity were developed: measurement of the pH drop after oxidation of a soil sample with H_2O_2 (Van Beers 1962) or after oxidation by air drying (FAO/Unesco 1974; USDA 1975; Van Breemen 1982), the active sulphide test with HCl and lead acetate paper (Neckers and Walker 1952), the sodium azide test developed by Feigl (Van Andel and Postma 1954) which was adapted for the field by Edelman (1973), the semi-quantitative sulphate test with $BaCl_2$ of Poelman (1973).

All these methods have certain disadvantages. They are qualitative methods or at the most, they give an indication of the intensity of acidification (pH). Some of the methods give an indication of the pyrite content only. These are unsuitable for soil materials rich in organic matter, because the latter may contain large amounts of potential acid organic sulphur compounds (Altschuler et al. 1983). The air drying method gives results only after several months. A sound land evaluation, however, requires a quantification of the actual and potential acidity of the soil in order to assess the amount of acid to be neutralized or leached after drainage and oxidation, to make the soil suitable for a given land use. Hence, the aim of the present study was to develop an easy, fast and low-cost quantitative field laboratory method for estimating potential and actual soil acidity.

3 Materials

For the development of the field laboratory method, samples were used of an actual acid sulphate soil with a potential acid peat substratum (the Zuidplaspolder profile) and of a potential acid sulphate soil (the Tholen profile), both located in The Netherlands. In the field, these samples were packed in thick-walled plastic pots, as air-free as possible and they were handled in the laboratory or freeze-dried within 24 hours. The method was tested on 61 freeze-dried samples from the Mekong Delta, Vietnam and from the Berbak area, eastern Sumatra, Indonesia. The latter samples varied from clay to peat, from totally oxidized to reduced materials, from pyrite-rich to non-potential acid materials without pyrite. A description of the profiles from which the samples were taken, is given in Appendix 1.

4 Methods

Determination of total potential and actual acidity.

Total acidity of the soil was determined by titration up to pH 5.5 with NaOH of a sample suspended in a NaCl solution (1 mol/l), in a soil/solution ratio of 1/5 by volume or 1/2.5 by mass. pH measurements were done with an Orion Digital Ionalyzer, model 801A. Total acidity at pH 5.5 was read from the titration curves. Potential acidity of the samples was determined after they were oxidized, actual acidity was determined of the fresh or freeze-dried samples.

Titration methods

Four titration methods were tested:

1. 'Slow titration' of the soil suspension. Different amounts of NaOH solution were added to 20 ml subsamples of the soil suspension. After various time steps (immediately after titration, after 1 h, 24 h, 48 h and 1 week), the pH of all subsamples was measured and titration curves were drawn;
2. 'Fast titration' of the soil suspension. Subsamples (100 ml) of the soil suspension were rapidly titrated by small additions of NaOH solution. After each addition the suspension was homogenized and the pH measured. Additions were continued until a pH between 6 and 7 was reached;
3. 'Back titration' of the suspension. After fast titration of the soil suspension to pH 6-7 and a 24 h waiting period (during which the pH dropped to 5.5-6), the suspension was back titrated with a HCl solution to pH 5.0-5.5. After another wait of 24 h the pH was measured again;
4. 'Fast titration' of the soil extract. Subsamples (50 or 100 ml) of the soil suspension were extracted twice with a NaCl solution (1 mol/l). The extract was titrated fast.

Oxidation method

After suspending the soil sample in a NaCl solution (1 mol/l), in a soil/solution ratio of 1/5 by volume or 1/2.5 by mass, the suspension was oxidized with 30% H_2O_2 at room temperature or on a moderately warm waterbath. Hydrogen peroxide was added until the mineral soil material became clear grey to clear brown coloured and no foam existed or was formed upon adding further H_2O_2. A possible surplus of H_2O_2 was evaporated by heating briefly on a boiling waterbath. The suspension was then brought to the original volume by evaporation or by addition of water.

Further chemical analyses

Pyrite was measured as Fe after extraction by HNO_3. Non-pyrite iron was excluded by a pretreatment with a HF/H_2SO_4 mixture. Water-soluble plus exchangeable sulphate and jarosite were determined turbidimetrically as sulphate, after successive extractions by EDTA.3Na (0.1 mol/l) and by HCl (4 mol/l) (Begheijn et al. 1978).

Elemental sulphur was determined turbidimetrically as colloidal sulphur after extraction with acetone and exchange of acetone by water.

Total sulphur was measured after conversion of all sulphur compounds to sulphate by partial fusion in a mixture of sodium carbonate and potassium nitrate at 700 °C (Begheijn 1980). Organic S was estimated from the difference between total S and the sum of all other sulphur compounds.

Total dissolved organic carbon (TOC) of the soil suspension extract was measured as CO_2 by IR-spectrometry with a TOC Analyzer, Beckman model 915-B.

NH_4 of the soil suspension extract was determined by spectrometry with Nessler's reagent.

CEC was measured by replacement of adsorbed cations by Li with Li.EDTA and determination of Li by flame photometry; determination of exchangeable Ca and Mg by atomic adsorption spectrometry and of exchangeable Na and K by atomic emission spectrometry (Begheijn 1980). NO_3^- in the soil solution was tested qualitatively by the ring test, using concentrated sulphuric acid and ferrous sulphate solutions.

Microscopic examination of pyrite

Fresh and H_2O_2-oxidized samples of the two Dutch profiles were examined for pyrite under a microscope with a combination of transmitted light and incident mercury light (Slager 1967). The microscopic slides were prepared according to Pons (1964).

5 Results

After oxidation, the pH of the soil suspension was measured in the clear liquid above the settled soil mass, as well as in the suspension after homogenization. The pH measured before and after homogenization differed by 0.2 pH unit or less for all samples. Stabilization of pH was faster in the homogenized suspensions. Differences between repeated pH measurements were smaller for the homogenized suspensions (0.3 pH unit). Also, the time required for titration was shorter if the pH was measured in the homogenized suspensions. Therefore, pH was always measured in the homogenized suspensions.

Total acidity was also measured in extracts from soil suspensions. The extractions required much time and work. Besides, total acidity of the extracts was about 15 per cent lower than the total acidity of the suspensions (Konsten 1984a). Therefore, this method was not considered further.

During titration a greenish blue precipitate was often formed. After leaving the suspensions for about two days, the colour slowly changed to orange. Upon addition of a drop of hydrogen peroxide, the colour of the precipitate changed immediately to orange. If a drop hydrogen peroxide was added to the soil suspension before titration, the colour of the precipitate forming in the suspension during titration was orange from the start.

Ten identical peat samples of the Zuidplaspolder subsoil were oxidized by different amounts of hydrogen peroxide. Initially, the pH decreased with increasing amounts of H_2O_2, while total acidity and dissolved organic carbon content of the soil suspension increased. Upon further addition of H_2O_2 the pH increased, while total acidity and dissolved organic carbon in the soil suspension decreased (Figure 1). Ammonium content of the soil suspensions increased upon oxidation. A qualitative test showed that ammonium was not oxidized to nitrate.

During oxidation, volatilization of H_2S, SO_2 and NH_3 was tested qualitatively. Tests for H_2S and NH_3 were negative, the test for SO_2 was positive. Sulphur budgets of some of the Dutch samples showed a decrease in sulphur content by 20 to 40 per cent of total sulphur after oxidation (Konsten 1984a).

Chemical as well as microscopic analyses of samples from The Netherlands showed that not all pyrite was oxidized after treatment with hydrogen peroxide. In particular samples rich in organic matter still contained part of their pyrite after oxidation (Table 1).

Table 1 Pyrite-S content of samples from The Netherlands determined chemically and microscopically before and after oxidation

Horizon and sample number	Pyrite-S content (mass %)		Microscopic pyrite*)	
	before oxid.	after oxid.	before oxid.	after oxid.
Tholen				
A12g	0.24	0.26	+	±
C1g1	0.68	0.13	+	–
C1g2	1.51	0.75	+	+
G1	0.68	n.d.	+	±
Zuidglaspolder				
A12g	0.43	n.d.	+	±
C12g	0.48	n.d.	+	±
CG	1.92	n.d.	++	+
G1	2.92	n.d.	++	+
G2	2.40	n.d.	++	+

n.d.: not determined

*) presence of pyrite framboids:
++ very clear
+ clear
± little or doubtful
– not present

Figure 2 shows the relation between pH and total acidity after oxidation by H_2O_2. As expected, an inverse relation was found. The predictive value of the pH after oxidation is low, however, especially below pH 2.5: the lowest and highest acidity at a certain pH may differ by a factor two or three.

Figure 3 represents the relation between the pyrite content of the soil and the amount of acidity which developed upon oxidation of the soil samples (= total potential minus actual acidity). The dashed line shows the theoretical relation between the two. Pyrite content is poorly related to total potential minus actual acidity. Most of the samples show a higher total potential acidity than would be expected from oxidation of pyrite only.

Figure 4 shows the relation between the total S content and total acidity after oxidation. Total sulphur content shows a better relation to total potential acidity than pyrite to total potential minus actual acidity.

After titration the pH continued to decrease slowly for one or two days and then became constant. The relation between total potential acidity measured immediately after titration (A_0) and measured 48 hours after titration (A_{48}), is extremely close

$$A_{48} = 1.1 * A_0 \, (r^2 = 0.99, n = 76).$$

For total acidity this relation is

$$A_{48} = 1.8 * A_0 \, (r^2 = 0.85, n = 58)$$

The back titration always resulted in a lower total acidity than the direct titration methods (Konsten 1984a) and was not further considered.

6 Discussion

Total acidity is measured in a 1 molar salt solution in order to eliminate influences of differences in salt concentration on pH and total acidity (McLean 1982). This also enables the use of slightly saline water in remote survey areas where no demineralized water is available. For the method described here, NaCl was chosen instead of the commonly used KCl, because it is cheaper and more easily available.

The greenish blue precipitate which was often observed to form in the soil suspension during titration, probably consists of a complex ferrous/ferric hydroxide. Maximal acidity, however, is measured only if, after oxidation, all iron is present in the ferric form. During titration ferric hydroxide will then be formed. This may be illustrated by the oxidation reaction of pyrite. Maximal acidity (4 mol H^+ per mol pyrite) is formed by the reaction

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

If jarosite is formed, however, the acidity arising from oxidation is only 3 mol H^+ per mol pyrite

$$FeS_2 + 15/4O_2 + 5/2H_2O + 1/3K^+ \rightarrow 1/3KFe_3(SO_4)_2(OH)_6 + 4/3SO_4^{2-} + 3H^+$$

Production of acidity is lower still, namely 2 mol H^+ per mol pyrite, if upon oxidation ferrous ions are produced (Van Breemen 1973)

$$FeS_2 + 7/SO_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

In order to measure the total amount of potential acidity after oxidation it is necessary to turn all iron into the ferric form before titration. This is done by adding a drop of hydrogen peroxide before titration. The precipitate forming then has the orange colour of $Fe(OH)_3$.

Before starting the titration it is very important to oxidize all organic matter as completely as possible. Initially organic acids are produced which raise the total acidity of the soil suspension (Figure 1). Poelman (1968) also warned for this. Upon further oxidation CO_2 and H_20 are formed, thus eliminating again the acidity initially formed by organic matter.

Also upon oxidation organic nitrogen is transformed into ammonium (Figure 1) which neutralizes part of the acidity. This neutralizing effect must be taken into account with samples rich in organic matter. Buffering of acidity by nitrogen amounted to a maximum of 17 mmol/100 g soil for peat samples (Konsten 1984b). The ammonium formed was not oxidized by hydrogen peroxide, probably because of the low pH.

During oxidation part of the potential acidity escaped by evaporation of SO_2. This was also observed by Van Breemen (1976) in oxidation experiments of pyrite-containing samples from Thailand. Volatilization of sulphur species was also found to occur during natural oxidation of acid sulphate soils (Allbrook 1973; Banwart and Bremner 1975; Thomas and Varley 1982). Comparison of volatilization under oxidation by hydrogen peroxide with evaporation under natural conditions is not yet possible as quantitative data are lacking.

Not all pyrite is oxidized by hydrogen peroxide, as was ascertained chemically, as well as microscopically for the samples from The Netherlands (Table 1). Under field conditions pyrite in mineral soils in Thailand was oxidized almost completely (Van Breemen 1976). Soil material rich in organic matter may, however, still contain pyrite after oxidation in the field, as is the case in the topsoil of the Zuidplaspolder profile. Probably, this stable pyrite is enclosed within the organic matter and thus protected from oxidation. Pyrite crystals enclosed in plant remnants are described by Altschuler et al. (1983).

A fairly good relation exists between pH after oxidation and potential acidity. However, the predictive value of this relation is very small, as is clear from Figure 2. Below pH 2.5, total potential acidity may vary manifold. Predicting potential acidity by measuring the pH after oxidation, as was done in many methods and surveys (Van Beers 1962; Allbrook 1973; Andriesse et al. 1973; Bloomfield 1973; FAO/Unesco 1974; USDA 1975; Van Breemen 1982) therefore is not a sound procedure. Titration after oxidation is a better and safer method to assess potential acidity of acid sulphate soils.

Potential acidity is often assessed by determination of the pyrite content. Chemical analysis of pyrite is complicated and expensive. Besides, as is clear from Figure 3, the relation between pyrite content and total potential minus actual acidity is poor ($r^2 = 0.53$). Not all pyrite is readily oxidized into sulphuric acid. But the main reason for this poor relation is that pyrite is not the only S compound that produces acidity upon oxidation. Other reduced sulphur species may be important as well, especially organic sulphur. Alteschuler et al. (1983) report 40 to 60 per cent of total sulphur to be bound in organic form in pyrite peat soils of Florida. From Annex 1 it is clear that samples rich in organic matter may contain considerable amounts of organic sulphur: the subsoil of the Zuidplaspolder profile (2.30% org. S); samples A_2X_5C (2.03%), TL1Cl (2.01%) and TL2B2 (1.92%) from Vietnam. Elementary sulphur is important in the Clg horizon of the Tholen profile (0.54%). As expected, total sulphur content already shows a better relation with potential acidity (compare Figs. 3 and 4).

As can be seen from Figure 4, there is a certain disagreement between total S-content and total potential acidity for many soil samples. This is due to several reasons. First, the buffering capacity of the soil is not accounted for. With the hydrogen peroxide method, the fast working acid neutralizing compounds can act before the acidity is titrated. For example, the calcareous subsoil of the Tholen profile has a pyrite content of 0.7 per cent, while its potential acidity is zero. Second, some of the potentially acid SO_2 is escaping the soil sample during oxidation. Third, acidity in the form of H^+, Al^{3+}. Fe^{2+}, as well as sulphate from already oxidized horizons may have been transported to other parts of the soil, thus deranging the relation between total sulphur content and potential acidity of different soil horizons.

From Figure 4 it may be concluded that the total potential acidity, as measured by this titration, gives a good indication of the maximum acidity which may arise upon oxidation of the soil.

Under natural circumstances the acidity after oxidation is less for several reasons:

- Under slow oxidation the slowly working buffer capacity of the soil may have its effect, i.c. the buffering of acidity by the weathering of minerals (Van Breemen 1973);
- End products other than $Fe(OH)_3$ may be formed, resulting in less acidity being produced (Van Breemen 1973);
- Oxidation of organic matter occurs more slowly, resulting in a more gradual release of acidity by the oxidation of organic sulphur;
- Leaching of soil acidity may occur under field circumstances.

Titration results are influenced by operational time, as was examined by Bruggenwert (1972). During the present study total acidity at pH 5.5 turned out to increase with increasing time between titration and pH measurement. The increase was maximal immediately after titration and lessened with time. After titration, the pH stabilized in all samples in 24 to 48 hours. For all samples, total potential acidity measured after the pH stabilized, was 10% higher than the total potential acidity measured immediately after titration. Finding the same relation for samples from different countries, different parent materials (clay as well as peat), different soil horizons (oxidized, well developed acid sulphate horizons as well as unripe layers), we may conclude this relation to be generally applicable. Therefore, the waiting time of 48 hours may be omitted and total potential acidity may be calculated by multiplying the total potential acidity measured immediately after titration by 1.1 and the total actual acidity measured immediately after titration by 1.8. This also reduces the amount of chemicals needed, the time required for analysis and the chance of mistakes.

7 Conclusions and recommendations

The assessment of potential acidity by existing methods using pH after oxidation or pyrite content has a low predictive value and is not recommended.

The method described here allows a fast and accurate assessment of the maximal potential acidity of acid sulphate soils. Under field circumstances the acidity arising from oxidation of the soil may be lower than the maximal potential acidity, because:

- Part of the acidity may be leached from the soil;
- Part of the acidity may be neutralized by slowly working buffers, for example by weathering of minerals;
- End products other than $Fe(OH)_3$ may be formed, resulting in a lower acidity of the soil;
- Oxidation of organic matter may occur more slowly, so that acidity formed by oxidation of organic sulphur is released more gradually.

The method therefore gives a safe estimate of potential acidity.

Samples rich in organic matter should be oxidized fully and with care. An amount of 100 ml 30% hydrogen peroxide may be needed to oxidize a 5 ml (10 g) sample of peat. If not fully oxidized, the presence of organic acids in the soil suspension may result in too high a potential acidity measured. A small part of the total acidity may be neutralized by organic nitrogen.

During oxidation with hydrogen peroxide, part of the potential acidity is volatilized as SO_2. Evaporation of sulphur species also occurs under natural circumstances.

Larger part of all reduced sulphur is oxidized by hydrogen peroxide, but part of the pyrite may be stable in samples rich in organic matter. The same was found under field conditions.

Potential acidity is maximal 48 hours after titration.

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Annex 1
Profile descriptions and results of chemical analyses and titration experiments

A1.1 Samples from The Netherlands

Profile descriptions (for full profile descriptions, refer to Konsten 1984a and b)

Th-Slikvaaggrond (Thionic Fluvisol; Typic Sulfaquent) from Tholen

A11g	0- 3 cm	heavy clay, unripe, rich in organic matter, strongly calcareous
A12g	3- 20	heavy clay, unripe, rich in organic matter, non- calcareous; samples from 8-18 cm
C1g	20- 60	heavy clay, unripe, rich in organic matter, non- calcareous; samples 1 from 25-35 cm; samples 2 from 47-57 cm
G1	60-100	very heavy clay, unripe, rich in organic matter, strongly calcareous; samples from 68-78 cm

ZP-Plaseerdgrond (Mollic Gleysol; Typic Sulfaquept) from the Zuidplaspolder

A11	0- 2 cm	peat, ripe, non-calcareous
A12g	2- 18	peaty clay, ripe, non-calcareous; samples from 5-15 cm
C11	18- 21	peat, almost ripe, non-calcareous
C12g	21- 60	very heavy clay, half-ripe, non- calcareous; samples from 35-45 cm
CG	60- 80/ 90	peaty clay, unripe, non-calcareous; samples from 65-75 cm
G1	80/ 90- 90/100	peat, unripe, non-calcareous; samples from 82-87 cm
G2	90/100-140	peat, unripe, non-calcareous; samples from 110-125 cm

A1.2 Samples from Vietnam

Profile description (for full profile descriptions, refer to Van Mensvoort et al. 1983)

X_4-from Do Hoa State Farm, Duy en Hai District, Hô Chi Minh City Province

A	0- 20 cm	clay, half-ripe, low in organic matter
AC	20- 47	clay, unripe, low in organic matter
C1	47-117	clay, unripe, high in organic matter
C2	117-217	clay, unripe, low in organic matter

X_{36}-from Do Hoa State Farm, Duy en Hai District, Hô Chi Minh City Province, Typic Tropaquent

A	0- 10 cm	heavy clay, ripe, low in organic matter
B21	10- 28	heavy clay, ripe, low in organic matter
B22g	28- 60	heavy clay, ripe, low in organic matter
B23g	60- 91	heavy clay, half-ripe
C1	91-153	heavy clay, half-ripe, low in organic matter

Results of chemical analyses

Horizon	Sample number	Before oxidation									After oxidation	
		pH NaCl	org.C (mass %)	Sulphur species (mass %, on oven dry basis)								pH NaCl
				pyrite S	elem. S	organ. S	water sol. S	jarosite S	total S	pyrite S	total S	
Tholen												
A12g	Th 1, 2, 3, 4	6.7	–	0.24	–	–	–	–	0.21	0.26	0.17	5.0
C1g1	Th 5, 6, 7, 8	6.7	–	0.68	–	–	–	–	0.80	0.13	0.49	2.6
C1g2	Th 9, 10, 11, 12	6.9	2.06	0.51	0.54	0	0.24	0.04	1.81	0.75	1.25	3.3
G1	Th 13, 14, 15, 16	7.8	–	0.68	–	–	–	–	0.65	–	–	7.8
Zuidplas												
A12g	ZP 1, 2	3.7	–	0.43	–	–	–	–	0.41	–	–	5.1
C12g	ZP 3, 4	3.2	–	0.48	–	–	–	–	0.42	–	–	2.8
CG	ZP 5, 6	3.4	–	1.92	–	–	–	–	1.49	–	–	2.3
G1	ZP 7, 8	4.0	20.47	2.92	0.22	0.01	0.62	0.26	4.02	–	–	1.8
G2	ZP 9, 10	5.0	36.31	2.40	0.14	2.30	0.29	0.20	5.33	–	–	1.9

C2	153-280	clay, unripe, low in organic matter
C3	280-330	clay, unripe, low in organic matter

F_2X_{47}-from Farm 85B, Ha Tien Plain, Kiên Giang Province; Typic Sulfic Tropaquept

A1	0- 22 cm	clay, ripe, low in organic matter; pH 3.6
B21	22- 57	clay, ripe, low in organic matter; pH 3.6
B22	57- 85	clay, ripe, low in organic matter; pH 3.6
B23	85-115	clay, half-ripe, low in organic matter
BC	115-150	clay, half-ripe, low in organic matter
C	150-230	clay, unripe, low in organic matter

A_2X_5-from Farm 85B, Ha Tien Plain, Kiên Giang Province; Typic Sulfaquept

B21	7- 25 cm	clay, ripe, low in organic matter
B22	25- 68	clay, ripe, low in organic matter
BC	68- 86	clay, ripe, high in organic matter
C	86-295	clay, half-ripe, peaty

TL1-from Tân Lâp Seedfarm, Châu Thành District, Tièn Giang Province

B23	69- 89 cm	clay, ripe, high in organic matter
BC	89-111	clay, half-ripe, high in organic matter
C1	111-178	clay, half-ripe, rich in organic matter

TL2-from Tân Lâp Seedfarm, Châu Thành District, Tièn Giang Province

B24	121-136 cm	clay, unripe, low in organic matter
BC	136-146	silty clay, unripe, low in organic matter
C	146-240	silty clay, unripe, low in organic matter

Results of titration experiments

Horizon	Sample number	Tot. act. acid.	Tot. pot. acid.		
		(mmol H^+/100 g soil)			
		quick	quick	24 h after titration	soil extract
A12g	Th4	–	1.61	1.23	–
C1g1	Th5	–	28.3	42.9	22.8
C1g1	Th7	–	33.7	34.2	–
C1g1	Th8	–	17.1	23.7	18.3
C1g2	Th10	–	17.3	31.9	–
C1g2	Th11	–	17.6	28.4	18.2
A12g	ZP1	–	0.59	0.80	–
A12g	ZP2	1.81	2.46	3.37	–
C12g	ZP3	–	18.9	25.7	15.4
C12g	ZP4	3.71	23.4	30.1	22.0
CG	ZP5	–	62.2	78.1	65.0
CG	ZP6	5.36	54.5	73.5	48.3
G1	ZP7	–	156.0	170.8	–
G1	ZP8	4.23	149.8	165.4	–
G2	ZP9	–	233.4	246.0	–
G2	ZP10	2.59	160.6	192.0	–

Results of titrations and of chemical analyses

Sample number horizon	Acidity and pH						Sulphur species (mass %)						CEC and total bases (ionic equivalents-mmol/kg)	
	pH fresh	pH after oxid.	total act.acid. (mmol H^+/100g soil)		total pot.acid. (mmol H^+/100g soil)		solub. S	jarosite S	pyrite S	elem. S	organ. S	total S	CEC	total bases
			quick	48h	quick	48h								
X4-A	5.5	5.1	–	–	1	2	–	–	–	–	–	0.03	158	383
Z4-AC	5.3	4.8	–	–	2	3.5	–	–	–	–	–	0.06	183	360
X4-C1	2.9	1.7	14.5	21.3	136.5	151	0.55	0.18	1.24	0.13	1.14	3.24	147	336
X4-C2	2.6	1.3	10.3	20.0	161	180	–	–	0.14	–	–	0.10	125	325
X36-A	5.9	5.9			0	0	–	–	–	–	–	0	162	313
X36-B21	5.8	6.3	0	0	0	0	–	–	–	–	–	0.10	179	261
X36-B22	6.1	6.0	0	0	0	0	–	–	–	–	–	0.04	163	349
X36-B23	6.1	6.0	0	0	0	0	–	–	–	–	–	0.06	148	409
X36-C1	6.4	3.2	0	0	0	7.5	0.07	0.17	0.23	0	0	0.35	120	469
X36-C2	3.6	2.0	4.2	7.9	71.5	80	0.28	0.06	0.77	0.06	0.04	1.15	82.0	684
X36-C3	6.7	2.7	0	0	33	43	0.08	0.08	0.58	0	0.10	0.84	101	645

F2X47-A	3.7	3.4	12.0	18	19	23	1.25	0.18	1.45	0.16	1.13	4.17	158	18.2
F2X47-B21	3.1	2.9	12.5	18	15.5	18	–	–	–	–	–	0.04	154	52.2
F2X47-B22	3.0	2.7	13.5	18.5	16	19.5	–	–	–	–	–	0.20	153	54.2
F2X47-B23	3.2	2.7	12.0	19	17.5	19	0.10	0	0.14	0	0	0.20	175	46.1
F2X47-BC	2.8	1.6	19.0	14.8	103	112	0.35	0.09.	0.82	0.10	1.04	2.40	166	42.2
F2X47-C	2.9	2.3	9.5	18	59	75	0.23	0.29	0.80	0.44	0.14	1.93	170	128
A2X5-B21	3.4	2.9	10.5	18.2	22	30	–	–	–	–	–	0.12	96.1	102
A2X5-B22	3.3	2.4	15.0	19.5	40	43	0.20	0.04	0.09	0	0.05	0.38	124	57.7
A2X5-BC	3.0	1.9	17.0	18	82	87	0.26	0.07	0.25	0.06	0.06	0.70	193	31.6
A2X5-C	2.6	1.5	32.0	46	183	220	0.65	0.07	0.96	0.09	2.03	3.80	171	19.1
TL1-B23	3.2	2.1	22	28	73	79	0.27	0.05	0.08	0.06	0.11	0.57	175	64.0
TL1-BC	2.5	1.3	45	56.8	237.5	248	0.80	0.14	0.61	0.14	1.47	3.16	164	29.1
TL1-C1	2.4	1.5	58	80	311	338	1.11	0.11	1.12	0.20	2.01	4.55	40.7	64.7
TL2-B2	3.4	2.9	11.8	–	12	15	0.26	0.11	0.10	0	1.92	2.92	154	158
TL2-BC	2.7	1.8	14.5	24	72	95	0.47	0.17	0.66	0	0	1.20	141	147
TL2-C	2.8	1.8	10	18	118	131	0.37	0.16	1.11	0.10	1.47	3.11	137	203

A1.3 Samples from Indonesia (Berbak, east Sumatra) Profile descriptions

Sample number	Horizon	Depth	
1-83844	IG	75- 85 cm	peat
83845	IIG	110-120	unripe clay, org. mat.
83846	IIICg	180-200	half-ripe clay, glauconite
2-83847	IG	270-280	peat
83848	IIG	300-310	unripe clay, org. mat.
83849	G	350-360	sediment
3-83850	G	70- 80	peat
83851	G	90-100	unripe clay, org. mat.
83852	G	140-150	sediment
4-83854	G	100-110	unripe clay, org. mat.
83855	G	140-150	sediment
5-83856	G	20- 40	unripe clay, org. mat.
6-83857	G	250-350	unripe clay, org. mat.
83858	G	400-450	sediment
7-83859	IG	310-320	peat
83860	IIG	340-400	–
83861	G	430-460	–
8-83862	G	650-700	peat
10-83864	G	120-140	unripe clay, org. mat.
83865	G	180-200	unripe clay, org. mat.
83866	G	250-280	sediment
11-83867	IG	30-100	half-ripe clay, org. mat.
83868	IIG	150-180	almost-ripe clay, org. mat.
83869	G	210-230	half-ripe clay
83870	G	340-350	sediment
12-83872	IG	80-130	half-ripe clay
83873	IIG	300-350	sediment, shell remains
14-83874	G	45- 60	half-ripe clay, org. mat.
83875	G	100-115	half-ripe clay, org. mat.
83876	G	240-250	sediment
15-83877	G	50- 90	half-ripe clay, org. mat.
83879	G	230-250	half-ripe clay
83880	G	230-250	half-ripe clay, org. mat.
16-83878	G	150-220	–

Annex 2
Manual of the field laboratory method for determination of total potential and actual acidity in acid sulphate soils

A2.1 Determination of total potential acidity

Principle of the method:
Oxidation of all reduced sulphur species in a soil sample, suspended in a sodium chloride solution (1 mol/liter) by hydrogen peroxide and subsequent determination of total acidity by quick titration with sodium hydroxide to pH 5.5.

Reagents:
- H_2O_2, 30%. (If stabilized hydrogen peroxide is used which contains some phosphoric acid, its acidity should be determined by quick titration with NaOH);
- NaOH solution, 0.50 mol/l;
- NaCl solution, approx. 1 mol/l (i.e. a saturated NaCl solution containing about 6 mol NaCl/l, diluted 6 times).

Equipment:
- Glass beaker (400-1000 ml);
- Stirring bar;
- Waterproof pen;
- (Field) pH meter;
- A buret or two plastic hypodermic syringes without needles (one of 1 ml, one of 5 ml);
- A volumetric sampling cylinder (or a balance).

Sample material:
- Field-moist or dried soil.

Procedure

Put a soil sample of known volume (V cm^3) or mass (W gram) into a glass beaker. Add about 5 times V (for volumetric sample) or 2.5 times W (for bulk sample) ml of the sodium chloride solution and homogenize. Mark the height of the suspension surface to the outside of the beaker. Add a small quantity of hydrogen peroxide. Take care with samples rich in organic matter or manganese: they may effervesce strongly. Wait for about one hour, add a new quantity of hydrogen peroxide. Swirl the suspension around from time to time. Repeat additions of hydrogen peroxide until the liquid above the suspension becomes clear and there is no foam anymore at the liquid surface and no faom is formed upon further addition of H_2O_2. Leave overnight. (The oxidation process may be accelerated by putting the glass beakers on a warm waterbath or exposing them to the sun). Oxidation is complete if the organic matter of the soil material has lost its dark appearance, if the mineral soil has got a clear gray to clear light brown colour and if the liquid above the settled suspension has become clear and transparant: then there is no foam any more at the surface of the solution and the

Results of titrations and of chemical analyses

Sample number horizon	pH fresh	pH after oxid.	Acidity and pH				Sulphur species (mass %)				CEC and total bases (ionic equivalents-mmol/kg)	
			total act.acid.		total pot.acid.		before oxidation		after oxidation			
			(mmol H^+/100g soil)				pyrite S	total S	pyrite S	total S	CEC	total bases
			quick	48h	quick	48h						
83844	2.9	5.4	30	83	2.0	0	0.23	0.38	–	49.1	–	–
845	3.8	4.3	3.8	6.9	4.7	7.1	0.22	0.24	–	1.14	167	111
846	4.2	2.5	2.8	6.3	47.9	53.3	0.83	0.86	–	28.2	212	161
847	3.6	6.3	23	74	0	0	0.24	0.44	–	54.8	–	–
848	4.5	2.1	2.1	4.8	75.0	86.7	1.06	1.03	–	3.78	189	171
849	6.0	3.2	0	0	41.9	47.9	0.72	0.81	–	1.89	210	192
850	3.6	4.2	53	117	31.0	27.0	0.24	0.27	0.05	41.1	–	–
851	4.6	2.7	2.3	6.3	44.1	51.1	0.72	0.63	–	6.66	237	163
852	5.5	2.8	0	0	50.0	56.7	1.11	1.10	–	2.77	220	200
854	4.8	3.1	1.6	4.7	42.7	52.2	0.86	0.87	0.04	2.64	208	188
855	6.9	4.9	0	0	3.0	8.5	0.91	1.00	0.03	2.29	221	276
856	7.6	2.6	0	0	50.6	61.5	1.28	1.29	–	1.96	121	785
857	3.5	1.7	12.6	20	193	226	2.53	4.17	0.13	6.74	207	56.2
858	6.2	1.9	0	0	136	146	2.30	2.56	–	1.83	199	198
859	3.0	3.4	19	71	149	146	0.15	0.61	–	33.3	–	–
860	3.6	2.1	13.9	32.4	136	151	0.70	0.96	0.01	20.6	300	17.0

861	4.5	1.5	2.9	7.8	196	216	2.60	3.24	–	6.00	239	149
862	2.8	4.6	45	81	34.8	44.8	0.24	0.59	–	83.3	–	–
864	3.7	1.7	10.0	15.4	155	165	2.71	2.62	–	10.1	231	52.6
865	3.7	2.2	10.4	15.7	70.7	76.7	0.92	0.96	–	2.95	178	41.9
866	3.9	2.0	4.1	9.0	102	114	1.86	1.77	–	0.25	249	121
867	3.1	2.9	12.8	20.0	57.1	65.5	0.71	1.16	0.02	5.12	132	185
868	6.7	1.9	0	0	90.7	119	1.28	1.90	–	3.26	150	477
869	7.2	1.6	0	0	144	178	3.05	5.05	0.16	5.81	145	386
870	7.4	1.7	0	0	152	168	2.85	3.30	–	3.20	154	448
872	3.6	3.6	7.0	10.6	10.4	13.0	0.10	0.50	–	1.23	161	83.6
873	7.8	3.4	0	0	14.7	21.5	0.91	0.93	–	8.69	215	508
874	5.5	2.2	0	0	55.6	62.9	0.39	0.42	–	5.24	158	265
875	4.5	1.8	4.7	10.5	98.0	137	1.93	3.36	0.07	7.26	164	281
876	7.2	2.3	0	0	69.3	76.8	1.54	2.00	–	0.83	168	284
877	4.9	2.0	2.0	7.4	71.9	99.8	0.92	1.44	–	14.4	125	631
878	6.1	3.0	0	0	65.9	76.4	1.21	1.33	–	3.55	197	410
879	5.5	1.5	0	0	355	387	3.61	5.62	0.27	11.4	195	595
880	5.1	3.9	2.4	3.9	26.7	34.0	0.62	1.15	0.06	21.3	83.9	1157

colour of the supernatant may be anything from colourless to tea brown. Adjust the volume of the suspension to the marked level or, in case the volume is larger, and if possible, evaporate excess water. Add a few drops of hydrogen peroxide to the suspension and homogenize. Measure and note the pH of the suspension. If the pH is below 5.5, titrate the suspension as follows: add exact and know quantities (1.0, 5.0 or 10.0 ml) of the NaOH solution. Homogenize well after each addition and insert the pH electrode into the suspension. After the pH stabilizes, note the pH as well as the quantity of NaOH added. Addition of NaOH solution is to be continued until a pH over 5.5 is reached. Draw a titration curve by plotting the cumulative volume of added NaOH against the pH. Read the amount of NaOH at pH 5.5 from the graph (= B ml). Total potential acidity of the soil is calculated from the following equations:

Total potential acidity (on a volume basis)

$$= 1.1 \times 0.5\,B \times \frac{1000}{V}\ \mathrm{mol/m^3\ soil}$$

$$= 550\frac{B}{V}\ \mathrm{mol/m^3\ soil}\cdot$$

or

Total potential acidity (on a mass basis)

$$= 1.1 \times 0.5\,B \times \frac{100}{W}\ \mathrm{mmol/100\ g\ soil}$$

$$= 55\frac{B}{W}\ \mathrm{mmol/m^3\ soil}$$

The latter equation gives acidity for the soil as analyzed, field-moist or freeze-dried.

In order to determine the total potential acidity on an absolute dry mass basis, the moisture content of the soil sample has to be corrected for. To determine the absolute dry mass, take a small quantity of the soil sample and dry it for 24 h at 105 °C. After cooling (preferably in an exsiccator), weigh again and calculate the correction factor C and total potential acidity as follows:

$$\text{correction factor } C = \frac{\text{moist mass}}{\text{dry mass}}$$

total potential acidity (on an absolute dry mass basis)

$$= 55\frac{B}{W} \times C\ \mathrm{mmol/100\ g\ soil}$$

If after oxidation the pH of the soil suspension equals or exceeds 5.5, the total potential acidity of the soil is zero at pH 5.5.

Remarks

1. Soil samples rich in organic matter may effervesce strongly and give rise to formation of foam. In such cases use high beakers and add hydrogen peroxide in small

quantities (5 ml each time), especially in the beginning. Add further amounts of H_2O_2 only after effervescence ceases;

2. For the determination of potential acidity it is crucial that the soil sample is oxidized completely, especially if it is rich in organic matter. After complete oxidation, nothing will be left of the soil organic matter, except for some fresh roots, wood remnants, etc. The supernatant solution may have a dark brown colour after oxidation, but it should be clear and transparant after the suspension has settled;
3. The total amount of hydrogen peroxide needed for the oxidation depends on the organic matter content of the soil: for the oxidation of a 10 g soil sample, about 20 ml of hydrogen peroxide will be required for soil material poor in organic matter, and up to about 80 ml of H_2O_2 for peat samples;
4. Also, some of the samples poor in organic matter may show a strong effervescense after H_2O_2 addition and this may continue indefinitely even after all sulphur species and organic matter has been oxidized and the colour of the soil has become bright. This effervescense is due to the presence of manganese oxides. MnO_2 acts as a catalyst in the decomposition of H_2O_2. As soon as the mineral soil becomes bright coloured, the liquid of the soil suspension becomes clear or, after the H_2O_2 has ceased to work and no foam is seen at the surface of the suspension, oxidation is complete.

A2.2 Determination of total actual acidity

Principle of method:
Determination of the total actual acidity of the soil by quick titration of a soil sample, suspended in a sodium chloride solution (1 mol/liter) with sodium hydroxide to pH 5.5.

Reagents:
- NaOH solution, 0.50 mol/l;
- NaCl solution, approx. 1 mol/l (i.e. a saturated NaCl solution, containing about 6 mol NaCl/l, diluted 6 times).

Equipment:
- A glass beaker (400 – 1000 ml);
- Stirring bar;
- (Field) pH meter;
- A buret or two plastic hypodermic syringes without needles (one of 1 ml, one of 5 ml);
- A volumetric sampling cylinder (or a balance).

Sample materials:
Field-moist soil, packed air-free and analysed, or at least vacuum-dried or freeze-dried, as soon as possible after sampling to prevent oxidation.

Procedure

Put a soil sample of known volume (V cm^3) or mass (W gram) into a glass beaker. Add about 5 times V or 2.5 times W ml NaCl solution and homogenize. Stir the suspension a few times. Leave overnight.

Measure the pH after stirring the suspension. If the pH is below 5.5 the suspension is titrated as follows. Add a known quantity (1, 5 or 10 ml) of the NaOH solution and homogenize. Insert the electrode and wait until the pH stabilizes. Note the pH, as well as the amount of NaOH solution added. Addition of NaOH is to be continued until a pH over 5.5 is reached. Draw a titration curve by plotting the cumulative volume of NaOH solution added, against the pH. Read the amount of NaOH at pH 5.5 from the graph (= B ml). Total actual acidity of the soil is calculated from the equations:

Total actual acidity (on a volume basis)

$$= 905 \times \frac{B}{V} \text{ mol/m}^3 \text{ soil}$$

Total actual acidity (on a absolute dry mass basis)

$$= 91 \times \frac{B}{W} \times C \text{ mmol/100 g soil}$$

in which C is the correction factor for the moisture content of the soil:

$$\text{correction factor } C = \frac{\text{moist mass}}{\text{dry mass}}$$

and which is obtained by the procedure as described in Section A2.1.

A2.3 Volumetric soil sampling

For the determination of the acidity of the soil it saves time and effort if volumetric soil samples are taken, instead of bulk samples. From the acidity of field-moist samples on a volumetric basis, the amount of acid per hectare per unit of depth can be calculated directly. Also, with volumetric sampling there is no need for a balance or for determination of the soil moisture content.

Volumetric sampling can easily be conducted with a tube sampler made out of hard PVC pipe. Because of the weak consistency of most (potential) acid sulphate materials, this PVC pipe is suited for the purpose. The sampler can be produced easily and cheaply (fig. 5). A 5-cm piece of pipe (internal diameter about 6 cm), is the sampling tube. A 2-cm piece of the same pipe allows excess sample to move beyond the end of the sampling tube, during insertion into the soil. These two pieces are held in a close-fitting tube of the same material with an internal ring or constriction. Such a holder may be available ready-made in the form of a connecting piece for PVC tubes. If not, it can be constructed by glueing two rings of the appropriate sizes together.

The sampling procedure is as follows: the sampling cylinder is placed on a soil surface that is cut smooth and flat with a spade. The side from which the longer tube sticks out, rests on the soil. A piece of wood is placed on the cylinder and by hammering on it the cylinder is driven into the soil until only the narrower end of the connection pipe sticks out. Then the whole apparatus is dug out carefully. The soil sticking out from the cylinder is cut off level. The soil sampling tube (the longer one) filled with soil is removed from the connector by twisting it. On the other side of the cylinder the soil is cut of level and the sample is ready. The volume of the sample can be calculated from:

$$\text{Volume } V = R^2 \times H$$
$$= 3.14\, R^2 \times H\ (\text{cm}^3)$$

in which H = height of the sampling cylinder (in cm); R = 1/2 internal diameter of the cylinder (in cm).

Another cheap sampling device can be easily made from a large transparant plastic syringe. The tapered end of the syringe is cut off. On the outside measuring marks are made to mark, for instance, a volume of 10 or 20 ml. (Figure 6).

The soil is cut to a smooth and level surface. The sampler is pushed into the soil with the open end downward until over the measuring mark. The sampler is then dug out carefully and the soil sticking out is cut of level. With the aid of the plunger the soil sampler is transferred into a plastic bag or directly into a beaker. The volume of the sample can again be calculated from:

$$\text{Volume } V = 3.14\, R^2 \times H\ (\text{cm}^3).$$

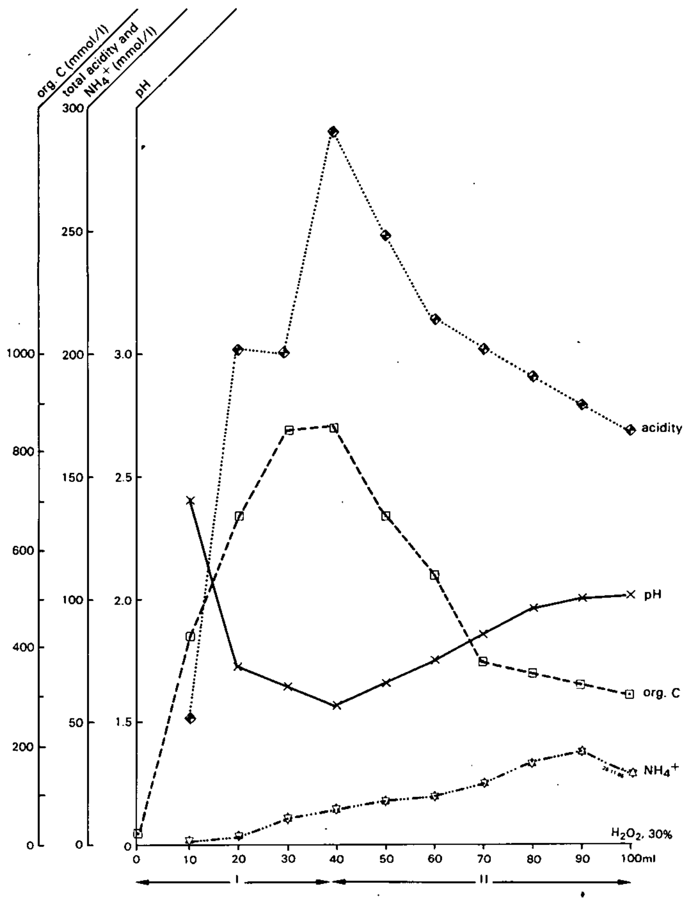

Figure 1 Total acidity, pH, organic carbon and ammonium in the clear supernatant of a suspended peat sample (ZP-G2, refer to text), after oxidation with increasing amounts of hydrogen peroxide

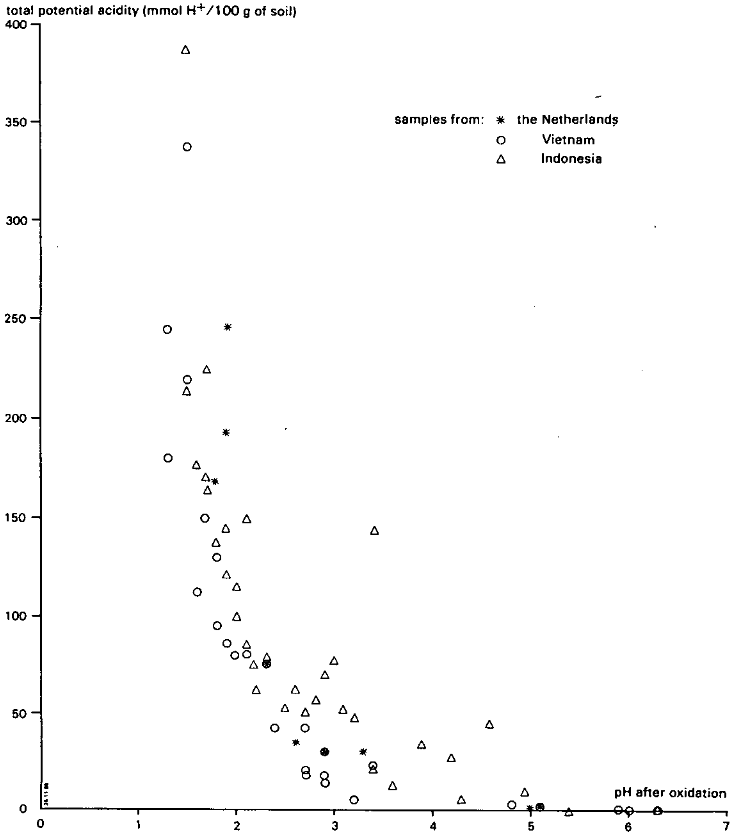

Figure 2 Relation between pH and total acidity of various samples, after oxidation by hydrogen peroxide

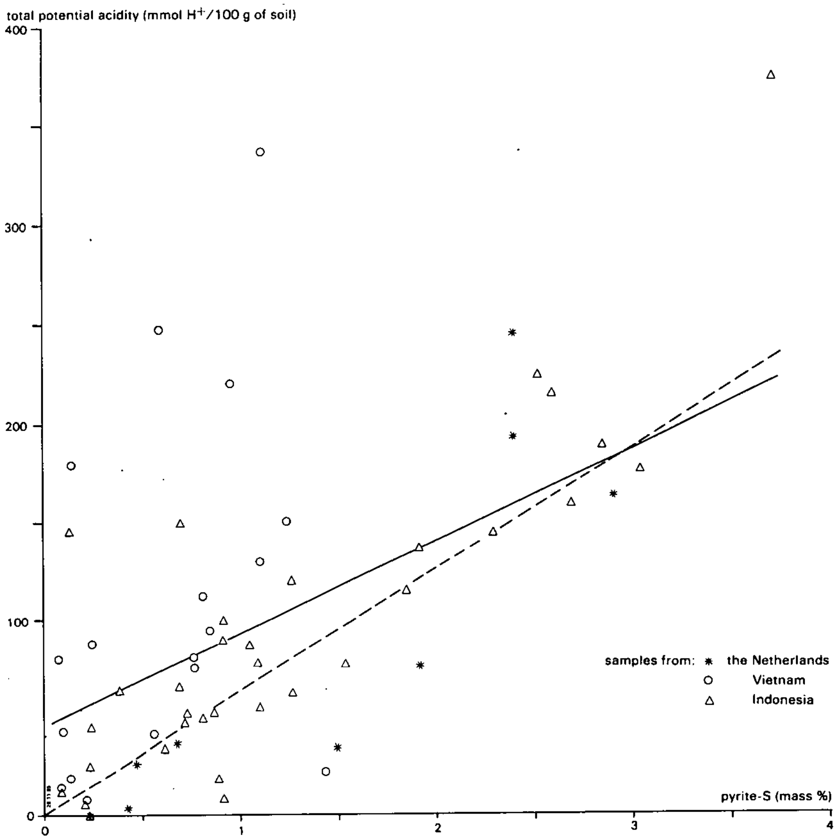

Figure 3 Relation between pyrite-S content and total potential acidity of various samples. Dashed line: theoretical relation according to reaction $FeS_2 + 15/4O_2 + 7/2H_2O \rightarrow Fe(OH)_3 + 4H^+ + 2SO_4^{2-}$ ($y = 62.4\,x$). Solid line: regression line ($y = 47.7\,x + 43.9$); $n = 34$; $r^2 = 0.20$)

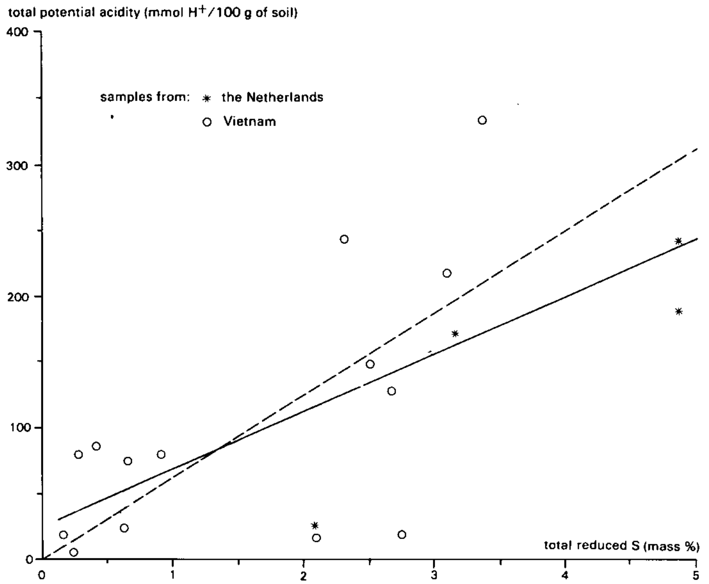

Figure 4a Relation between total reduced S content and total potential acidity of various samples. Dashed line: theoretical relation assuming complete oxidation and formation of maximal acidity. Solid line: regression line ($y = 43.9\,x + 25.4$; $n = 23$; $r^2 = 0.47$

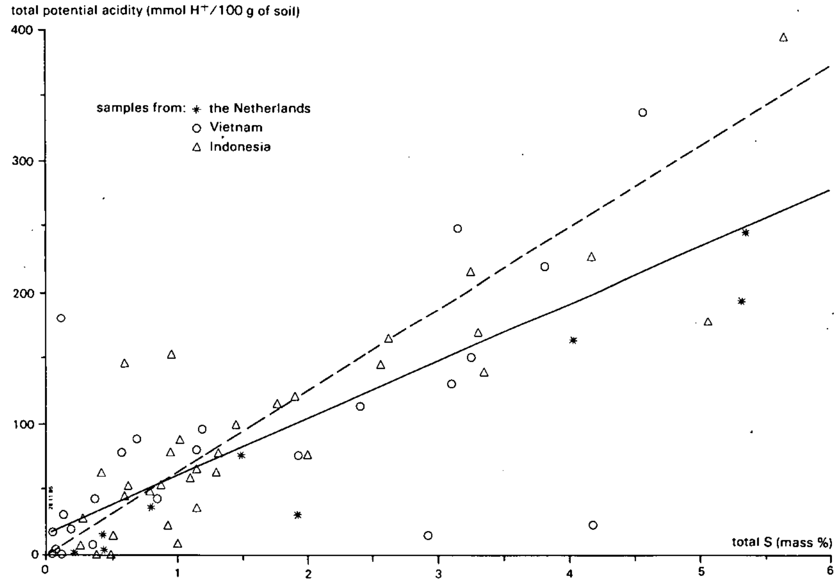

Figure 4b Relation between total S content and total potential acidity of various samples. Dashed line: theoretical relation as in Figure 4a. Solid line: regression line ($y = 43.9\,x + 16.4$; $n = 70$; $r^2 = 0.64$)

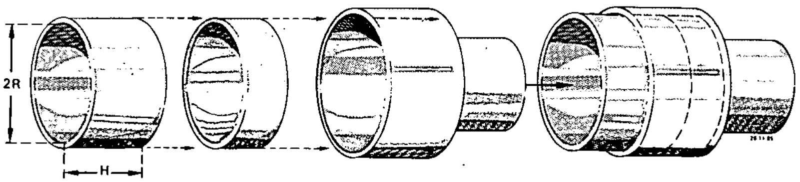

Figure 5 Volumetric soil sampler, made from pieces of PVC tube. (R = $^1/_2$ internal diameter; H = height of tube)

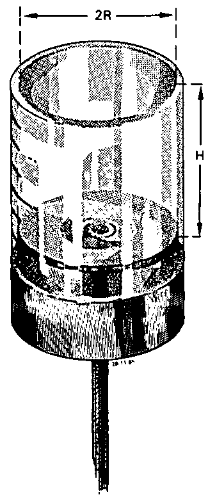

Figure 6 Volumetric soil sampler, made from a plastic syringe. R = $^1/_2$ internal diameter; H = distance between open end of tube and measuring mark

The evaporation and acidification process in an acid sulphate soil

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1 Summary

Fourteen undisturbed soil columns of 20 cm in diameter and 70 cm length from an acid sulphate soil in Mijdrecht, Netherlands were used to study the acidification process upon drying. Two groundwater levels: 40 cm and 65 cm below the soil surface, 5 different durations of evaporation and 2 agronomic practices were imposed.

Among treatments, averaged total acidity over 14 layers in the soil profile did not show much variation as the cumulative evaporation increased. The depth of the acidity maximum in the soil profile with low groundwater varied with the presence or absence of peat on the surface. Without peat, the total acidity maximum in the soil profile was about 35 – 40 cm below the surface, with a thin peat layer, they remained about 10 cm deeper.

The presence of peat layer on the surface reduced the rate of acidification, presumably mainly by reducing evaporation rate and perhaps by reducing the input of oxygen in the soil profile.

The average pH value over 14 layers along the soil profile decreased as the depth of groundwater increased from 40 to 65 cm. In treatments with a low groundwater table, the average pH decreased sharply with increasing evaporation: to about 3.5 after 140 mm of evaporation. The decrease was less drastic where groundwater remained high. Mulching or plowing at the start of a dry season to reduce the flux of solutes by capillary movement and maintaining the water table as high as possible to reduce oxidation may be a good management practices in acid sulphate soils.

Résumé

14 Colonnes des sols en structure naturelle, d'un diamètre de 20 cm et une longueur de 70 cm ont été prélevés d'un sol sulfaté-acide de Mijdrecht, Pay-Bas, dans le but d'étudier les processus d'acidification consécutifs au séchage.

Deux profondeurs de la nappe aquifère (à 40 cm et à 65 cm), cinq différentes durées d'évaporation et deux pratiques agricoles ont été expérimentées.

Parmi ces traitements, l'acidité totale moyenne des 14 colonnes, n'a pas montré beaucoup de variation avec l'augmentation de l'évaporation cumulative. La profondeur de l'acidité maximale dans le profil à nappe aquifère profonde, a varié en fonction de la présence ou de l'absence d'une couche de tourbe à la surface. Sans tourbe, le maximum de l'acidité totale a été jusqu'à environ 35-40 cm de profondeur. Avec un couche mince de tourbe elle s'est résumée à rester seulement à environ 10 cm de profondeur.

La présence de la couche de tourbe à la surface réduit la vitesse d'acidification, vraisemblablement surtout par le réduction de la vitesse de l'évaporation et peut-être aussi par la réduction de l'intrant de l'oxygène dans le profil du sol. La valeur pH moyenne sur les quatorze couches le long du profil du sol a été diminuée si la profondeur de la nappe aquifère a augmente de 40 à 65 cm. Dans les traitements à nappe aquifère profonde, la moyenne des valeurs pH a diminué d'une manière tranchante avec l'augmentaion de l'évaporation (jusqu'à 3,5 après 140 mm d'évaporation). La diminution a été moins drastique si la nappe aquifère est restée élevée. Le mulch ou le labour au début de la saison sèche, éffectués dans le but de reduire le flux de sels par ascension capillaire ainsi que la maintenance de la nappe aquifère à une profondeur aussi haute que possible, peuvent être des pratiques d'améliorations valables dans les sols sulfaté-acides.

2 Introduction

The formation of acid sulphate soils results from the presence of sulphides, the introduction of aerobic conditions, and the lack of bases, usually calcium carbonate, to neutralize the acidity. Soils may become aerobic when they are drained for agriculture but also when there are seasonal changes in soil drainage, e.g. by a lowering of the groundwater table. Evaporation from bare soils may have the same effect owing to the loss of soil water. Evaporation may also cause accumulation of toxic salts in surface horizons because of upward capillary movement. Low pH, high acidity and accumulation of toxins can degrade the productivity of the soils. Results of field experiments about the effects of changes in groundwater level on the acidity of acid sulphate soils and on crop yields were reported by Beye (1973), Kanapathy (1973) and Yin and Chin (1982), but basic information about the effect of evaporation in the dry season is lacking. Field observation in Vietnam indicate that plowing in the dry season followed by leaching of salts accumulated just below the surface soil may depress the toxicity to crops in acid sulphate soils (Vo tong Xuan, personal communication).

The objective of this study was to determine the effects of groundwater levels and other factors related to the evaporation rate on the acidification process of an acid sulphate soil.

3 Materials and methods

An acid sulphate soil from Mijdrecht Polder in the Netherlands was used for this study.

The soil profile consisted of a thin (10 cm) peat layer, somewhat compacted, over 35 cm jarositic material, with a half ripe pyritic substratum. Before the experiment, the peat layer was removed except where stated.

In spite of the artificial drainage in the polder the acid sulphate soil has remained in its poorly drained condition, being protected by a 35 cm thick man-made soil cover. This was removed before sampling. Undisturbed soil columns were collected in 14 PVC pipes with 20 cm inside diameter and 70 cm length (Figure 1). One end of the PVC pipe was sharpened in order to have a good cutting edge. The procedure used

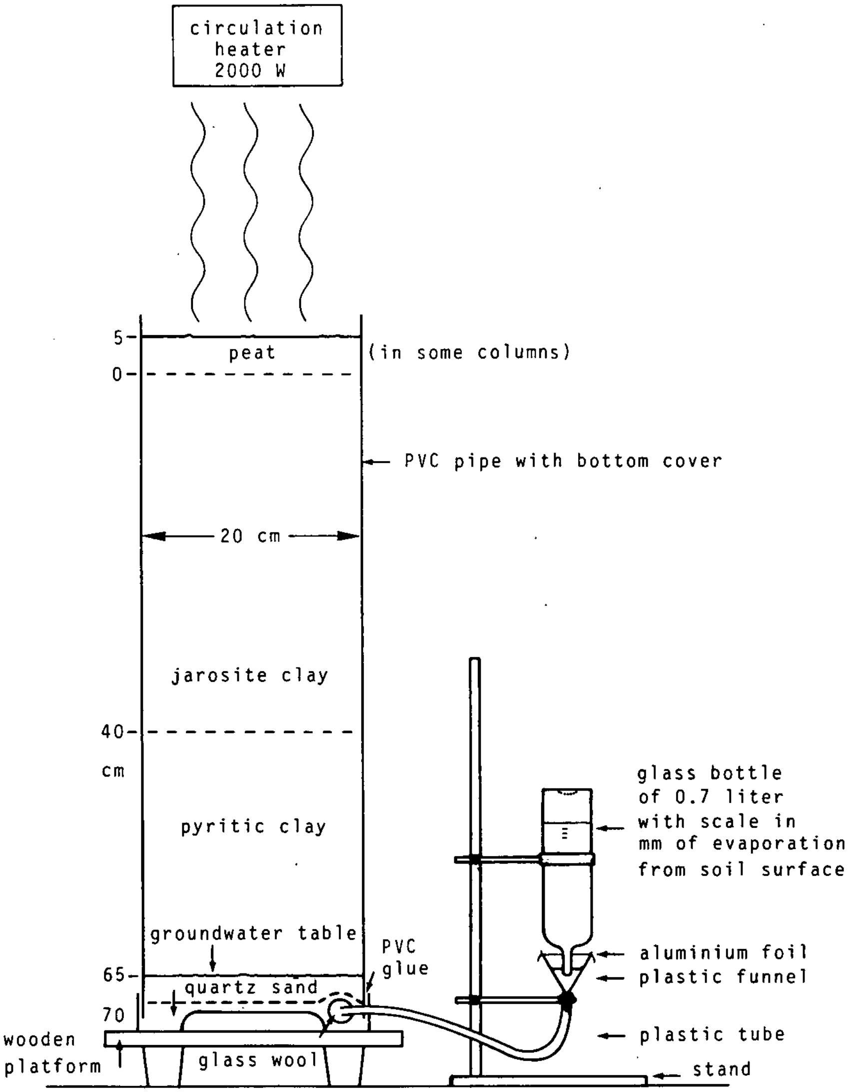

Figure 1 Cross-section of a soil column with low groundwater

in obtaining the columns was similar to that described by Le Ngoc Sen (1982). The columns were excavated in two rows close to each other in an area of 0.5 × 2 m (Figure 2). The filled PVC pipes were tied with rope, turned 45 degrees 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 PVC cover placed over the top of the column, which was then inverted and kept wet during transport. In the laboratory, a 1.5 cm layer of soil was removed from the bottom of the pipe, replaced by quartz sand and connected with a plastic tube through a bored hole at the side. The end of the plastic tube inside the pipe was covered with glass wool and the other

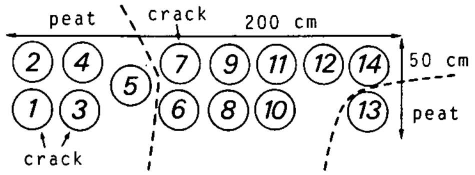

Figure 2 Place of soil columns in the original soil

end connected with a source of water to regulate the groundwater table in the profile (Figure 1). A PVC cover was then sealed to the bottom of the pipe with PVC glue, the column replaced in its original position and the top cover was removed. Two of the fourteen columns were used as controls and were sampled at the beginning of the experiment. The remaining ones were arranged at random (Figure. 3). Two electrical circulation heaters of 2000 watts placed at 0.50 meter above the surface of the columns increased the evaporation rate.

The depths of ground water were maintained at 40 and 65 cm below the soil surface. Different combinations of treatments were imposed (Table 1). The high groundwater level, 40 cm below the surface was chosen to saturate the pyritic horizons, which started at about that depth. The low groundwater level, 65 cm, should allow some oxidation in the upper part of the pyritic horizons.

Table 1 Characteristics of different soil columns

Column number	Groundwater level (cm)	Duration of evaporation (weeks)	Plowing surface soil	Presence of peat on surface	Presence of jarositic crack
1	65	14	yes	yes	yes
2	65	10	no	yes	no
3*	–	–	no	yes	yes
4	65	15	no	yes	no
5	40	7	no	yes	no
6	65	10	no	no	no
7	40	14	no	no	yes
8	65	5	no	no	no
9	65	14	yes	no	no
10	65	15	no	no	no
11	40	14	no	no	no
12*	–	–	no	no	no
13	40	7	no	yes	no
14	65	5	no	no	no

* control column

At the end of a run, the bottom of each pipe was removed and the pipe itself cut into two along the profile by electric saw. The columns were then sectioned into 5 cm segments. In each segment, two samples of 25 ml were taken with the aid of a PVC auger of 5 cm diameter and placed in plastic bottles, then mixed with 100 ml demineralized water, shaken for one hour and centrifuged for 30 minutes at 3000 rpm.

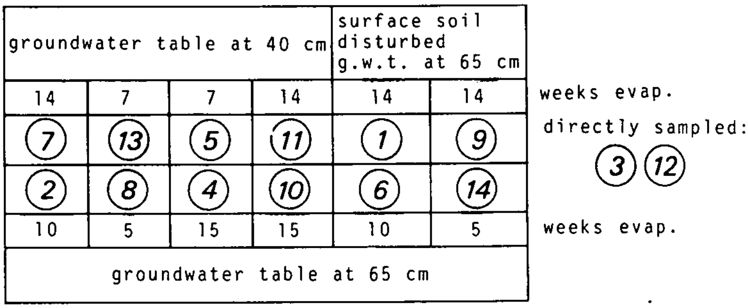

Figure 3 Arrangement of soil columns in the laboratory

In the supernatant EC and pH were determined electrometrically.

Total acidity was determined by titration with 0.1 N NaOH to the end point by phenolphtaleine as indicator. Total acidity comprises three kinds of acid: H^+, Al^{3+} and Fe^{2+}. The former is neutralized directly during titration, Al^{3+} is hydrolyzed to $Al(OH)_3$ releasing $3H^+$; and Fe^{2+} is oxidized in the mechanically stirred solution during titration, producing $Fe(OH)_3$ and $2H^+$. Vertical moisture distribution was determined along all profiles except for the control columns 3 and 12. Bulked samples over 10 cm depth increments were freeze-dried for sulphur fractions and other chemical analyses, according to Begheijn (1980). Samples of columns 4 and 10 were collected in 100 ml aluminium rings for bulk density determination. In supernatants of columns 4, 10 and 11, determinations of Ca, Mg, Na, K, Fe, Cl, NO_3, SO_4 and HCO_3^- were made additionally. Except for HCO_3^-, which was determined by organic carbon analyzer after centrifugation, these determinations were made on solutions stored in the refrigerator for 2 weeks after adding a few drops concentrated HCl.

Some of the water samples from columns 4, 10 and 11 were also analyzed for Ca, Fe, Mg by atomic spectrophotometer; Na and K by atomic emission spectrometer; Al by spectrophotometer with pyrocatechol violet; Fe, Cl, NO_3 and SO_4^{2-} by ion-chromatography.

Freeze-dried samples of columns 3, 4, 10 and 12 were used to determine CEC, Ca, Mg, Al and total acidity, and freeze-dried samples of columns 2, 3, 8, 12 and 10 for sulphur fractions.

4 Results and discussion

4.1 Evaporation

The evaporation rate appeared to be influenced by the level of the groundwater table, by disturbance of the surface soil and by the presence of peaty layer on the surface. The evaporation rate was about 1.5 to 2.1 mm per day with a high groundwater table and about 0.7 to 1.5 mm per day with a low groundwater table (Table 2). This amounts to about 30 – 60 percent of the evaporation from a free water surface measured in the experiment (3 mm/day). The presence of a peaty layer on the surface decreased the evaporation rate by about 50 percent compared with the columns without peat. Disturbance of the upper 10 cm decreased the rate by about 20 percent.

Table 2 Evaporation rate, average soil moisture, EC, pH, total acidity and basic cations of different soil columns

Column number	Evaporation rate (mm/day)	Averaged* soil moisture (mass %)	Averaged EC (ms/cm)	Averaged pH	Averaged total acidity (mol/cm^3)	Averaged basic cations (mol/m^3)
1	0.82	85	0.93	3.95	1.71	11.5
2	0.66	102	1.02	3.97	2.07	12.8
3	0.00	-**	0.79	3.78	1.04	9.2
4	0.73	94.	1.11	3.96	2.50	14.0
5	1.47	88	1.03	4.19	2.12	12.9
6	1.37	92	1.16	3.77	3.01	14.4
7	1.69	93	0.97	3.90	1.78	12.0
8	1.28	87	1.28	4.04	3.44	16.2
9	0.99	88	1.60	3.70	11.84	13.8
10	1.19	85	1.89	3.61	16.96	14.0
11	1.61	92	1.11	3.93	4.56	11.9
12	0.00	-**	0.82	4.25	1.74	10.0
13	2.14	92	0.97	4.15	1.77	12.2
14	1.54	95	1.06	4.16	2.16	13.3

* Averaged value of 7 layers in the soil column
** Not determined

4.2 Sulphur fractions

Four columns subjected to different durations of evaporation were selected for sulphur fraction analysis. Total S, pyrite, jarosite and water-soluble S are shown in Figure 4. In general, total S and pyrite of the four columns showed similar trends along the soils profile: both total S and pyrite increased with depth. The difference in total S and pyrite trends between the treated columns and a control (column 3) may be attributed to the strong microvariability of soil in the field. The lower pyrite content in column 3 is related to oxidation along a deep crack with a concentration of jarosite in this column; the low average jarosite and water-soluble S contents must have been the result of preferential leaching. Because of the variability between columns, even taken adjacent to each other, no quantitative calculation was made about the rate of oxidation and the results were studied by inividual columns.

4.3 The distribution of pH, total acidity, non-acid cations and soil moisture in different soil columns

The distribution of pH, total acidity, non-acid cations and soil moisture in water extracts of different soil columns is presented in Figure 5.

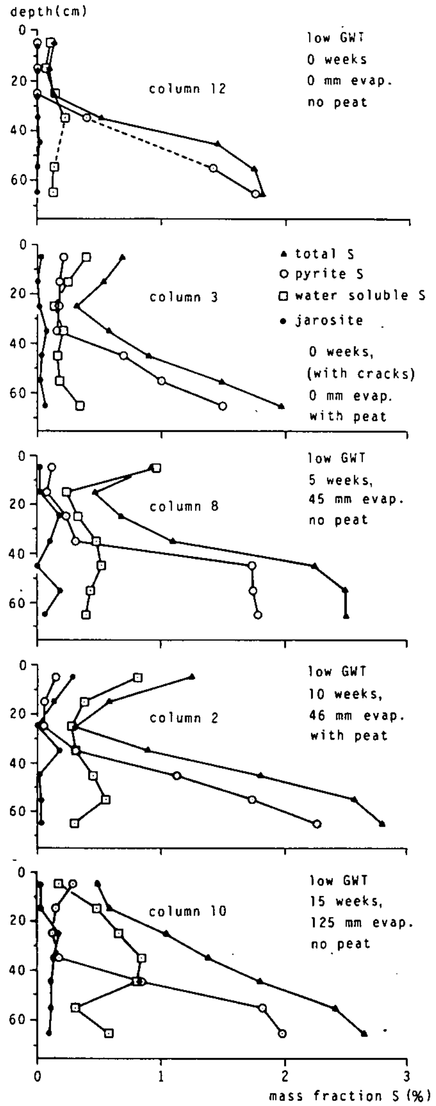

Figure 4 Sulphur fractions of five soil columns with low groundwater table

4.3.1 pH

In general, the pH of the water extract of samples from all columns showed the same trend along the soil profile (Figure 4): a slight decrease in pH during the first 50 mm of evaporation only in the 40 cm surface soil, followed by a drop of half a pH unit throughout the profile as evaporation increased. For columns with a low groundwater

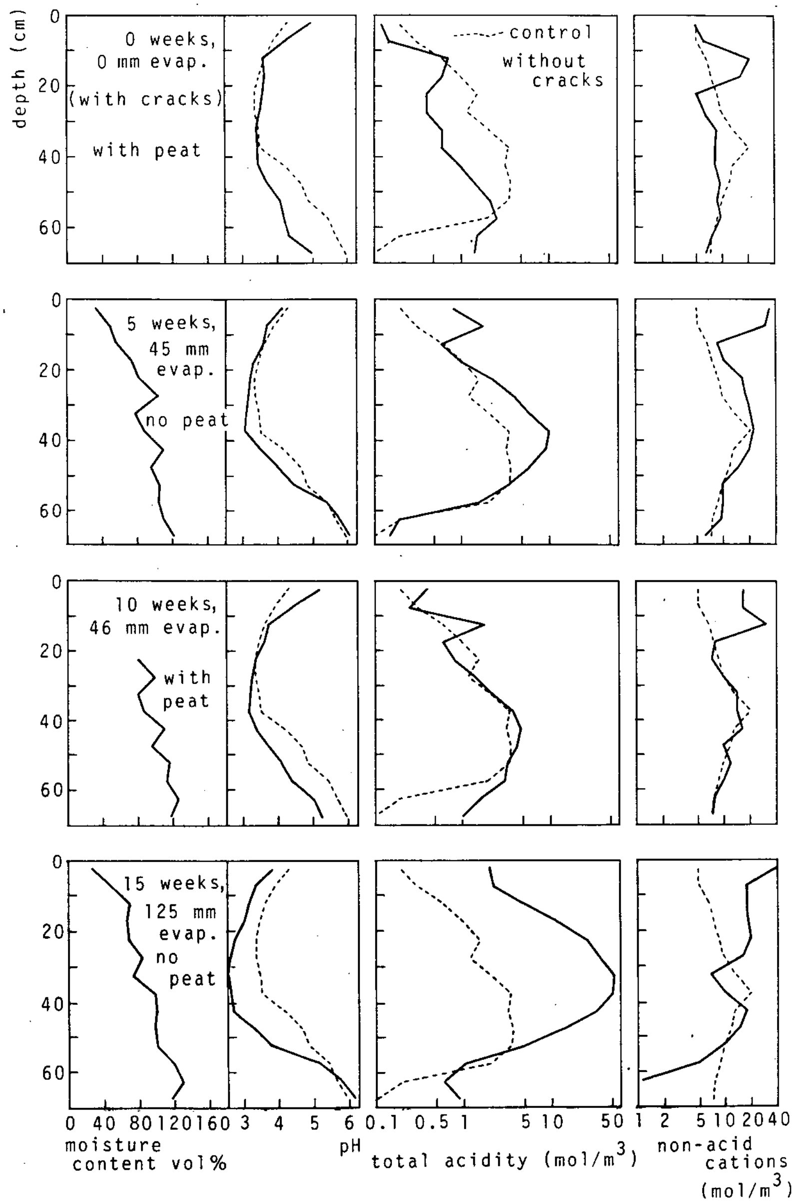

Figure 5 The distribution of soil moisture content and pH, total acidity, basic cations in water extracts of selected soil columns with groundwater at 65 cm depth

level the lowest pH values were observed at the pyrite-jarosite boundary at 35 to 40 cm; with high groundwater, about 5 cm higher (Table 4). This difference is attributed to the upward movement of acidity from the oxidation products of pyritic layers.

4.3.2 Total acidity

The total acidity of water extracts along the soil profile shows a clear picture with relatively small variations (Figure 5). Acidity maxima were found at 45 – 50 cm depth, just below the pyrite-jarosite boundary, in columns with low groundwater and a peaty layer on the subsurface; about 10 cm higher without peat (Table 4).

The position of total acidity maxima for both high and low groundwater treatments were higher in the profile compared with the control (Table 4). As the evaporation increased, more acidity was developed in the profile and the position of the total acidity maximum moved upward. The frequency distribution of the acidity maxima is shown in Figure 7 for low and high groundwater levels separately. Although there are few data points only, the peak concentrations of soluble acidity in the low groundwater treatments whithout peat appear to be far higher than with high groundwater. The total acidity of surface soil in treatments with a thin layer of peat was less than without peat.

For both groundwater levels, the average soluble acidity over the whole profile is about 3 mol/m_3 ($s = 0.3$).

A comparison between the controls with a jarositic crack and without cracks respectively shows that the subsoil in the column with a crack has a lower pH, but less total dissolved acid than the column without cracks; this may be ascribed to preferential movement of both-oxygen and leaching water into the subsoil along the crack under field conditions before the experiment.

Table 3 Averaged pH. EC, total acidity of the first 30 cm in the profile of different columns

Column number	pH	EC mS/cm	Average total acidity mol/m^3
1	4.05	0.95	0.75
2	3.90	1.05	0.89
3	3.92	0.76	0.38
4	4.00	1.15	0.99
5	3.59	1.24	1.27
6	3.49	1.16	1.19
7	3.54	1.08	1.13
8	3.51	1.36	1.77
9	3.31	1.50	5.57
10	3.10	1.98	13.88
11	3.37	1.26	2.94
12	3.64	0.64	0.79
13	3.79	1.14	0.83
14	3.62	1.08	1.04

4.3.3 Basic cations

In general, the soluble basic cations did not show much variation between treatments at depths of 25 to 55 cm (Figure 4). An increase in soluble non-acid cations was found in surface soil only as the evaporation increased. A sharp decrease in concentrations

Table 4 Depths of total acidity maximum and pH minimum

Column number	Groundwater table	Presence of peat	Depths, cm Total acidity maximum	pH minimum
1	low	+	45–50	35–40
2	low	+	40–45	35–40
4	low	+	45–50	40–45
Average	low	+	45–50	35–40
14	low	–	40–45	25–30
6	low	–	40–45	40–45
8	low	–	35–40	35–40
9	low	–	35–40	35–40
10	low	–	30–35	30–35
Average	low	–	35–40	35–40
13	high	+	45–50	25–30
7	high	–	50–55	30–35
5	high	+	40–45	25–30
11	high	–	30–35	35–40
Average	high	+ and –	40–45	30–35
3	control	+	55–60	30–35
12	control	–	45–50	25–30
Average	control	+ and –	50–55	30–35

of non-acid cations was found in soil horizons below 55 cm (Figure 4). Among the control columns, the surface soil of the cracked core has a higher concentration of basic cations; this is probably due to less leaching water passing through the surface soils near a crack than further away (short circuiting).

4.3.4 Soil moisture

As expected, the soil moisture contents of different layers along the profile increased with depth. In the half ripe subsoil the gravimetric soil moisture content of the lower layers exceeded 100 percent. The moisture distribution showed little variation among treatments. Disturbance of the surface layer allowed this layer to dry out (Figure 5), but did nor appreciably change the soil moisture distribution along the profile. The disturbed layer may not have been thick enough to decrease drastically the evaporation from lower horizons.

4.4 Changes of pH and total acidity of water extracts with cumulative evaporation

4.4.1 Average pH and total acidity over the profile

As the evaporation increased, the average pH of water extracts along the profile decreased (Figure 6a). In columns with a high groundwater table, the pH decreased slowly with increasing cumulative evaporation. It decreased sharply in columns with low groundwater. About 140 mm of evaporation in low groundwater treatments resulted in an average pH about 3.5. Except in three columns (9, 10 and 11), the average total acidity of water extracts over the profile did not show much variation with time (Figure 6b).

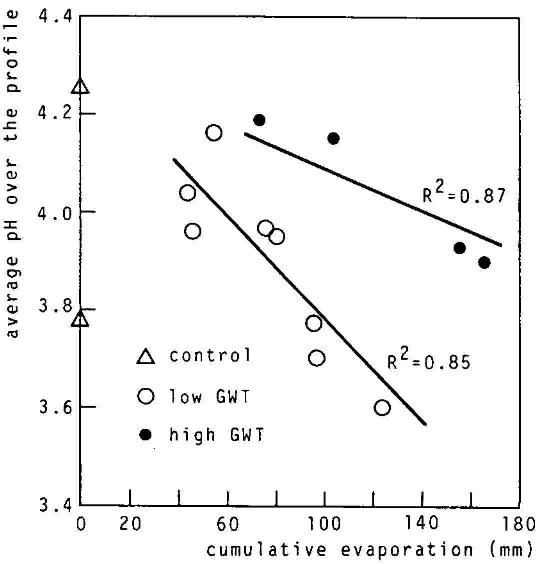

Figure 6a Average pH of extract over the profile in relation to cumulative evaporation

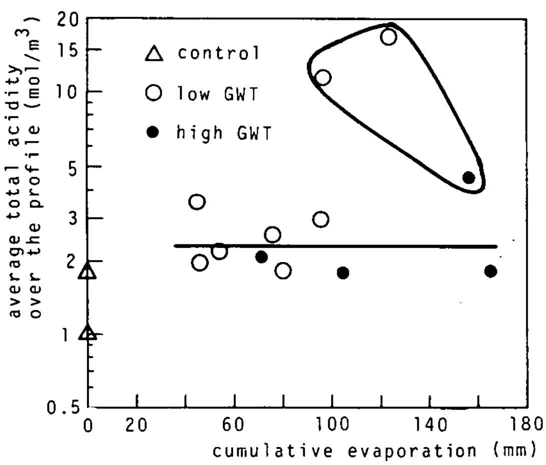

Figure 6b Average total acidity of extract over the profile in relation to cumulative evaporation

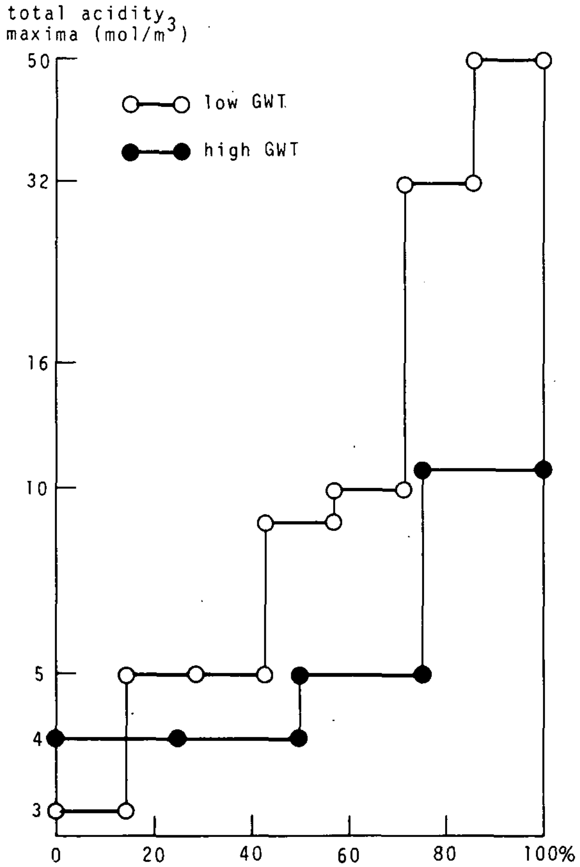

Figure 7 Frequency distribution of total acidity maxima of extracts in the profile

4.4.2 Average pH and total acidity of water extracts in the upper 30 cm

Regardless of groundwater table levels, the average total acidity over the upper 30 cm did not show much variation (Figure 8a, Table 3).

Average pH of surface soil for both groundwater treatments remained 3.5 until the cumulative evaporation exceeded about 100 mm (Figure 8b). After that, the pH tended to fall below 3.5.

5 General results and discussion

Average total soluble acidity over the soil profile did not show much variation with cumulative evaporation or with differences in groundwater levels or other factors related to the evaporation rate.

The position and magnitude of the soluble acidity maximum in the soil profile depends on the groundwater table and the presence of peat. A groundwater table below

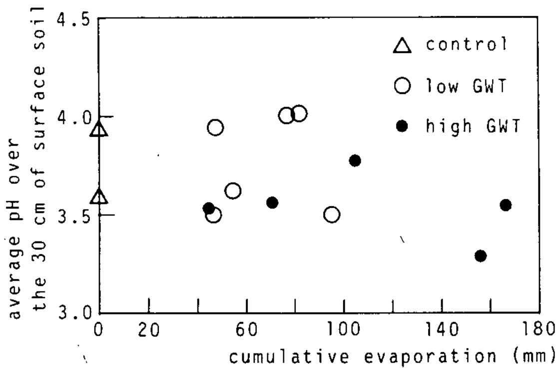

Figure 8a Average pH of extracts over the 30 cm of surface soil in relation to cumulative evaporation

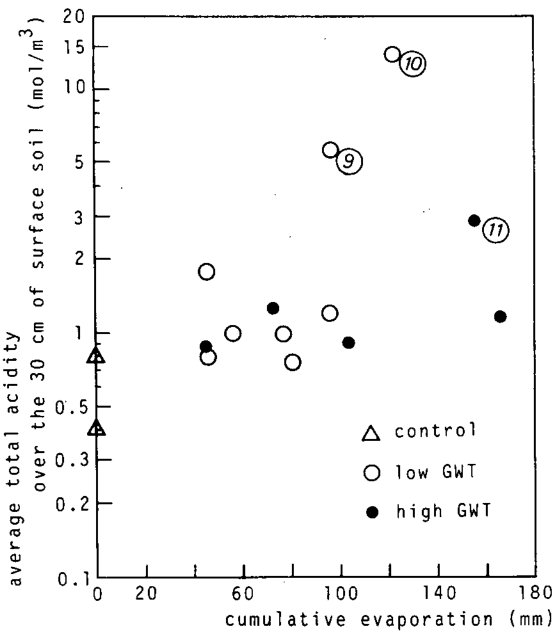

Figure 8b Average total acidity of extracts over the 30 cm of surface soil in relation to cumulative evaporation

the top of the pyritic layer apparently created conditions enhancing the oxidation of pyritic materials, resulting in high acidity maxima.

Hydrogen ions would be expected to move faster in the soil than Al (or Fe) ions because the diffusion coefficient of hydrogen is about three times higher than Al and Fe.

Changes of average pH over the soil profile with cumulative evaporation depended on groundwater depth. In high groundwater table treatment, pH gradually decreased with cumulative evaporation whereas it decreased sharply where groundwater table was low. The pH of the surface soil only started to drop after about 100 mm of evaporation, in both groundwater levels.

The average pH turned out to be a more sensitive indicator for the development of acidity during the 15-week period of evaporation than the average soluble acid concentration.

With longer periods and higher totals of evaporation, as would occur during the dry season in monsoon climates, pH is expected to become less diagnostic; average soluble acid over the profile and in the surface horizon should then become better indicators for the potential growth of crop plants.

Further research is needed to ascertain the critical amount of evaporation causing unacceptable acidification with different groundwater levels and different depths to pyritic material in the field and different agronomic practices.

Disturbance of 10 cm surface soil only lowered the evaporation rate by about 20 percent. Mulching at the start of the dry season would seem to be a promising management practice in acid sulphate soil, even though its effects in this experiment were small. Further work along this line is needed.

The presence of a peaty layer on the surface reduced the evaporation rate and the total soluble acidity in the soil profile. The peaty layer was relatively dense and slightly platy, however. After ploughing it would have been broken up and incorporated in the Ap horizon.

Because of the local variability of acid sulphate soils, only gross differences become apparent by traditional small-sample methods. The variability, as shown by the data in this study, consists of two parts: a limited variation about a mean, and some outliers indicating extremely acid, toxic or potentially toxic conditions. Therefore, sampling methods based on bulking even large numbers of subsamples do not fairly represent conditions in most of the soil mass.

Sampling methods should either be based on extensive replication, or depend on close observation and recording of soil differences over small distances, with interpretation of individual results in relation to the observed characteristics of each sample or profile. In either case, efforts should be made to estimate the frequency distribution of the different values encountered.

The present experiment represents about one month of unchecked evaporation from soils with shallow groundwater during the dry season of a monsoon climate. Therefore, it only shows the beginning of the acidification that bedevils rainfed wetland crop production on acid sulphate soils in such climates.

It is clear, however, that even at relatively low evaporation rates, a groundwater table below the top of the pyritic layer is far more dangerous than a high groundwater table, although this tends to accelerate evaporation and transport of existing acidity to the surface horizon.

Minimizing evaporation during the dry season appears to be the next most important management measure if acidification is to be minimized.

Acknowledgement

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Excessive iron uptake (iron toxicity) by wetland rice (Oryza Sativa L.) on an acid sulphate soil in the Casamance/Senegal

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1 . Summary

In order to evaluate the impact of the nutritional status of rice plants (in particular with respect to K, P and Ca) on the uptake of iron, a fields trial (with IR8) on a typical acid sulphate soil was carried out in South Casamance in cooperation with the Institut Sénégalais des Recherches Agricoles (ISRA) at Djibelor. In the experiment the effect of fertilization (N, N+P, N+K, N+Ca) on nutrient uptake (leaf analyses), the symptoms of Fe toxicity and the development of pH, Eh and Fe(II) concentrations in the soil solution of the rhizosphere were measured periodically throughout the vegetation period. The experimental site and other rice fields with severe Fe toxicity symptoms were characterized physico-chemically. In the untreated control, two peaks of intensive Fe(II) formation and -uptake occurred, one during the first week after transplanting (primary iron toxicity) and the second between heading and flowering (secondary IT). Fertilization (particularly P application) decreased Fe(II) uptake, which seemed to be governed neither by soil pH or redox potential nor by the Fe concentration in the soil solution. The phosphorus and potassium status of the plants, however, significantly affected the Fe contents of the leaves. Primary iron toxicity is explained by an apparent sensitivity of freshly transplanted rice seedlings to high amounts of Fe(II) accumulated just after flooding, while secondary IT may be ascribed to the excessive Fe(II) uptake caused by an increased root permeability (K deficiency) and enhanced microbial iron reduction in the rizosphere (intensive exudation) during the physiological active phase between heading and flowering. In terms of managament, rice seedlings should be transplanted only 5-20 days after flooding and well fertilized afterwards (particularly with P and K), if iron toxicity is to be eliminated.

Résumé

Afin d'évaluer l'impact de l'état de nutrition (particulièrement avec K, P et Ca) des plantules de riz sur l'absorption du fer, des essais au champ (avec IR8) ont été mis en place sur les sols sulfaté-acides typiques du sud de la Casamance. Ces essais ont été effectués avec la collaboration de l'Institut Sénégalais de Recherches Agricoles (ISRA) à Djibélor.

L'effet de la fertilisation (N, N + P, N + K, N + P + K, N + Ca) sur l'absorption d'éléments nutritifs (analyse des feuilles) ainsi que l'effet de la toxicité ferreuse sur le développement du pH, du Eh et du Fe(II) dans la rhizosphère, ont été évalués pendant toute la durée du cycle végétatif.

Le site expérimental, de même que d'autrès rizières où l'on avait relevé des graves symptômes de toxicité ferreuse, ont été caractérisés du point de vue physico-chimique.

Dans le cas du témoin non traité, deux périodes de pointe ont été observées dans la formation et l'absorption du Fe(II). Une, survenue au cours de la première semaine après le repiquage (toxicité ferreuse primaire) et la seconde, entre l'épiaison et la floraison (toxicité ferreuse secondaire). La fertilisation et particulièrement celle avec du phosphore, a diminuée l'absorption du Fe(II), qui semble n'être pas dirigé par le pH du sol ou le potentiel redox, et non plus par la concentration du fer dans la solution de sol. Pourtant, les quantités de phosphore et de potasium présentés dans les plantes, affectent d'une manière significative la teneur en fer des feuilles.

On explique la toxicité ferreuse primaire par une sensibilité apparente des plantules de riz fraîchement repiquées aux quantités élevées de Fe(II) accumulés immédiatement après l'inondation, tandis que la toxicité ferreuse secondaire, peut être attribuée à l'absorption excessive du Fe(II) provoquée par une plus grande perméabilité des racines (déficience en K) et une augmentation de la réduction microbiennes du fer dans la rhizosphere (intense exudation) pendant la phase de grande activité physiologique qui se situe entre l'épiaison et la floraison.

Dans la pratique, les effets nocifs de la toxicité ferreuse primaire peuvent être facilement evités par repiquage des plantules seulement 5 à 20 jours après la submersion. Cet interval varie d'un sol à l'autre, et dépend surtout de la vitesse de réduction microbienne du fer, qui est généralement directement proportionelle à la teneur en matière organique facilement décomposable. La toxicité ferreuse secondaire, peut être allégé par fertilisation, soit avec d'engrais minéraux (particulièrement phosphore et potassium), soit par incorporation de restes organiques, fumure et/ou cendre. Une fertilisation à niveau satisfaisant et répété, est nécessaire surtout sur les sols sulfaté-acides lessivés (qui commencent à s'oxyder dès qu'ils sont sechés et désalinisés après un lessivage intensif) ainsi que sur les Histosols oligotrophes fortement altérés. En fait, la toxicité ferreuse secondaire, peut être considérée comme 'une maladie de mise en culture' qui disparaît aussitôt que les sols sont régulièrement fertilisés (Japon).

2 Introduction

Disorders of wetland rice due to high iron uptake ('bronzing') may be encountered in nearly all rice producing areas of the world. In south Senegal this stress limits rice yields increasingly, particularly on the mangrove-derived soils (IRAT 1969). Farmers in these regions claim iron toxicity to be responsible for major yield losses during the past 15 years.

In the last decades several views have been discussed to explain the mechanism(s) of excessive Fe(II) uptake. Special attention, however, was paid to the role of low soil pH and/or high Fe(II) concentration in the soil solution (Howeler 1973; Ponnamperuma 1977; van Breemen and Moormann 1978). Other authors (Sahu 1968; Tanaka and Tadano 1972; Trolldenier 1977) considered potassium to be involved in the prob-

4 Results and discussion

4.1 IR8 performance in the field

The first IR8 seedlings were transplanted immediately after field inundation and a nearly total loss of plants occurred within a few days due to heavy iron toxicity. This damage was recorded irrespectively of fertilization. The iron contents of the leaves increased in one week from 156 to 3780 ppm. This period of iron intoxication (= primary iron toxicity) coincided with a very high Fe(II)-sol.

Transplantation was repeated 3 weeks later when Fe(II)-sol had decreased. These plants again suffered heavily from 'bronzing' as revealed by symptoms and increased Fe content of the leaves. However, losses were limited and dead plants were replaced 10 days later.

Only fertilization with P (in the treatments N+P and N+P+K) visually improved rice growth, diminished 'bronzing' and reduced Fe uptake. This effect was maintained throughout the whole vegetation period and resulted in significant (at 5% level) yield differences between P-fertilized and non-P-fertilized treatments. However, factors other than iron toxicity (rice borer attack, consumption of paddy by weaver birds and asynchronous ripening) affected grain yields considerably.

Highest mean paddy yield was obtained with N+P+K application (1100 kg/ha) while the treatment +N (with P+K only into the nursery) gave lowest results (160 kg/ha). Several plots had to be excluded from evaluation because they virtually yielded no rice. Although plants recovered quite well from primary iron intoxication, a second increase in 'bronzing' was observed beginning at heading.

4.2 Development of pH, Eh and Fe(II)-sol

The developments of pH and redox potential in situ (in 0-10 cm layer) are shown in Figure 1. The rapid decrease of the redox potential is accompanied by an increase of pH. No real differences between the treatments could be observed except that non-planted plots revealed less intensive microbial reduction processes as judged from lower pH- and higher Eh-values. Correspondingly, the Fe(II)-sol reached a higher level in planted plots over a long period (Figure 2). Immediately after inundation, the Fe(II)-sol increased up to 4700 ppm but diminished rapidly during the vegetation period. A second peak of Fe(II)-sol was observed in the planted plots during flowering. No clear difference in iron reduction between the different treatments could be detected.

These results indicate that the presence of rice roots in the soils favour microbial processes, especially iron reduction. This can be explained by an improved energy supply (root debris and/or exudation of carbohydrates) that stimulate microbial activity in general and anaerobic respiration (denitrification and/or ferric iron reduction) in particular.

The occurrence of a pronounced peak of Fe(II)-sol immediately after flooding, also reported previously by Ponnamperuma (1977b), was confirmed for other examined acid sulphate soils in the area. This intensive microbial iron reduction should be considered responsible for the high mortality of seedlings transplanted too soon after

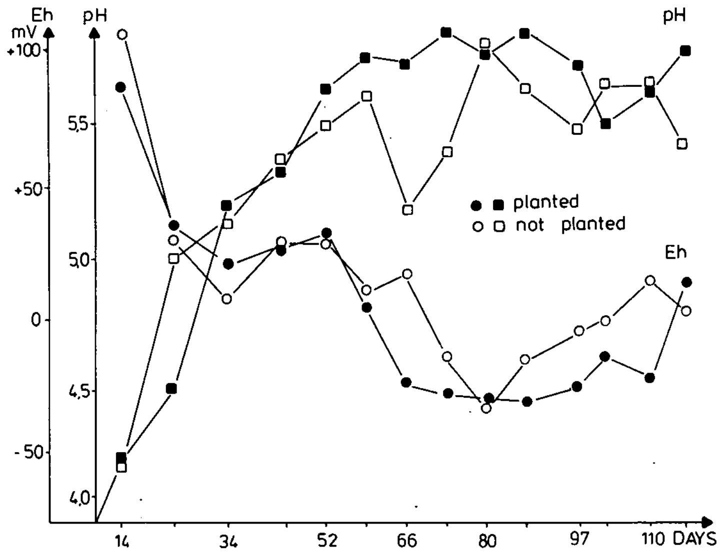

Figure 1 Development of pH and redoxpotential on an acid sulfate soil during the growth period. Experiment 'Loudia Ouolof'

reflooding an oxidized soil. No significant correlation between Fe(II)-sol (or pH, or Eh) and leaf iron content could be established at any sampling time.

4.3 Plant nutrient and Fe uptake

The effects of phosphorus fertilization were not only visible in plant development and yield, but were also reflected in the P contents of rice leaves (Figure 3). P-fertilized plants had higher P contents than those without P. The same leaves showed also higher K contents than all other treatments (Figure 4). However, leaf analysis failed to reveal any effect of K fertilization on K uptake. The positive effect of P on K uptake may be explained by its significant role in root growth (Jones et al. 1982). A well developed root system facilitates the uptake of all soil nutrients that become available by diffusion and interception (K, P).

A comparison of the total Fe content of leaves from P-fertilized and non-P-supplied plots suggests (Figure 5) that plants well supplied with P (and consequently with K) can recover more rapidly from an initial Fe stress after transplantation than those without P fertilization.

From Figure 5 a second slight increase in the leave iron content is observed at flowering. The correlation between leave iron content at the beginning of heading and the grain yield finally obtained in the corresponding plots is presented in Figure 6. This Figure supports the significance of an excessive iron uptake in this phase for the productivity of the site. Nearly identical results were obtained by Leihner (1975). High

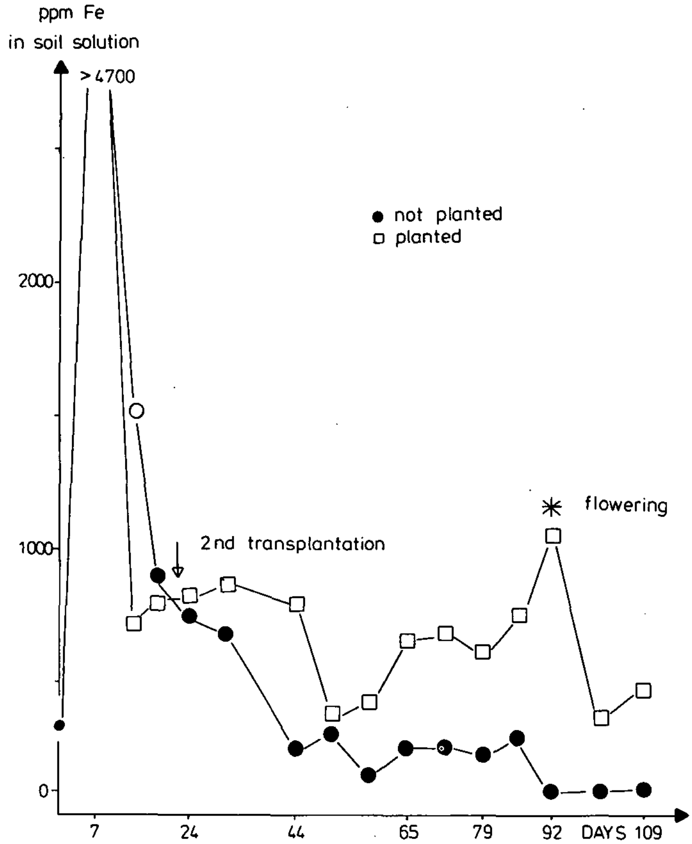

Figure 2 Development of Fe(+ +)-concentrations in the soil solution in planted and not planted plots throughout the growth period at Loudia Ouolof

iron contents in leaves at this stage indicate that tillering as well as spikelet formation might have been hampered by high iron influx.

A highly significant correlation between iron and potassium content of the leaves at the early heading stage is shown in Figure 7. At this physiologically active phase of the vegetation, iron uptake seems to depend highly on the potassium status of the plant. The better the K supply, the lower is the uptake of Fe. This result supports findings of Tanaka and Tadano (1972), Trolldenier (1977) and Benckiser et al. (1984) who stressed the importance of K deficiency for iron toxicity. Based on the experiments performed, the positive effect of P application should be explained at least partly by an improved K nutrition of the plant and, in consequence, by a more effective Fe(II)-excluding and oxidizing mechanism.

If phosphorus itself affects the plant metabolism in a way similar to potassium, such a feature was not detected by the results presented. This may be due to the fact that the relatively high P content in the Fe-oxide fraction of the soil permitted simultaneous P uptake of those plants who took up high amounts of iron after reductive dissolution of P-rich Fe oxides. But at present the involvement of potassium in the iron intoxication process seems to be more evident.

The chemical analysis of some other acid sulphate rice soils in Basse Casamance (Table 1) revealed to a large extent low nutrient availability, especially for P and K. In the same area we frequently witnessed well developed rice populations suffering heavily from iron toxicity at the heading stage, finally resulting in very low grain yields. These findings are in agreement with those of Ottow et al. (1982) who noticed the congruency of low nutrient availability and iron toxicity on various soils.

4.4 Management and alleviation

The excessive uptake of Fe(II) by wetland rice seems to be most pronounced shortly after the beginning of submergence (primary iron toxicity) as well as during growth phases of high physiological activity between maximum tillering and flowering (secondary iron toxicity). In terms of management, primary iron toxicity should be easily excluded by transplanting the seedlings not until 5-20 days after the onset of flooding. This delay in planting may vary from soil to soil and depends largely on the rate of

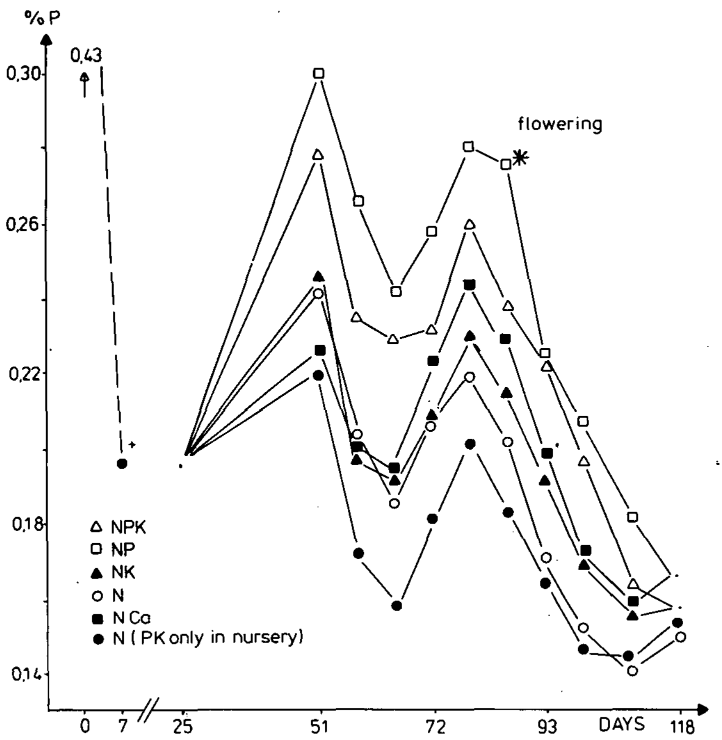

Figure 3 Development of P-contents in the leaf dry matter throughout the growth period (% total phosphorus in the second and third leaf from top)

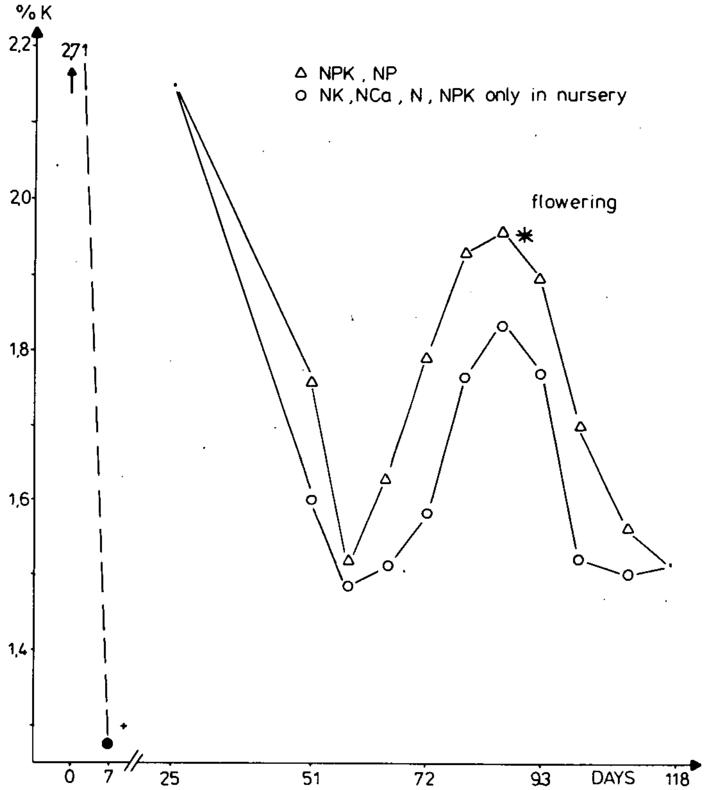

Figure 4 Development of K-contents in the leaf dry matter throughout the growth period (% total potassium in the second and third leaf from top). Compared are treatments with or without P-application

microbial iron reduction under the soil conditions given. Generally speaking, the higher the amount of easily decomposable organic matter, the more intensive and rapid are the bacterial reduction processes (Ottow and Glathe 1973; Munch and Ottow 1983).

Under field conditions, re-precipitation of dissolved ferrous iron as ferrous sulphide usually indicates the end of mineralization with Fe(II) oxides as an electron acceptor. This situation may also be indicated by the formation of a red scum on the flood water and/or on the soil surface. In southern Senegal, we ascribe a major part of rice crop losses to primary iron toxicity because presently most farmers tend to transplant their seedlings immediately after flooding and salt removal. This is a change of customs caused by a significant shortening of the rainy season during the last 15 years.

While primary iron toxicity may be explained by a high sensitivity of the rice plant to Fe(II) stress immediately after transplanting (caused by death and replacement of the primary root system), secondary IT should be considered as a physiological disorder induced by an insufficient supply of essential nutrients involved directly (K, possibly also Ca and Zn) or indirectly (P) (see also Benckiser et al. 1984a, b). An insufficient supply of K, Ca and Zn (in relation to the uptake of N) probably increases root permeability, carbohydrate exudation and iron reduction, which are a pre-

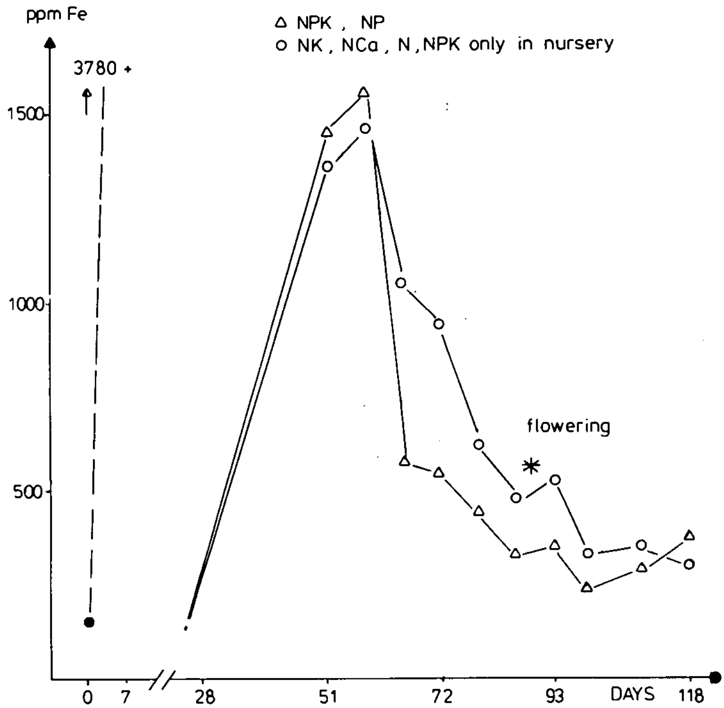

Figure 5 Development of Fe-contents in the leaf dry matter throughout the growth period (ppm total iron in the second and third leaf from top). Compared are treatments with or without P-application

requisite for the breakdown of the effective iron-oxidizing and excluding mechanism, particularly during the most active phase of plant metabolism. This secondary iron toxicity may be alleviated only by fertilization, either in mineral form or by the incorporation of organic remains that are rich in at least P, K, Ca and Zn such as manure and/or ashes. To be effective, intensive, repeated nutrient supply is necessary, particularly on leached acid sulphate soils (which become oxidized upon drying and desalinized by intensive leaching) or on highly weathered Ulti-, Oxi- or oligotrophic Histosols. In fact, secondary iron toxicity can be considered as a 'reclamation disease', which disappears as soon as the soils are regularly fertilized (Japan).

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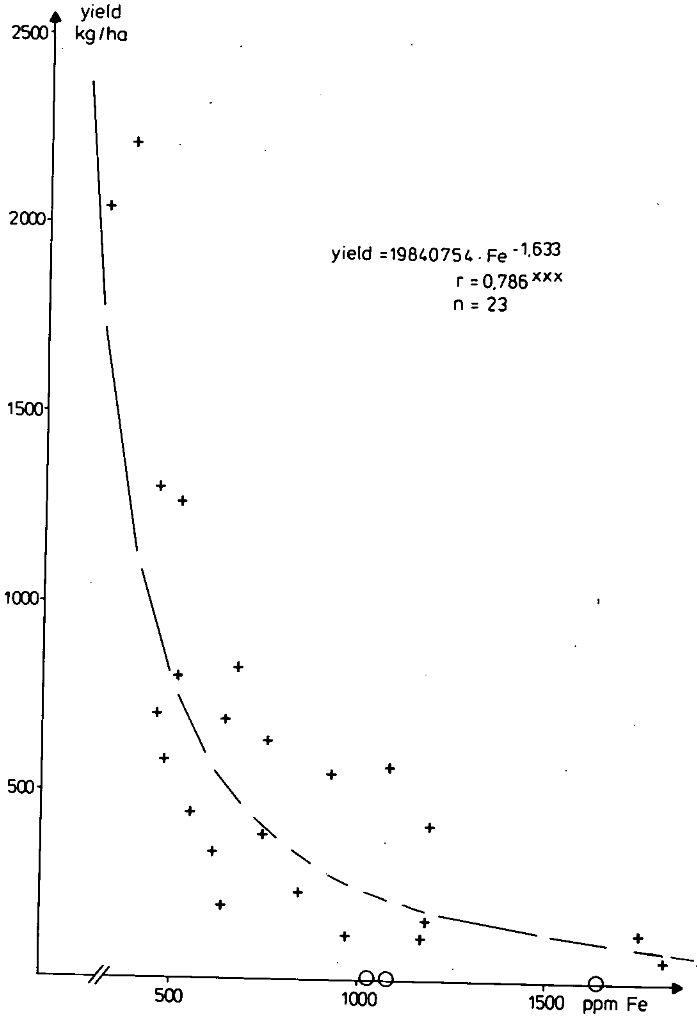

Figure 6 Correlation between Fe-content of leaves at the beginning of the heading stage and subsequent yield in the corresponding plots

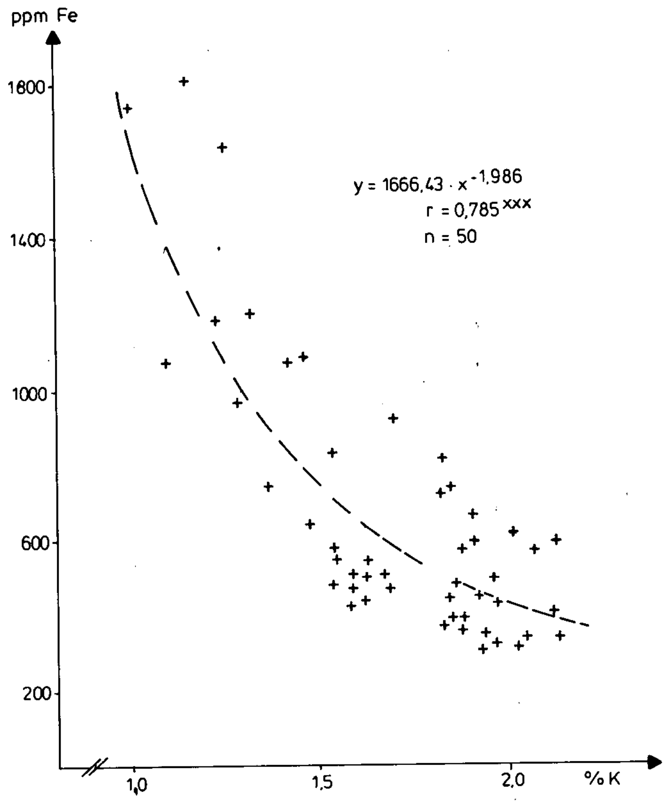

Figure 7 Correlation between K- and Fe-content of the leaves at the beginning of the heading stage

Rice improvement in the mangrove swamps of West Africa

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1 Summary

In West Africa more than 200,000 ha of mangrove swamp, with predominantly acid sulphate soils are being cropped for rice. Rainfall regimes, tidal movement, fresh water supply from river and rainfall, and environmental stress of the mangrove swamp differ from area to area and the need for varieties and farming practices differ accordingly. Constraints of mangrove swamp rice farmers have been identified and research strategies to solve the problems are developed by West Africa Rice Development Association at Rokupr. Results of the research work on Varietal Improvement, Soil and Crop Management, Pest Management, Technology Assessment and Transfer Training are discussed.

Résumé

Le régime de précipitations, le mouvement tidal, l'apport de l'eau douce des rivières et précipitations, ainsi que les stress de l'environnement des mangroves, différent d'une place à l'autre. C'est pour cela que les pratiques d'aménagements doivent être différentes, comme différentes doivent être aussi, les variétés de riz cultivées.

L'association pour le Développement de la Riziculture en Afrique Occidentale de Rokpur, a étudié les contraintes des 'rizières profondes' et a élaborée des stratégies de recherches pour l'amélioration.

L'article discute les résultats concernant l'aménagement du sol et des cultures, la tolérance des variétés, la lutte contre les maladies, la vulgarisation des connaissances et technologies.

Un monitoring du pH et de la teneur en sels a été réalisé durant plusieurs années, en vue de connaître l'acidité et la salinité des sols, et d'expériences à divers doses de fertilisants (NPK) ont été conduites, afin de pouvoir determiner les meilleurs reponses de plantes.

Au Sierra Leone, l'application de l'azote par injection d'une solution aqueuse d'urée à 20 cm de profondeur a donné d'excelents résultats. De même, l'application de 20 kg P/ha sous forme de superphosphate a augmenté l'efficacité de l'azote et a apporté d'importants surplus de récolte. Par contre, en Gambie, seul le phosphore a été l'élément nutritif défficitaire et l'application de l'azote n'a pas apporté d'augmentation de récolte.

La potassium, seul ou en différentes combinaisons, n'a pas apporté non plus d'augmentation de récolte.

En 8 années, environs 3000 variétés/lignées de riz ont été introduites et triées pour des conditions de mangroves à influence tidale et non-tidale.

Les régions tidales de Guinée, semblent très favorables à la cultivation du riz à courte période végétative. Environ 1000 variétés locales et séléctionées ont été identifiées comme résistantes aux Diopsis thoracica et Maliarpha separatella, et quelques centaines, comme multirésistantes aux maladies, insectes et crabes.

La destruction des mauvaises herbes par des moyens mécaniques et chimiques c'est avérée efficace tant au Sierra Leone, que dans les autres pays de l'Afrique Occidentale.

La vulgarisation des résultats et la culture de certaines variétés résistantes, comme l'utilisation massive de certaines techniques est de plus en plus large.

ROK 5 est une variété utilisée par 90% des paysans de Gambie et Guinée-Bissau et ROK 10 commence aussi d'être acceptée à large échelle.

2 Introduction

2.1 The mangrove rice situation in West Africa

Rice is grown on about 214,000 ha of cleared mangrove swamps in Guinea-Bissau, The Gambia, Guinea, Nigeria, Senegal and Sierra Leone (Figure 1) and large areas are being brought under cultivation. A further 150,000 ha remain uncleared in Sierra Leone up to Senegal, and about 800,000 ha in Nigeria (WARDA 1983b). These swamps are mainly acid-sulphate soils.

The swamps have been continuously cropped for over 100 years with about 100,000 farm families involved in the West Africa sub-region. Most farms are manually operated and cultivated with low yielding varieties without fertilizer or pest control. The farmers are also constrained by limited labour, transportation, extension and education and by lack of credit and input availability.

However, the mangrove swamp environment is still more fertile than the other traditional rice areas. For example, mangrove swamp rice comprises about 7 per cent of the area under rice in West Africa but it accounts for about 12 per cent of production. Yields of husk rice average 2.0 metric tons per ha. but there are indications that the use of practical modern techniques can double production per unit area (WARDA 1984).

The relative importance of mangrove swamp rice cultivation varies from country to country as indicated in Table 1.

Table 1 Relative importance of mangrove swamp rice cultivation in West-Africa

Country	Area under mangrove swamp rice (ha)	% National	
		Rice area	Rice production
Guinea-Bissau	90,000	80	80
The Gambia	10,000	52	54
Guinea	64,000	12	18
Senegal	10,000	20	16
Sierra Leone	35,000	6	12
Nigeria	5,000	–	–

Source: WARDA 1983b

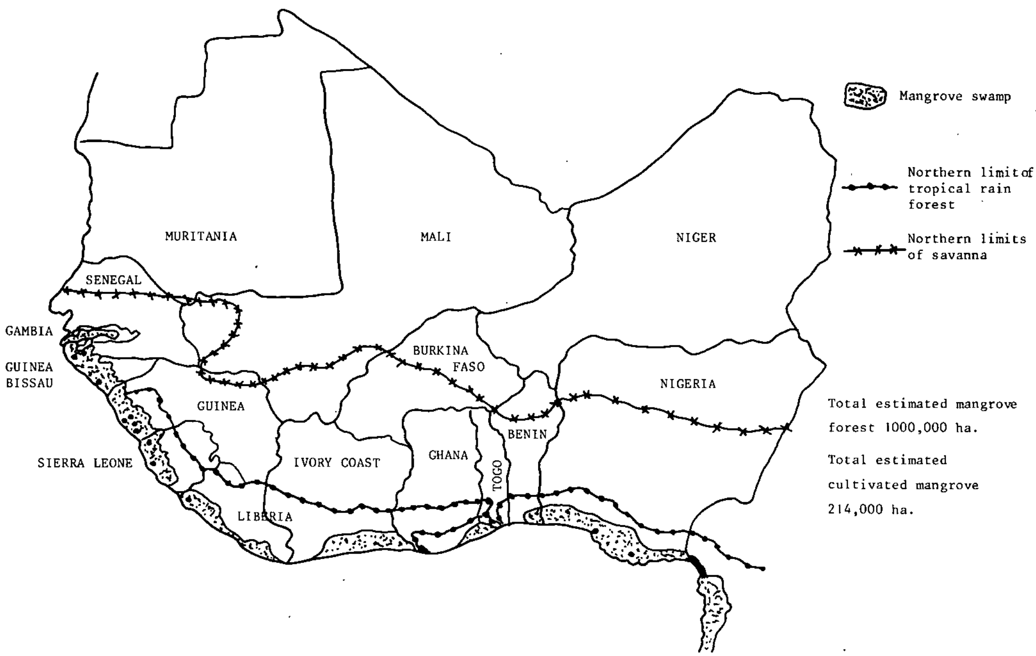

Figure 1 Distribution of mangrove swamps in West Africa

The mangrove swamp rice area in West-Africa covers a wide range of climatic conditions from dry tropical climate with about 1,000 mm of rain at Casamance (Southern Senegal) to humid tropical climate with about 4,000 mm of rain in Sierra Leone, Southern Guinea and southern Nigeria. However, successful cultivation of rice on any one area depends on the length of 'the salt free period' which is the result of an interplay of the volume of fresh water available and salt water intrusion from the sea. Between the tidal swamps and the uplands lie so called 'associated mangrove swamps' which are characterized by excessive grass and sedge weeds, with fewer broad leaved ones.

2.2 Strategy for Rice Improvement

The combined factors of variable climatic conditions and the different durations of the salt free period provide a strong challenge to the West Africa Rice Development Association (WARDA) Regional Mangrove Swamp Rice Research Station at Rokupr. The methodologies developed for rice improvement are based on a multidisciplinary team strategy. Generally, the station has five broad responsibilities, namely, Varietal Improvement, Soil and Crop Management, Pest Management, Technology Assessment and Transfer, and Training. Concerted activity by the multi- disciplinary team is obtained by interactions as well as delivery and feedback relationships among the various sections (Figure 2).

The development of new technologies starts with the testing of techniques on farm scale and evaluating promising techniques together with the farmers in our Technology

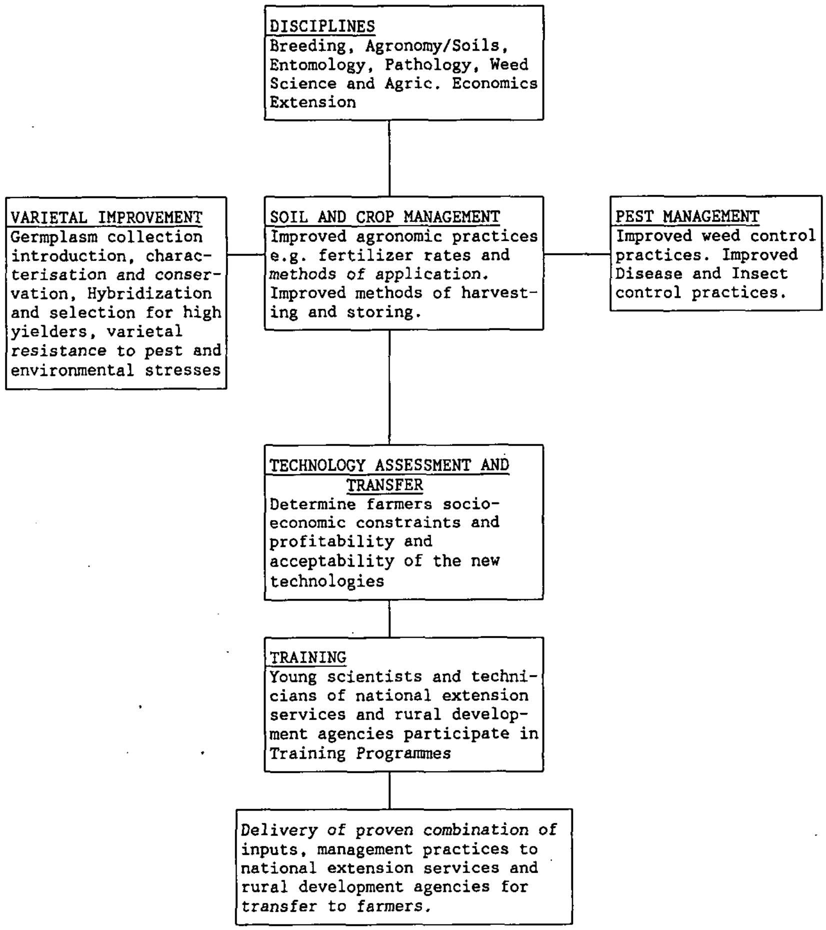

Figure 2 Strategy of inter-disciplinary approach at the WARDA regional mangrove swamp rice research station, Rokupr, Sierra Leone to solving rice production problems.

Assessment and Transfer section. Successful techniques are then passed on directly to farmers by the scientists involved and to established extension authorities and other development agencies or projects in Guinea, Guinea-Bissau, The Gambia, Senegal and Sierra Leone. The salient findings of the Station to date are summarized hereafter on a section by section basis for ease of presentation.

3 Varietal improvement

3.1 Introduction of varieties

Between 1976 and 1984 2840 varieties/lines have been introduced and screened for adaptation to the mangrove swamp environment. Their origins and the number selected for further testing and nomination into mangrove swamp Advance Varietal

Trials (AVT) are shown in Table 2. The AVT varieties have proved suitable for both the empoldered mangrove swamps in the north of the region and for the open tidal swamps of Sierra Leone and Guinea (Table 3). In view of recent drought conditions in the Sahel selection of short duration varieties is of increasing importance (WARDA 1982-1984).

Table 2 Introduced varieties/lines screened at Rokupr for adaptation to mangrove swamp conditions

Year	Number of introductions	Origin of Materials	Number of Varieties /lines selected	Number nominated for advanced variety trials
1976	330	IITA, Nigeria	54	2
1977	343	WARDA, Liberia	49	1
1978	437	IRTP (IRRI) Germplasm Bank, Philippines	62	10
1979	57	IRRI Germplasm Bank, Philippines	18	5
1980	71	IRTP (IRRI), Philippines	9	4
1981	536	IRTP (IRRI), Philippines	127	–
1982	132	IRTP (IRRI), Philippines	22	–
1983	407	IRTP (IRRI), Philippines	89	–
1984	529	IRTP (IRRI), Philippines	103	–

Table 3 Varieties nominated by WARDA Regional Mangrove Swamp Rice Research Station, Rokupr, Sierra Leone for mangrove swamp Region-wide variety trials

Year	Variety	Year of introduction	Height (cm)	Duration (days)	Average yield (t/ha)
1980	Bali Grodak	1976	135	162	3.1
	Djabon	1976	139	162	3.1
1981	Kuatik Jambi	1978	137	169	3.8
	Kuatik Kundur	1978	142	175	3.7
	Padi Mentul	1978	151	173	3.6
	Tat No	1978	154	170	3.4
	Sentral Merah	1978	147	159	3.3
	Nang Ra	1978	145	170	3.2
	Kuatik Putih Tinggi	1978	151	174	3.2
1982	IR3259-P5-160-1	1977	94	143	4.6
	IR4707-140-1-3	1979	92	135	3.7
	IR2797-125-3-2-2-2	1979	94	134	3.5
	IR4712-113-3-1-2	1979	102	131	3.3
1983	IR5677-17-3-1-1	1979	117	150	4.3
	Rohyb6-WAR-6-2-B-2	**	153	170	3.2
	Haji Haroun	1978	133	160	2.9
	Bay Danh	1978	156	171	2.6
	Raden Mas	1978	166	175	2.4
	Rohyb1-WAR-5-2-B-2	**	156	168	2.3
1984	IR10781-143-2-3	1980	108	134	4.9
	IR13426-92-1	1980	99	130	4.6
	IR14753-120-3	1980	98	135	3.7
	Rohyb15-WAR-3-3-B-2	**	125	157	3.9
	IR11248-148-3-2-3-2	1979	88	124	3.5
	IR13240-39-3	1980	87	121	3.2

** Bred at Rokupr

3.2 Breeding

In the past 6 years a total of 146 crosses have been successfully made and several promising lines have been tested on farmers rice fields and are now being recommended for release in Sierra Leone. Notable among these are Rohyb15 and WAR74 for tidal swamps with a short salt free season (Jones 1985). Several promising lines for long season swamps are also in the offering (WARDA 1984).

3.3 Varietal resistance to Pests

About 1000 local and introduced rice varieties have been evaluated for resistance to 'dead heart' caused by Diopsis thoracica, and 'stem infestation' caused by Maliarpha separatella under natural level of infestation in collaborative work between the entomologist and breeders. In general the introduced varieties do not perform well in mangrove swamps and are more susceptible to 'dead heart' than local varieties. However, stem infestation is higher in local varieties than in exotic rices (WARDA 1983b).

Mass screening of the Station's genetic stock for resistance to crab damage was initiated in 1981 using a method developed at Rokupr (Agyen-Sampong, in press). The results indicate that all seedlings with long leaves and thick bases are generally more tolerant to crab damage, with the resistance mechanism being morphological in nature.

3.4 Varietal resistance to diseases

Several hundreds of varieties/lines have been screened against rice diseases in multi-locational testing since 1982 in the Scarcies and Moyamba regions of Sierra Leone. Several test entries showed multiple resistance to seedling blast (Pyricularia oryzae) in the nursery, brown spot (Cochliobolus miyabeanus = Helminthosporium oryzae), leaf scald (Rhynchosporium oryzae) and leaf smut (Entyphoma oryzae) and also the white borer, M. separatella viz. WAR24-10-2-2, WAR25-14-1-2, WAR25-18-5-1, WAR27-34-4-1, WAR35-19-1-2, and WAR74-23-2-2-B-2 (Fannah et al. 1985). Also several varieties or lines were rated resistant to rice yellow mottle virus (RYMV) in a seedling screening test at Rokupr. These include TOX 502-SLR, LAC23, ITA116, IRAT170, and ROK 16 (WARDA 1984).

4 Soil and crop management

4.1 Salinity and pH levels

The salt content and pH along the Great Scarcies river have been routinely monitored for several years. The data obtained have facilitated the establishment of safe levels of salinity and acidity conditions for rice growth in different areas of the Scarcies region mangrove swamps.

4.2 Nitrogen fertilization

Nitrogen is limiting in the mangrove swamps of Sierra Leone (WARDA 1976-84). The Station has therefore developed a point application technique of injecting an aqueous solution of urea at about 20 cm depth. The device comprises a Knapsack sprayer with the lance converted into a needle for placement of fertilizer solution at the required depth (WARDA 1976; Jones this symposium).

4.3 Response to phosphorus and potassium

Results of long term trials evaluating nitrogen (N), phosphorus (P) and potassium (K) alone, and in various combinations indicated no response to potassium, and only occasional response to phosphorus. However, Will and Janakiram (1974) had earlier reported positive results with phosphorus at Rokupr. It appears that application of 20 kg per ha as single superphosphate produced a response to nitrogen and increased grain yield significantly in tidal swamp with limited flooding but increasing the level to 40 kg P per ha does not cause a significant increase in yield (WARDA 1983). In the Gambia phosphorus was observed to be the limiting nutrient; here no consistent response to nitrogen was observed.

4.4 Mechanical cultivation

A 8 hp single axed power tiller has been successfully utilized for cultivating the swamps in Sierra Leone and Guinea (WARDA 1983b). In on-farm trials comparing mechanical cultivation to the farmers traditional method of land cultivation using a long wooden handled hoe or 'mattock', mechanical cultivation gave superior grain yields (WARDA 1982-84). This result was probably due to greater mineralization of organic matter and better suppression of weeds with mechanical cultivation. However, ploughing below 15 cm in some areas can expose potentially acid sulphate sub-soil.

5 Pest management

The ultimate aim of mangrove swamp rice pest management is to devise a practical integrated control strategy based on sound knowledge of the ecology of key pests and the crop losses caused by them and coupled with sound crop husbandry and the use of resistant cultivars.

5.1 Weed surveys

Paspalum vaginatum, or 'Kire Kire', a salt tolerant graminaceous weed is the dominant weed in tidal mangrove swamps of Sierra Leone, The Gambia, Guinea and Guinea Bissau. Alternanthera sessilis is also found in saline swamps of these countries though it is relatively less in Sierra Leone (Bernard 1978; WARDA 1977-84). In the 'associated swamps' in areas that are transitional to the upland, a broad spectrum of weeds including grasses, sedges, and some broad leaved weeds occur.

5.2 Weed control

In the 'associated swamps' farmers usually hand weed once but this is hardly enough to control the serious weed infestation problem. However, in the normal tidal mangrove swamps single hand weeding is enough and in some cases no weeding is necessary.

Land preparation (ploughing and puddling) by the power tiller before transplanting has been found to suppress weeds most effectively and to yield more grain in Sierra Leone, and Guinea (WARDA 1978-84). This method can be applied in other West-African mangrove areas with similar weed flora (Fomba et al. 1984).

Trials with the herbicide Stam F34T (Propanil + Fenoprop) indicate that this chemical can control a broad spectrum of weeds in the 'associated swamps' especially where the fields are mechanically cultivated.

5.3 Disease surveys and monitoring

Disease surveys conducted in mangrove swamps of Sierra Leone, Guinea, Guinea-Bissau, The Gambia and Nigeria, and field observations at Djibélor in the lower Casamance region of Senegal have revealed the incidence of a broad spectrum of rice disease (WARDA 1977-84). The major rice diseases recorded were blast (Pyricularia oryzae) on upland nursery rice and in some fields, brown spot (Helminthosporium oryzae), leaf scald (Rhynchosporium oryzae), leaf smut (Entyloma oryzae) and 'dirty panicle' or grain discoloration syndrome; rice yellow mottle virus (RYMV), a potential problem, was also recorded in Sierra Leone, Guinea and Guinea-Bissau (WARDA 1977-84; Raymundo 1980).

However, the intensity varied from place to place and from country to country. Sierra leone, southern Guinea and Nigeria are ecologically similar, and so are the disease problem.

Guinea-Bissau, parts of northern Guinea and Casamance are also similar with respect to disease incidence and severity; The Gambia mangrove swamps were relatively less affected than the others in the sub-region.

5.4 Assessment of crop losses due to diseases

Grain yield losses caused by foliar rice brown spot disease (H. oryzae), in mangrove swamps of Sierra Leone were estimated at 7.3 to 19.8 per cent on a number of varieties of both improved and traditional cultivars (WARDA 1984). For neck blast (Pyricularia oryzae) losses from 16.4 to 30.7 per cent were observed. Potential grain yield losses due to rice yellow mottle virus range from 19.6 to 95.8 per cent with 4 week old seedlings incurring the greatest damage when rice plants were artificially infested with the virus in a screenhouse study; adult plants were generally least affected (WARDA 1984).

5.5 Disease control

Soil amendment with straw in 'associated mangrove swamps' and balanced fertilizer application reduced brown spot infection (WARDA 1984). In a tidal mangrove swamp at Rokupr early transplanting in July and August resulted in less brown spot infection and larger grain yields even without nitrogen than with crops sown in September to October (WARDA 1982-84).

Several fungicides such as Kocide, Beam (Tricyclazole), Protector (S-Haris), Prochloraz, Cuprosam 311 super D, and a mixture of Benlate (Benomyl) and Kocide reduced brown spot, leaf scald and leaf smut incidence on rice in an 'associated mangrove swamp' at Rokupr, and again adequately controlled seedling blast (P. oryzae) in rice and dryland (WARDA 1983-84).

5.6 Insect survey and collections

A wide range of rice pests has been recorded in mangrove swamps of West Africa with varying intensity of infestation and damage from place to place depending on the climate, time of planting, varieties and soil fertility. The white borer, Maliarpha separatella had been found to be the most dominant stemborer in mangrove swamps of Nigeria, Sierra Leone, Guinea-Bissau, and The Gambia (WARDA 1976-84). The striped rice borer, Chilo spp., the stalked-eye borer, Diopsis thoracica, and rice bugs are also quite common in these swamps.

At Caboxanque in Guinea-Bissau there was usually high incidence of gall midge, Orseolia oryzivora. Chilo zacconius was found to be a common stemborer at both Caboxanque and Djibélor in the lower Casamance region of Senegal.

5.7 Assessment of crop loss due to insects

Preliminary on-farm trials in mangrove swamps of northwest Sierra Leone indicate a range 35-1000 kg/ha grain yield reduction due to infestation by M. separatella (WARDA 1977-83).

Per cent grain yield loss due to insect pest infestation in some promising varieties ranged from 4.0 to 20.2 (WARDA 1978-83).

Rice bugs (Aspavia armigera and Stenocoris southwoodi) caused considerable grain yield losses and are associated with the 'dirty panicle' or discoloured grains syndrome (Agyen-Sampong and Fannah 1980). It was established in a screenhouse study that the percentage of grain damage increased as the rice bug density increased.

5.8 Pest control

Cultural control methods restrict or prevent pest damage by reducing pest population, and are generally economical and widely applicable. Destruction of rice stubbles after harvest, timely planting to avoid peak periods of adult emergence, and close plant spacing alone, and in combination lead to lowering Maliarpha infestation in mangrove swamp rice (WARDA 1978-81).

Twenty-two species of egg and larval parasitoids of eight species of rice pests have been recorded in biological control studies in mangrove swamps of northwest Sierra Leone. Parasitism of about 15.0 per cent was recorded at 6 weeks after seedling transplanting and up to 90.0 per cent at the latter part of the season.

5.9 The ecology of crab pests in mangrove swamp rice

Of the nine species of crabs recorded in mangrove swamp rice fields, Sesarma huzardi, S. Alberti, and Sarmatum curvatum cause extensive destruction of newly transplanted rice seedlings by their feeding habits (Jordan 1958; Agyen-Sampong, in press).

Sesarma huzardi is the most voracious and common species in tidal mangrove swamps along the Great Scarcies river in Sierra Leone. It is transversely distributed across and along rivers and creeks up to the tidal limit (WARDA 1977-84).

5.10 Crop losses due to crabs

Grain yield losses on farmers' rice fields have been estimated at 19.0 to 34.0 kg/ha for every 1.0 per cent crab damage (WARDA 1978-83). Crab damage can be lessened by growing fewer older, vigorous, fertilizer treated seedlings and/or seedlings soaked in 1.0 per cent a.i. concentration of Furadan for 24 hours (WARDA 1978-83). Use of resistant cultivars further reduced crab damage in mangrove swamp rice (WARDA 1983).

6 Technology assessment and transfer

The Technology Assessment and Transfer (TAT) aspect of the Station's programme ensure that technology developed at the Station are passed by studies which help the scientist to understand farming systems more adequately and determine the constraints to which solutions can be addressed.

The technologies developed by the multidisciplinary team of scientists are then organized into packages and placed in adaptive trials for testing under farmers' socioeconomic situation for suitability, acceptability and profitability (Prakah-Asante et al. 1984).

6.1 Farming systems

In the Scarcies area of Sierra Leone 90% of the population is agrarian. For the Conakry and Coyah regions of Guinea 22% is non-farming, main non-farm activities being trading, fire-wood industry and boat-making. Roughly 80% of the farming population in the Scarcies area and about 75% in the Conakry and Coyah regions of Guinea, cultivate rice in the mangrove swamps but combine this with upland crops such as cassave, potatoes, and upland rice.

The average rice holding of the Scarcies farmer is about 1 ha, for which he nurses roughly 100 kg of seeds. Average yields in the areas with long fresh water season of the Scarcies region was recorded at 2.0 tons per ha against 2.6 tons per ha in the short season areas near the sea. In the Conakry regions of Guinea rice holdings are smaller (less than 1 ha) and yields are generally below 2 tons per ha.

6.2 Farm labour

In the Scarcies about 85% of farm labour is provided by the household which comprises about 3 male adults and youth, 4 female adults and youth, 2 children, 1 aged and 1 permanent labour. The remaining 15% is obtained from non-household sources. The household spends about 350 man-days per ha per year. Transplanting (including uprooting of seedlings), harvesting, and ploughing are the most labour intensive operations demanding about 220 man-days per ha.

6.3 Constraints to rice production

The main general constraint to rice production in mangrove swamps, is early recurrence of mineral stress, especially salinity due to vinicitudes of rain and hydrological regimes, or deficiencies in water control systems. Inadequate availability of fresh water may lead to complete crop failure and even abandonment of fields.

Biological constraints such as weeds, disease and pests could lead to serious losses in production, as discussed earlier. Low yielding varieties and the traditional practices of farming which generally exclude soil amendments, effective control of weeds, diseases and pests, also limit production. Most of the farmers in the Scarcies area are also faced with capital and labour scarcity which generally prevent input acquisition and farm expansion.

6.4 New technologies

The results of adaptive trials under farmers' management indicate that a technology package consisting of mechanical cultivation with single axled power tiller, modern varieties (ROK10 for areas with a long salt season, and ROK5 in short season areas), and injection of urea fertilization can increase yields by almost 100%. Morever, the package can reduce labour use by approximately 13-23 man-day per ha. Though there is evidence of large scale adoption of the modern varieties, adoption of the complete package requires support by a programme for credits, supply of farm inputs and marketing. Net revenue analysis of the package indicates that it is profitable at existing price levels and within a reasonable range of input and output prices.

6.5 Cooperation with other agencies

WARDA is developing and diffusing new technologies in active cooperation with local, national, regional and international authorities, institutions and projects. With such agencies joint protocols for field trials are agreed upon that secure the necessary feedback from the farmers' experiences all over the region.

In Sierra Leone, for example, a joint programme of field trials and demonstrations is taken up with the North West Integrated Agricultural Development Project (NWIADP), the Adaptive Crop Research and Extension (ACRE) Project, and the Moyamba Integrated Development Project (MIRDP). The Rokupr team has similar relationship with Opèration Nationale pour la Dèveloppement de la Riziculture (ONADER) in Guinea, Freedom From Hunger Campaign (FFHC) in The Gambia; the Dutch, Swedish, and USAID Projects in Guinea-Bissau; National Crop Research Institute (NCRI), and the University of Port Harcourt in Nigeria and the Ministry of Agriculture in each of the specified countries. Among the programmes of field trials and experimentation, the Rokupr Station offers training for supervisory and field staff for most of the countries indicated.

7 Conclusions

Research activities undertaken by the West Africa Rice Development Association (WARDA) Regional Mangrove Swamp Rice Research Station at Rokupr, Sierra Leone since 1976 indicate that it is feasible to double the present average yields of rice of 2.0 tons per ha in most mangrove swamps of the humid tropical part of West Africa by use of appropriate technology packages developed at Rokupr. The implementation of the new technologies requires continued cooperation between research, development and extension agencies in the region and also increase of training facilities and availability of credit and technical assistance to farmers.

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La mangrove a usages multiples de l'estuaire du Saloum (Sénégal)

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1 Résumé

Cette étude interdisciplinaire met en exergue les usages multiples de la mangrove et s'inscrit dans l'optique de la Stratégie Mondiale de la Conservation (UICN, PNUE, WWF, 1980), du développement intégré et de la gestion durable de la mangrove, écosystème forestier à usages multiples.

La mangrove est une formation spécialisée (Ozenda 1982). Elle représente un écosystème littoral complexe et fragile, d'une importance capitale pour les populations locales.

La composition, la structure, la biomasse aérienne ont été déterminées. La production et la productivité primaire on été définies grâce à la détermination de l'âge par analyse densitométrique aux rayons X de la coupe basale des tiges inventoriées et abattues.

Des tarifs de cubage peuplement à une et deux entrées ont été calculés à des fins pratiques.

Cette analyse dendrométrique nous permet d'appréhender les potentialités locales de la mangrove à Rhizophora racemosa G.F.W. Meyer de la zone de Toubacouta, estuaire du Saloum, Région de Siné-Saloum, République du Sénégal.

Cette étude souligne les facettes multiples de cet écosystème spécifique.

L'Homme, composante du système, est intégré à ce milieu depuis de nombreuse générations. Il en tire des produits alimentaires, pharmaceutiques, des colorantes, des tanins, des bois de service, du bois de chauffe et du charbon de bois, matière énergétique de base pour différentes activités domestiques et de petites industries (four à chaux).

Sa meilleure connaissance est un élément que nous portons au dossier afin de maintenir les processus écologiques essentiels de ce système entretenant la vie et garant de la diversité génétique.

L'occasion nous est ainsi donnée d'insister sur l'urgence de la conservation de la mangrove, tampon crucial entre la mer et le continent, sensible aux pollutions atmosphériques et marines, à la surexploitation de ses ressources ligneuses et fauniques, et aux péjorations climatiques.

La mangrove possède une valeur scientifique, mais aussi culturelle, éducative, touristique et socio-économique. Ses ressources renouvelables sont à la base des activités humaines.

Les fonctions de protection des côtes, de conservation du patrimoine végétal, faunique et hydrologique complètent l'ensemble de ses caractéristiques.

Summary

This multidisciplinary study highlights the ecological and social-economic dimension of the mangrove in the Toubacoute zone of the Saloum estuary (Sine-Saloum Region, Republic of Senegal).

The composition, structure and aerial biomass were determined. Primary production and productivity were estimated thanks to the determination of age by densitometric X-ray analysis of specimens cut and inventoried. Cubage was variously calculated for practical purposes. Results of dendometric analysis indicate the potentialities of the local *Rhizophopra racemosa* G.F.W. Meyer mangrove.

The survey underlines the many facets but also the fragility of the ecosystem in question. It shows that man has been an integral part of this system for generations and that he draws on it for nutritional and pharmaceutical purposes, for dyes and wood for many uses – firewood, charcoal, building – as well as for different domestic aims and small-scale industries (lime kilns).

Ecologically the mangrove belt is a crucial barrier between sea and land, vulnerable to atmospheric and marine pollution as well as to overexploitation of its faune and flore. The mangrove is menaced by the deteriorating climatic conditions of the Sahel which induces hypersalinity and extreme acidity in soils. The preservation of the mangrove environment is urgent because of its rôle as protector of the coast, preserve of vegetal, wildlife and hydrological heritages and socio-economical significance. A balanced management of this ecological system requires further basic and applied investigation.

2 Introduction

La présente étude s'intègre dans le cadre des recherches entreprises par l'Equipe Pluridisciplinaire d'Etudes des Ecosystèmes côtiers (E.P.E.E.C.), placée sous le patronnage de l'unité ROSTA-BRETA/UNESCO, division des Sciences de la Mer à Dakar.

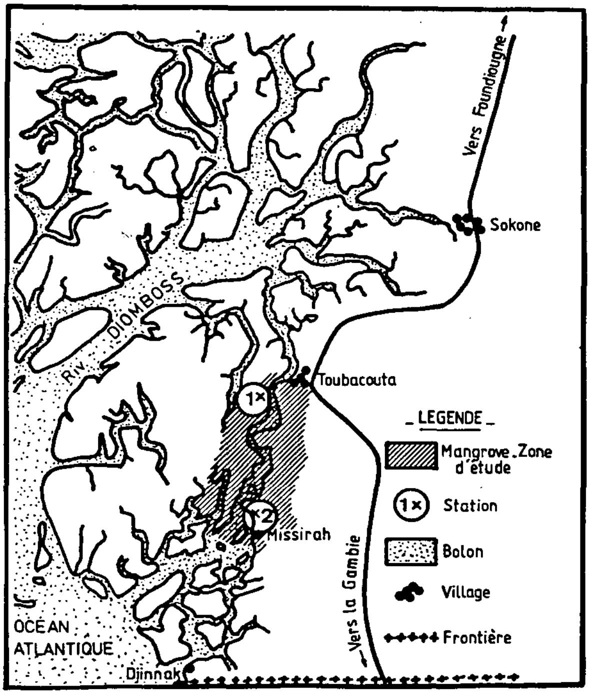
3 Situation de la zone d'étude

La mangrove du village de Toubacouta est située à 66 km de Kaolack, sur la route de Banjul (Gambie), (Carte 1 comme référence pour ses recherches).

La mangrove à Rhizophors, formation végétale spécifique de l'estuaire du Saloum, se situe entre les 13°35′ et 14°10′ de latitude Nord et les 16°50′ et 17°00′ de longitude Ouest.

4 Les aspects géologiques (Source: EPEEC 1982)

Les formations récentes caractérisent ce domaine, comme en témoigne l'épaisseur des



Carte 1 Zone d'étude

sables, argiles, vases et autres couches de sédiments fins révélées par les coupes et sondages des sociétés pétrolières.

Parmi les différentes unités, les vasières à mangroves se localisent sur la bordure immédiate des bolons, dans la zone de fluctuation des marées.

5 Les facteurs climatiques (Source: EPEEC 1982)

L'estuaire du Saloum fait partie du domaine soudanien caractérisé par 2 saisons nettement tranchées:

- Une saison sèche, fraîche de novembre à mars, chaude de mars à juin au cours de laquelle les vents dominants sont des alizés maritimes frais (de direction Nord à Nord-Ouest) et continentaux, secs(de direction Est à Nord-Est: harmattant);
- Une saison chaude et humide ou saison des pluies (de juillet à octobre), qui a tendance à s'écourter et où dominent les vents de direction Ouest et Sud-Ouest (vents de mousson). D'après les moyennes calculées pour la période de 1958 à 1982, ce domaine s'inscrit entre les isohyètes 900 mm au sud, à Djinak, et 700 mm légèrement au Nord de Foundiougne (le nombre de jours de pluie variant entre 45 et 55 jours par an). La température moyenne annuelle est environ de 25,3 °C. Par ailleurs, les totaux moyens annuels de l'évaporation peuvent être très élevés, même pour les stations de Foundiougne et Dionewar. Une comparaison entre l'évaporation moy-

enne annuelle et la pluviométrie annuelle a été effectuée; elle concerne trois stations et donne le résultats suivants (Tableau 1).

Tableau 1. Caractéristiques climatiques

Stations	Années	Evaporation totale en mm	Précipitations annuelle en mm	Déficit pluviométrique théorique
Kaolack	1971/81	2 208,6	609,8	1 598,8
Foundiougne	1971/81	1 606,8	703,2	903,6
Dionewar	1971/81	1 245,8	842,0	403,8

Source: EPEEC (1982)

6 Les facteurs hydrologiques

La salinité de l'eau du Saloum est partout supérieure à celle de l'eau de mer; 42 g/l à Djifère, 75,1 g/l à Foundiougne (Saos et Pages 1982). Les phénomènes de marée dynamique et de marée de salinité sur l'ensemble du réseau hydrographique sont déterminants. Il y a très peu d'apport de l'amont même en saison des pluies, le débit d'eau douce étant très faible en hivernage.

Les conséquences sont sensibles au niveau de certaines unités géomorphologiques. Les vasières à mangroves sont caractérisées par leur salinisation et leur acidification, car pour compenser la perte importante d'eau due à l'évaporation, un écoulement prédominant doit se faire dans le sens Océan – Foundiougne, au moins pendant 9 mois de l'année.

L'estuaire du Saloum est très particulier. EPEEC a montré l'existence d'un fonctionnement inverse de l'hydrodynamique estuarienne dans le Saloum. Il pourrait être confondu avec une ria sillonnée par de larges bolons présentant de multiples ramification.

7 Les aspects pédologiques

La Figure 1 indique les trois sites de prélèvement choisis pour l'analyse pédologique.

Le site S1 (station 1, placette d'inventaire 1) caractérise la formation à Rhizophora racemosa G.F.W.

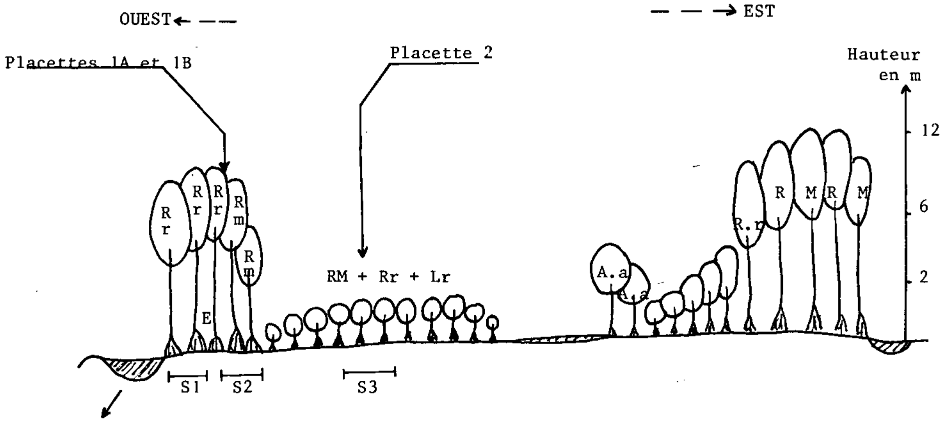
Le site S2 (station 1) est représentatif de la formation à Rhizophora mangle L.

Le site S3 (station 1, placette 2) est situé dans la zone de régénération de Rhizophora racemosa G.F.W. Meyer, Rhizophora mangle L. et Laguncularia racemosa Gaerth.

Le gradient d'éloignement par rapport à l'axe du chenal est: S1, S2 et S3.

7.1 Analyse granulométrique

Les résultats obtenus au laboratoire de pédologie de l'ORSTOM, Dakar (Sénégal) par Loyer, mettent en évidence une sédimentation fluvio-marine à nette dominance

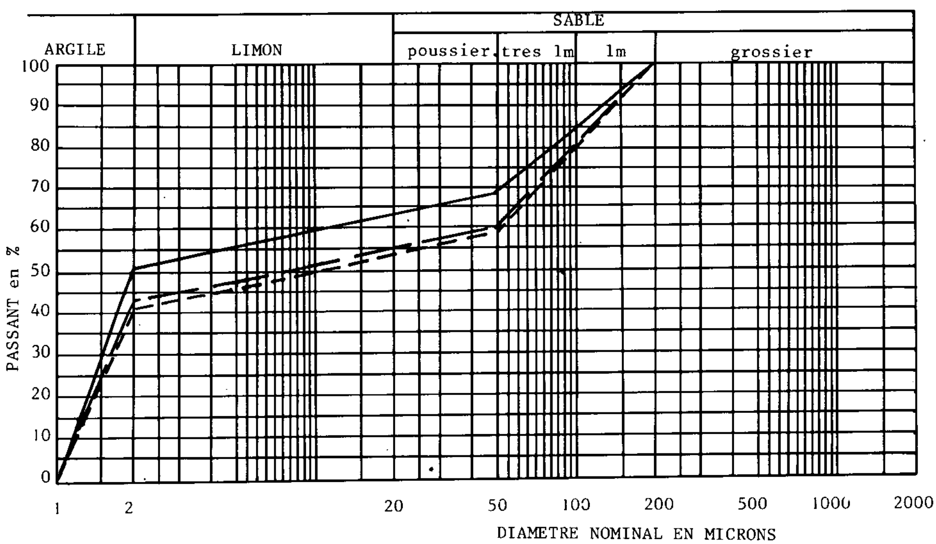


Légende: R.r=Rhizophora racemosa G.F.W.Meyer
R.m=Rhizophora mangle L.
L.r=Laguncularia racemosa Gaerth
A.a=Avicennia africana P.Beauv

Echantillon de sol: S1 sous Rhizophora racemosa G.F.W.Meyer
S2 sous Rhizophora mangle L.
S3 zone de régénération

Source: schéma Bodian A.(1983), modifié par Doyen A.(1985)

Figure 1 Présentation de la station n[0] 1 et des placettes 1A, 1B et 2



Légende: S1 sous Rhizophora racemosa G.F.Meyer
S2 sous Rhizophora mangle L.
S3 zone de régénération

Figure 2 Courbes granulométriques cumulatives argileuse (> 40%). Parmi les éléments plus grossiers, la fraction sables fins (50 à 200 μ) domine très largement (> 30%); la fraction sables grossiers étant pratiquement nulle. On ne constate pas de variations verticales sur la profondeur étudiée. Latéralement au chenal, le site S1 est le plus argileux. Ils sont représentés graphiquement par les courbes granulométriques cumulatives (Figure 2) et par le diagramme triangulaire FAO (Figure 3) et repris dans le Tableau 2.

Tableau 2. Granulométrie des sols de mangrove étudiés

	argiles	limons		sables		
		fins	grossiers	fin	grossiers	
Site Profondeur	<2 μ	2 à 20 μ	20 à 50 μ	50 à 200 μ	200 à 2 000 μ	Total%
S1 0-10 cm	50,7	13,2	6,5	29,6	0,2	100,2%
S1 10-20 cm	50,6	11,3	4,6	33,1	0,4	98 %
S1 20-40 cm	50,5	13,3	4,8	31,3	0,2	100,1%
S1 moyen	50,6	12,6	5,2	31,3	0,3	100 %
S2 0-20 cm	43,7	11,2	5,4	38,7	1,0	100 %
S2 20-40 cm	43,8	10,6	5,3	39,5	0,9	100,1%
S2 moyen	43,8	10,9	5,4	39,1	1,0	100,2%
S3 0-10 cm	41,5	12,5	5,5	39,6	0,9	100 %

7.2 Analyse chimique

Par comparaison avec le site S2 à Rhizophora mangle L., le site 1 à Rhizophora racemosa G.F.W. Meyer est moins riche en sulfate. Son pH est plus élevé, presque neutre. Il est caractéristique du milieu salin marin à dominance de chlorure mais enrichi en sulfate. Sa neutralité relative est maintenue par l'eau de mer. Le milieu (S1) est plus vaseux.

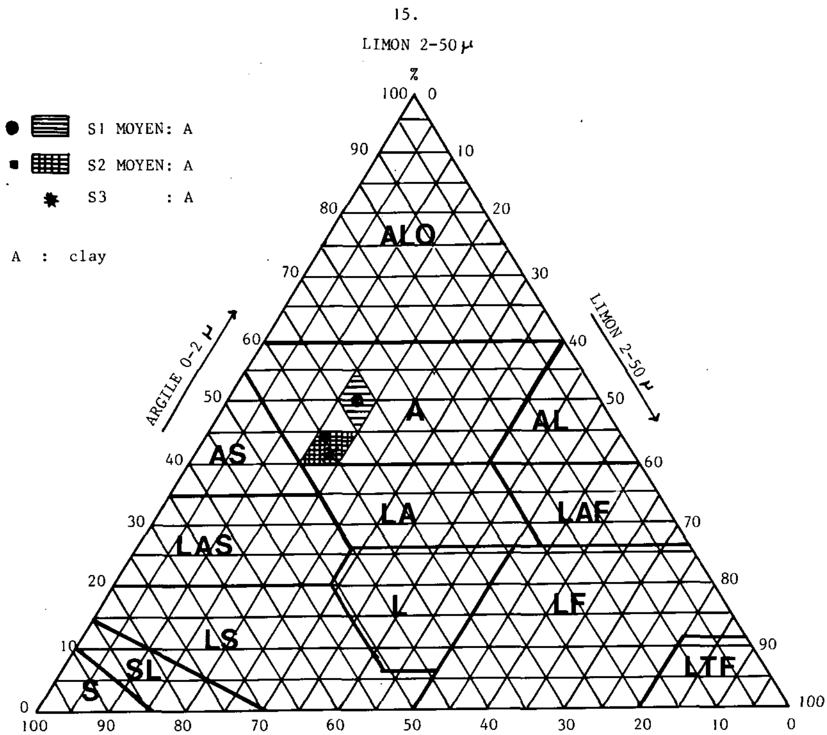
Le site S2 à Rhizophora mangle L. est moins chloré, moins riche en bicarbonate et plus riche en calcium et en magnésium, notamment en profondeur.

Le site S2 est caractérisé par une réoxydation avec apparition d'un pH acide. Il est plus proche de la partie exondée, des tannes. Le milieu est plus sableux. Ceci est lié au régime hydrique et à la dynamique des courants qui déterminent la sédimentation dans la zone.

La matière organique de ces sols varie de 11,6 à 13,4%.

Fournier et Sasson (1983) signalent 'la tendance au monophytisme des forêts placées dans de mauvaises conditions édaphiques, avec des répercussions physionomiques, alors que le polyphytisme est de règle pour les forêts placées dans des conditions édaphiques moyennes'.

Aussi, nous nous intéresserons à l'essence forestière la mieux représentée et, nous semble-t-il, la plus dynamique dans la zone de Toubacouta, le Rhizophora racemosa G.F.W. Meyer (palétuvier rouge).



LTF : silt
LF : silt loam
L : loam
LS : sandy loam
SL : loamy sand
S : sand
LAF : silty clay loam

LA : clay loam
LAS : sandy clay loam
AL : silty clay
A : clay
AS : sandy clay
ALØ : heavy clay

Figure 3 Diagramme triangulaire des textures FAO

8 Les usages multiples de la mangroves (BA 1985)

La mangrove de Toubacouta est composée principalement du genre Rhizophora avec les espèces Rhizophara racemosa G.F.W. Meyer et Rhizophora mangle L.

8.1 Utilisations domestiques

Le palétuvier, au bois dur et dense, est l'arbre le plus recherché pour la construction des maisons. Il offre un bois idéal pour la fabrication des manches de marteaux, de pelles, de haches et 'd'hiler'.

Le bois de Rhizophora donne d'excellents piquets: les dalles des deux ponceaux menant au bras de mer sont supportées par des piquets. La résistance de ce bois est vantée par le dicton Niominda: 'Celui qui n'amarre pas sa pirogue à un pieu en bois de palétuvier est responsable de la perte de la pirogue'.

Le bois de palétuvier est un excellent bois de chauffe. Il se consume totalement et une fois allumé ce bois s'éteint difficilement. En saison pluvieuse, quand tous les bois sont mouillés et difficilement inflammables, le bois de Rhizophora brûle sans peine.

Il est utilisé préférentiellement pour la fabrication de la chaux locale à base de Coquilles d'huîtres. L'opération consiste à amasser du bois de feu de palétuvier sur le tas de coquilles à fondre.

Les feuilles de palétuviers séchées et pilées donnent une poudre qui mélangée à l'eau, est la base de teintures, de vernis ou de détergents, selon le mode de mixage et de concentration.

8.2 Utilité alimentaire

Les huîtres, Crassostrea gaser (Adanson) consommées par les populations se reproduisent dans la mangrove et établissent leurs colonies sur les racines échasses des palétuviers. Vendues aux marchés, elles sont sources de numéraire.
Nous signalons l'existance de colonies de Balanes (Chthamalus rhizophorae) fixées aux racines échasses, n'ayant apparemment aucune utilité alimentaire.

Les racines de Rhizophora racemosa G.F.W. Meyer sont arrachées et mangées. Dans le passé, tous mangeaient les racines. Actuellement, seuls les enfants les apprécient. En cas de disette, les adultes les mangent également.

8.3 Le rôle sanitaire ou pharmaceutique du Rhizophora

Les feuilles jaunes de Rhizophora racemosa G.F.W. Meyer repoussées à la berge et en voie de putréfaction sont pilées et appliquées sur une plaie ouverte. C'est un remède efficace.

Les feuilles fraîches sont coupées et attachées à la tête d'un malade que se plaint de céphalées.

Les racines sont utilisées pour calmer les maux de dents. Le malade essaie de mordre la racine préalablement bouillie, fait des bains de bouche avec l'eau de cuisson.

Les femmes utilisent les feuilles de Rhizophora mangle L. après l'accouchement. Dans un premier temps, les feuilles sont bouillies et la femme en couche inhale la vapeur dégagée. Dans un second temps, les feuilles sont retirées et servent à masser la même femme. Enfin, elle boit l'infusion pour arrêter l'hémorragie de la délivrance et pour éliminer les dernières lochies.

La partie supérieure des racines de Rhizophora mangle L., non soumise aux variations du plan d'eau, est utilisée selon nos informations, dans la guérison de certains maux de ventre et contre les diarrhées.

La mangrove est aussi associée à des pratiques mystiques, incantations à Toubacouta.

Tableau 3. Résultats des analyses chimiques des sols de mangroves

Site	pH	EC 20°	Anions mé/l			Cations mé/l				Somme		S.tot $^0/_{00}$	M.O. $^0/_{00}$	C $^0/_{00}$
			Cl^-	SO_4^{--}	HCO_3^-	Ca^{++}	Mg^{++}	K^+	Na^+	Anions	Cations			
S1 0-10	6,7	18,0	175	29,6	1,40	5,25	29,8	4,89	159	206,0	198,94	19,7	13,4	78,0
S1 10-20	6,9	19,0	180	34,7	1,70	6,71	32,8	5,25	165	216,4	209,76	21,1	12,1	70,0
S1 20-40	6,3	21,5	189	46,3	0,60	8,78	42,2	6,35	186	235,9	243,33	24,9	12,6	73,0
S2 0-20	6,0	18,0	158	47,6	0,50	8,03	38,7	4,48	151	206,1	202,21	25,1	11,6	67,0
S2 20-40	3,7	20,0	173	65,6	0,00	14,50	50,0	4,10	162	238,6	230,6	31,8	13,3	77,0
S3 0-10	6,0	18,0	162	46,7	0,50	7,38	41,7	4,71	153	209,2	206,79	26,0	12,1	70,0

Remarque: Extrait 1/5

Les sites S1 et S2 sont homogènes quant à la quantité de K^+ et Na^+, et à la conductivité.

La conductivité des extraits est nettement inférieure à celle de l'eau de mer. Les pH sont également inférieurs de 2 unités environ par rapport à l'eau de mer ce qui est corroboré par un net enrichissement en sulfate par rapport au chlorure. L'echantillon le plus acide S2 est le plus riche en sulfates non neutralisés. Le rapport $Cl/S0_4$ est en moyenne deux fois inférieur à celui de l'eau de mer; concernant les cations on constate dans cet extrait, par rapport à la composition de l'eau de mer, un léger enrichissement en magnesium par rapport au calcium et en potassium par rapport au sodium.

8.4 Conclusions

La mangrove est bien une formation forestière spécifique à usages multiples. Outre la présence d'autres formations forestières (forêt semi-sèche de plateau...), elle joue un rôle très important dans la vie quotidienne des populations locales. Nos enquêtes montrent qu'aux plans domestique et médical, elle assure la satisfaction de nombreux besoins.

9 Conservation et développement (Doyen 1985)

La mangrove est un écosystème alimenté par l'énergie solaire et subventionné par la nature.

Selon (Odum 1967), il s'agit de 'systèmes de la nature qui sont naturellement productifs et qui non seulement ont une capacité élevée de maintien général de la vie, mais encore produisent en excès de la matière organique exportable vers d'autres systèmes, ou entreposable. On rencontre dans un estuaire un mélange de trois importantes formes de vie autotrophes qui jouent différents rôles dans le maintien du taux élevé de la production brute; ce sont le phytoplancton, la microflore benthique (algues), la macroflore dont la mangrove'.

Forts de ces considérations multiples, soucieux de répondre aux besoins exprimés par les populations, il était indispensable de maîtriser les potentialités de cette formation ligneuse: la mangrove.

Nous avons analysé par échantillonnage la mangrove à Rhizophora racemosa G.F.W. Meyer, la plus luxuriante pour la zone d'étude fixée. Les données que nous avons recueillies sont à la base de tout aménagement sylvicole.

Mais c'est avant tout la gestion rationelle d'un patrimoine total qui reste notre objectif prioritaire.

9.1 Inventaire, biomasse et productivité de la mangrove à Rhizophora racemosa G.F.W. Meyer

9.1.1 Dispotif expérimental (Toubacouta-Missira)

Deux stations ont été choisies en fonction de leur composition, de leur structure et de la hauteur dominante.

La station 1 est caractéristique de la mangrove à Rhizophora racemosa G.F.W. Meyer, formation haute.

La station 2 est caractéristique de la mangrove à Rhizophora racemosa G.F.W. Meyer, formation de hauteur moyenne.

Des placettes d'échantillonage ont été fixées pour l'inventaire en plan et l'abattage de tiges en vue d'une analyse précise de la biomasse, des caractéristiques dendrométriques, technologiques et de l'âge.

Les mesures de biomasse sèche ont été effectuées à l'Institut des Sciences de l'Environnement, I.S.E., aux Départements de botanique et de biologie animale, Faculté des Sciences, Université de Dakar. Les caractéristiques anatomique et mécaniques du bois à la Station de Technologie Forestière de Gembloux en Belgique.

Tableau 4. Classification des sols de la mangrove à Toubacouta

Classification	S1 Rhizophora racemosa G.F.W. Meyer	S2 et S3 Rhizophora mangle L. zone de régénération
Française	Sol peu évolué d'apport non climatique	Sol peu évolué d'apport non climatique avec tendance sulfatée acide
F.A.O.	Fluvisol eutrique avec sels solubles	Fluvisol thionique
Américaine	Halic Tropaquepts à tendance Sulfaquepts	Sulfic Tropaquepts

9.1.2 Structure

L'ensemble des observations réalisées en 1982 dans la partie septentrionale de l'estuaire du Saloum a montré que la mangrove présente la structure d'une futaie jardinée (EPEEC 1982).

L'examen de la répartition des tiges fait ressortir clairement que la mangrove à Rhizophora racemosa G.F.W. Meyer est une futaie jardinée par groupes de hauteur homogène se jouxtant les uns les autres.

9.1.3 Méthode de calcul

Pour chaque placette inventoriée et analysée, les données recueillies (biomasse, paramètres dendrométriques, etc...) ont été ventilées dans les catégories de grosseur de tiges exprimées en cm par rapport à la circonférence de base des grumes, sommées pour fournir une moyenne observée et reportée par simple multiplication à l'unité de surface: l'hectare.

Les données de l'inventaire forestier ont été stockées et traitées sur ordinateur Apple II dans un fichier à accès direct sur disquette en vue du calcul des tarifs de cubage par ajustement à une ou deux entrées exprimant le volume en fonction de la circonférence des grumes en cm à la base ou à 1,5 m. de hauteur et de la hauteur totale en m.

L'analyse de la biomasse aérienne a été fragmentée. Les pesées à l'état frais (sur place) et sec (au laboratoire de l'I.S.E.) ont été réalisées sur les feuilles, les fleurs et fruits, les pédoncules, les branches et les tiges ou grumes. Le pourcentage d'eau a été défini et la densité estimée après calcul du volume des tiges par la formule de Simpson.

La détermination de l'âge par la méthode densitrométrique (radiographie aux rayons X), nous a permis d'estimer la productivité primaire.

Une estimation de la surface foliaire simple a été réalisée par la méthode simple: poids-surface.

9.1.4 Résultats globaux de la station 1

Présentation

Les placettes 1A et 1B caractérisent la station 1.
Leurs données regroupées figurent au Tableau 5.

Tableau 5. Résultats globaux de la station 1. Répartition des tiges par catégories de grosseur exprimées en cm, mesures prises en circonférence à la base de la tige

Catégories de grosseur — Indice	Circf. à la base en cm	Résultats globaux Placette 1A et 1B Nombre de tiges	Petit bois	Moyen bois	Gros bois
I	0- 9,9	4			
II	10-19,9	68	72 (40%)		
III	20-29,9	47			
IV	30-39,9	36		83 (46%)	
V	40-49,9	14			
VI	50-59,9	6			
VII	60-69,9	3			
VIII	70-79,9	2			
IX	80-89,9	1			
X	90-99,9	1			27 (15%)
Total		182		182 (100%)	
Densité estimé	: nombre de tiges/ha	3 033			
Age moyen	: an	28			

Objectifs

Estimer de manière aussi précise que possible, la production et la productivité primaire d'un peuplement d'allure jardinée de Rhizophora racemosa G.F.W. Meyer et réaliser des tarifs de cubage peuplement à une et deux entrées.

Echantillons

Choisis de manière dirigée en fonction des catégories de grosseur en circonférence à la base des grumes; l'analyse de la biomasse est réalisée sur un échantillon de 30 grumes abattues. Les tarifs de cubage peuplement sont calculés sur l'étude dendrométrique d'un échantillon de 56 grumes abatues.

L'inventaire des placettes 1A et 1B a répertorié 182 tiges sur 6 ares.

Le peuplement à Rhizophora racemosa G.F.W. Meyer
(station 1)

Ses caractéristique sont les suivantes:
- Densité: 3 000 tiges/ha;
- Volume sur pied: 62 m^3/ha;
- Volume bois fort tige: 46 m^3/ha;
- Hauteur dominante: 9,6 m;
- Hauteur totale maximale observée: 10,60 m;
- Circonférence moyenne à la base: 33 cm;
- Age moyen du peuplement à la base: 28 ans;
- Surface terrière: 22 m^2/ha;
- Surface foliaire simple: 13692 m^2/ha $\approx$ 1,4 ha/ha;
- Biomasse aérienne totale: 60055 kg/ha M.S. $\approx$ 60 T/ha; M.S. ou 90083 kg/ha M.F. $\approx$ 90 T/ha M.F.;
- Productivité primaire nette totale: 2145 kg M.S./ha/an ou 3217 kg M.E./ha/an.
- La biomasse des feuilles: 6651 kg M.S.[2]/ha; 6651 kg M.S./ha × 2,5[1] = 16627,5 kg M.F.[3]/ha;
- La biomasse des bourgeons: 1464 kg M.S./ha; 1464 kg M.S./ha × 2[1] = 2928 kg M.F./ha;
- La biomasse aérienne ligneuse:
- 51947 kg/ha M.S. 52 T/ha M.S.
- 77021 kg/ha M. 78 T/ha M.F.;
- Productivité primaire nette ligneuse:
- 1855 kg/ha/an M.S. ou 2783 kg/ha/an M.F. ou 3638 m^3/ha/an à l'état vert[4];
- 1 m^3 apparent égale 0,527442 m^3 réel ou 1 m^3 réel égale 1,89543 m^3 apparent;
- Densité à l'état vert: 1450 kg/m^3;
- 1 m^3 empilé à l'état vert pèse: 765 kg;
- La productivité primaire nette ligneuse: 2 783 kg/ha/an M.F ou en m^3 empilé à l'état vert 3,638 m^3.

1. Mesure et détermination du coefficient réalisées à l'ISE Dakar;
2. M.S.: matière sèche;
3. M.F.: matière fraîche;
4. En fonction du coefficient d'empilement.

Diamètre des bois	Coef. d'empilement	Vol. réel m^3	Station 1 Répartition des tiges
5 cm	2,26	0,442	39 %
10 cm	1,77	0,568	45,6 %
15 cm	1,54	0,649	14,8 %

Comparaison de la productivité primaire et de la biomasse sur pied de la mangrove à Rhizophora racemosa G.F.W. Meyer avec les principaux écosystème forestiers du monde (Tableaux 6 et 7)

Commentaires: Il ressort de cette comparaison entre écosystèmes forestiers que la forêt de mangrove à Rhizophora racemosa G.F.W. Meyer a une biomasse comparable à une formation arbustive et buissonnante et correspond à la limite inférieure des forêts ombrophiles tropicales, des forêts tropicales caducifoliées, des forêts tempérées de conifères, des forêts boréales.

Sa productivité primaire est faible 215 gr/m^2/an et comparable à la savane. Elle est à la limite inférieure des formations arbustives et buissonnantes.

9.2 Valorisation énergétique des produits ligneux de la mangrove (Doyen 1985)

9.2.1 Introduction

Nous avons calculé le pouvoir calorifique potentiel de la mangrove à Rhizophora racemosa de la zone de Toubacouta.

Sur base de la biomasse ligneuse totale, nous avons estimé le pouvoir calorifique inférieur du bois anhydre feuillus à 4 300 kca l/kg ou 18 MJ/kg.

9.2.2 Résultats

Le pouvoir calorifique inférieur d'un hectare de mangrove est estimé à: 223 372 100 kca l/ha $\approx$ 223.10^6 kca l/ha ou 935 046 MJ/ha = 935.10^3 MJ/ha/an.

Le pouvoir calorifique inférieur de la productivité nette primaire est estimé à: 7 976 500 kca l/ha/an $\approx$ 8.10^6 kca l/ha/an ou 33 390 MJ/ha/an $\approx$ 33.10^3 MJ/ha/an.

9.2.3 Bilan énergétique de la valorisation d'un hectare de mangrove

Il est présenté à la Figure 4.

9.3 Les tarifs de cubage peuplement pour Rhizophora racemosa G.F.W. Meyer (Delaye 1985)

9.3.1 Méthode

Les tarifs de cubage proposés ont été élaborés sur la base des données dendrométriques prélevées sur 56 arbres abattus.

Le choix de ces arbres a été déterminé de manière à refléter dans la mesure du possible la distribution statistique des circonférences de base sur la placette.

Tableau 6. Productivité primaire et biomasse sur pied des principaux écosystèmes forestiers du monde

Type	Surface (en 10^6 ha)	Productivité primaire (en matières sèches) Intervalle en $t.ha^{-1}.an^{-1}$	Moyenne en $t.ha^{-1}.an^{-1}$	Total mondial en 10^9 $t.an^{-1}$	Biomasse sur pied (en matière sèche) Moyenne en $t.ha^{-1}$	Total mondial en 10^9 t
Tropicales						
Pluvieuses tropicales	1 000(1) – 1 200(2)	10-35	23	23	420	420
Sèches tropicales	450	10-25	16	7,2	250	112
Mangroves	30	–	10	0,3	300	9
Tempérées						
Sempervirentes tempérées**	300	6-25	15	4,5	300	90
Caducifoliées + mixtes	300	6-25	13	3,9	280	84
Boréales						
Taîga (conifères)	900	4-20	8,0	7,2	230	205
Plantations	150	6-30	17,5	2,6	200	30
Totaux	3 130	–	–	48,68	–	950
Mangrove à Rhizophora racemosa			t/ha/ax M.S.		t/ha M.S.	
G.F.W. Meyer, Sine-Saloum, Senegal(3)			2,1		60	

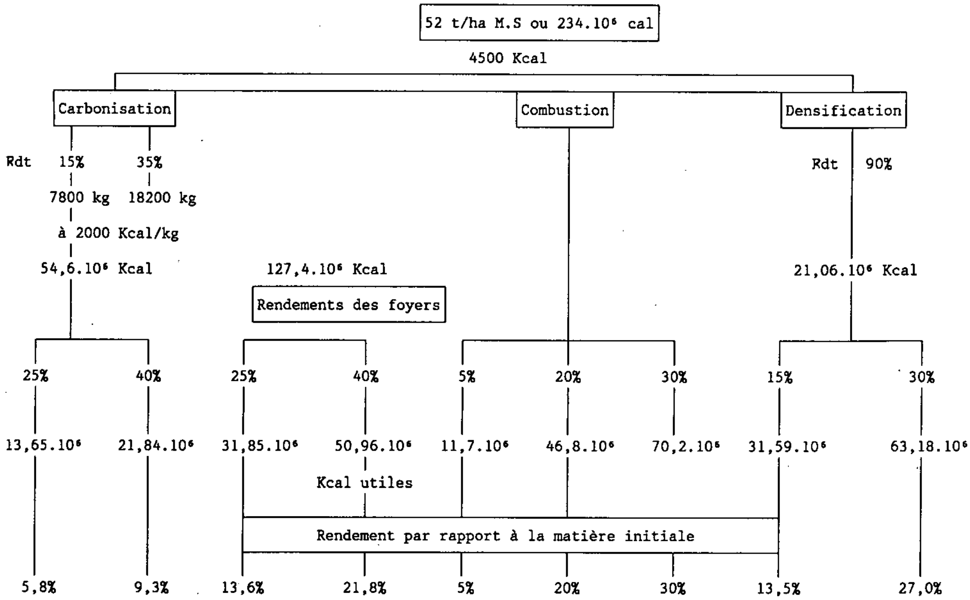
* D'après Ajtay, Ketner et Duvigneaud 1979, mais modifié
** Forêts méditerranéennes incluses.
Sources: (1) Ramade, F. 1981
(2) Inventaires GEMS/PNUE-FAO 1978/80
(3) Doyen, A. 1984

Commentaire

Nos résultats sont le cinquième des données moyennes mondiales pour les mangroves. Nous confirmons ainsi les faibles biomasses sur pied et productivité primaire de la mangrove de la zone de Toubacouta par rapport aux mangroves asiatiques. De ce fait, ses fonctions de protection et de conservation seront mises en exergue sans négliger pour autant sa fonction de production.

Tableau 7. Productivité primaire, production nette et biomasse végétale des grands biomes, exprimées en tonne de matière organique sèche (d'après Whittaker et Likens in Lieth et Wittaker 1975)

Type d'écosystème	Surface 10^6 km^2	Production primaire nette par unité de surface g/m^2/an		Production primaire nette mondiale 10^9 t/ha	Biomasse par unité de surface t/ha		Biomasse mondiale 10^9t
		gamme normale	moyenne		gamme normale	moyenne	
Forêts ombrophiles tropicales	17,0	1000-3500	2200	37,4	60- 800	450	765
Tropicale caducifoliée	7,5	1000-2500	1600	12,0	60- 600	350	260
Forêt tempérée de conifère	5,0	600-2500	1300	6,5	60-2000	350	175
Forêt caducifoliée tempérée	7,0	600-2500	1200	8,4	60- 600	300	210
Forêt boréale (Taïga)	12,0	400-2500	800	9,6	60- 400	200	240
Formations arbustives et buissonnantes	8,5	250-1200	700	6,0	20- 200	60	50
Savanes	15,0	200-2000	900	13,5	2- 150	40	60
Steppes tempérées	9,0	200-1500	600	5,4	2- 50	16	14
Toundra	8,0	10- 400	140	1,1	1- 30	6	5
Déserts et semi-déserts buissonnantes	18,0	10- 250	90	1,6	1- 40	7	13
Déserts extrêmes, zones polaires	24,0	0- 10	3	0,07	0- 2	0,2	0,5
Agroécosystèmes	14,0	100-3500	650	9,1	4- 120	10	14
Marécages	2,0	800-3500	2000	4,1	30- 500	150	30
Lacs et fleuves	2,0	100-1500	250	0,5	0- 1	0,2	0,05
Total des continents	149	2- 400	773	115	0- 005	123	1837
Océan (au large)	332,0		125	41,5	0,05- 1	0,03	1,0
Zones d'Upwelling	0,4	400-1000	500	0,2	0,01- 1	0,2	0,008
Plateau continental	26,6	200- 600	360	9,6	0,4 - 40	0,1	0,27
Récifs coralliens et herbiers d'algues	0,6	500-4000	2500	1,6	0,1 - 60	20	1,2
Estuaires	1,4	200-3500	1500	2,1		10	1,4
Total océanique	361		152	55,0		0,1	3,9
Total général	510		333	170		360	1841
Mangrove à Rhizophora racemosa G.F.W. Meyer Estuaire du Siné-Saloum (Doyen 1984)			215 g/m^2/an			60 t/ha	



Source: Carré, J., Lacrosse, L., Hebert, J., (S.D.)

L'utilisation de la biomasse en tant que substitut du bois de feu. C.E.E. Direction Générale du Développement. Station de Technologie Forestière Gembloux. Belgique. Volume 1/64 pp. (Tableau p. 45).
Modifié par Doyen, A. (1984) pour un ha de mangrove.
Remarque: Le rendement du foyer constitué de 3 pierres varie entre 5 et 15%. Les foyers améliorés ont un rendement estimé entre 15 et 30%.

Figure 4 Bilan énergétique de la valorisation d'un hectare de mangrove à Rhizophora racemosa G.F.W. Meyer

Les paramètres retenus sont la circonférence à la base (C_B), la circonférence à 1,50 m (C_{150}), la hauteur totale (H), qui sont les plus accessibles à la mesure sur arbres non-abattus.

Une première approche consistant à reporter graphiquement le volume mesuré (méthode de Simpson) en fonction de C_B, C_{150} et H, ceci pour chaque arbre, nous autorise à penser que les relations liant ces paramètres sont du type logarithmique ou exponentiel.

Les équations retenues correspondent aux meilleurs coefficients de corrélation obtenus.

Il a été en outre possible d'évaluer la dispersion des résultats en calculant après chaque régression un coefficient Va dit 'de variation', exprimant en % le rapport de l'écart-type résiduel à la moyenne des volumes mesurés.

9.3.2 Les résultats

Tarif de cubage no 1:

$$V = 25{,}39\, C_{150}^{1{,}91}\, e^{0{,}084\, H} \text{ en cm}^3\text{, avec } c_{150} \text{ en cm et H en mm}$$

Coefficient de corrélation: $r = 0{,}996$
Coefficient de variation : $Va = 21{,}7\%$

Note: ce coefficient de variation peut paraître élevé, mais sa valeur est fortement conditionnée par la présence de deux très grosses tiges auxquelles la formule précédente est mal adaptée. En faisant abstraction des deux volumes correspondants, Va retombe au dessous de 13%. Cette remarque vaut pour les autres tarifs de cubage.

où C_{150}: circonférence à 1,50 m de hauteur en cm;
h : hauteur totale de l'arbre en m;
V : volume en cm_3;
e : exponentielle.

Tarif de cubage no 2:

$$V = 18{,}44\ C_B^{0{,}32} \quad C_{150}^{1{,}87} \text{ en } cm^3\text{, avec } C_B \text{ et } C_{150} \text{ en cm}$$

où C_B : circonférence à la base de la tige, en cm;
C_{150}: circonférence à 1,50 de hauteur, en cm;
V : volume en cm_3.

Coefficient de corrélation: $r = 0{,}993$
Coefficient de variation : $Va = 14{,}5\%$

Tarif de cubage no 3:

$$V = 14{,}36 \quad C_{150}^{1{,}91} \quad H^{0{,}61} \text{ en } cm^3 \text{ avec } C_B \text{ et } C_{150} \text{ en cm}$$

où C_{150}: circonférence à 1,50 m de hauteur, en cm;
h : hauteur totale en cm;
V : volume en cm^3.

Coefficient de corrélation: $r = 0{,}996$
Coefficient de variabilite : $Va = 22{,}4\%$

Tarif de cubage no 4:

$$V = 0{,}65\ (C_B3^*c_{150})^{1{,}91} H^{\cdot 76} cm^3\text{, } C_B \text{ et } C_{150} \text{ en cm, H en m}$$

où C_B : circonférence à la base, en cm;
C_{150}: circonférence à 1,50 de hauteur, en cm;
h : hauteur totale en m;
V : volume total en cm^3.

Coefficient de corrélation: $r = 0{,}997$
Coefficient de variation : $Va = 13{,}6\%$

Cette formule donne les meilleurs résultats car elle intégre le plus grand nombre de paramètres. Elle n'est donnée toutefois qu'à titre indicatif, son emploi sur le terrain exigeant le calcul intermédiaire de $(C_B + 3^*C_{150})$ avant de pouvoir exploiter le tarif de cubage correspondant.

Tarif de cubage no 5:

$$V = 22{,}37c_{150}^{2{,}16}\ cm^3, \text{ avec } C_{150} \text{ en cm}$$

où V : volume en cm^3
C_{150}: circonférence à 1,5 m de hauteur, en cm

Coefficient de corrélation: r = 0,993
Coefficient de variation : Va = 18,6%

Cette formule n'intégrant que la seule circonférence à 1,50 m (plus fiable que la circonférence à la base car le tronc ne comporte plus de cannelures à ce niveau), est d'utilisation particulièrement commode sur le terrain.

9.4 Caractéristiques technologiques (Leclercq 1985)

Elles sont présentées au Tableau 8.

Usages potentiels du bois

Le Rhizophora racemosa se situe, par son retrait total, à la limite des bois susceptibles de se conserver à l'état rond sans manifester une tendance exagérée aux fentes intolérables. C'est probablement sous cette forme qu'il se verra utilisé la plupart du temps, comme piquets, poteaux ou étançons, d'autant plus qu'il paraît doué à cet égard de propriétés mécaniques largement suffisantes.

Il semble bien que l'espèce qui nous occupe n'atteigne pas régulièrement les dimensions adéquates pour qu'il soit possible d'utiliser son bois dans la filière du sciage traditionnel malgré les qualités mécaniques dont il fait preuve.

Toutefois, les billes de dimensions suffisantes pourraient trouver un usage dans le domaine de la charpente, mais dans ce cas, sa nervosité élevée impose un débit peu de temps après l'abattage pour éviter les fentes de dessication si préjudiciables au rendement de sciage.

Les résistances unitaires relevées à la suite des essais de compression et de flexion statique, ainsi que son excellente durabilité naturelle en font un matériau de choix pour la construction en zone tropicale. De même, les travaux hydrauliques (écluses, pilotis, jetées, ponts, estacades) y verront un matériau propre à satisfaire leurs exigences quant à la solidité.

Diverses qualités telles que l'adhérence, la dureté, la finesse du grain font encore de cette espèce un materiau convenant pour certains usages spéciaux: tournerie, fabrication de poulies, engrenages...

Le bois de palétuvier rouge, principalement sous forme de rondines de faible diamètre, peut enfin constituer un excellent combustible en région tropicale, soit sous forme brute, soit sous forme de charbon de bois.

Pour cette dernière utilisation, le bois de cette espèce permet sans doute d'atteindre un haut rendement si l'on tient compte de sa densité très élevée.

Tableau 8. Caractéristiques mécaniques du bois de Rhizophora racemosa G.F.W. Meyer

Propriétés	Echantillons				Moyenne générale	Minimum	Maximum	Interprétation
	10	12	13	14				
Résistance en compression axiale (kg/cm^2): C	645	648	769	746	702	461	821	moyenne
Cote statique $\frac{C}{100D^2}$	5,79	6,11	7,36	7,36	6,70			moyenne
Cote spécifique $\frac{C}{100D^2}$	5,52	7,77	7,04	7,27	6,40			faible
Résistance à la flexion statique (kg/cm^2): F	1515	1301	1254	1717	1447	959	1895	moyenne
Cote de flexion $\frac{F}{100D}$	14,01	12,27	12,00	16,95	13,81			faible
Cote de tenacité $\frac{F}{C}$	2,35	2,01	1,63	2,30	2,07			moyennement tenace
Module d'élasticité (kg,/cm^2): E (x10^3)	182,6	160,7	152,0	196,0	172,8	107,3	220,5	forte
Résistance au choc (kgm/cm^3): K	0,61	0,46	0,60	0,57	0,56	0,42	0,71	moyenne
Cote dynamique $\frac{K}{D^2}$	0,52	0,41	0,55	0,56	0,51			faible
Résistance à la traction (kg/cm^2): T	45	48	44	48	46	27	63	moyenne à forte
Cote d'adhérence $\frac{T}{100D}$	0,42	0,45	0,42	0,47	0,44			moyennement adhérente
Résistance au fendage (kg/cm): Fd	28	26	23	18	24	15	31	moyenne à forte
Cote de fendage $\frac{Fd}{100D}$	0,26	0,24	0,22	0,18	0,22			moyennement fissile
Résistance au cisaillement (kg/cm^2): Cis.	197	232	205	185	205	158	261	forte

9.5 L'aménagement forestier de la mangrove à Rhizophora racemosa G.F.W. Meyer (Doyen 1985)

Martinot-Lagarde (Barry et al 1979) résume d'une façon réaliste la notion d'aménagement adaptable à toutes forêts:

Aménager une forêt, c'est 'décider ce que l'on veut faire, compte tenu de ce qu'on peut y faire et en déduire ce que l'on doit y faire'.

Il convient de définir les rôles de la forêt.

La mangrove de Toubacouta a pour rôles principaux: la protection des côtes, la production écologique (végétale et animale), et énérgétique.

Elle est limitée par sa croissance; 3,6 m^3/ha/an à l'état vert, par les conditions très spécifiques du milieu et son accès difficile. Si la main-d'oevre est nombreuse, les moyens financiers pour l'exploitation et la régénération devront être relativement importants et d'un coût total probablement supérieur, aux mêmes opérations réalisées sur terre ferme. Notons que les transbordements nécessiteront une main-d'oeuvre importante.

L'exploitabilité est fixée à 60 ans et devra être testée au fur et à mesure de l'amélioration de nos connaissances.

La possibilité qui est la quantité de matière qu'il est possible de tirer chaque année d'une forêt, fixée par volume, a pour objet de réaliser (découper) chaque année un nombre fixe de m^3 sans tenir compte du nombre d'arbres exploités ni de la surface parcourue.

Son application nécessiterait la réalisation d'inventaires successifs pour vérifier l'accroissement annuel moyen, estimé à 3,6 m^3/ha/an. (Doyen 1984).

Nous pensons cependant que ce système doit être assoupli. Le forestier soucieux de conserver une lisière de protection, en cordon des bolons, aussi efficace que possible, y interviendra en fonction de l'état sanitaire des tiges par des coupes sanitaires successives et assurera la régénération en conservant une densité de 3000 tiges/ha, garante d'une bonne protection.

La Figure 5 propose une rotation de 20 ans avec passage autorisé à mi-rotation.

Les coupes seront assises de proche en proche, des plus vieux groupes vers les plus jeunes, de la zone intérieure vers la lisière de protection en bordure des bolons. La proposition de planification des interventions sylvicoles en mangrove est représentée à la Figure 5. Elle décrit la suite des opérations à mener en fonction des peuplements existant à l'état initial dans la zone étudiée.

Cette sylviculture et cet aménagement nécessitent beaucoup de précautions de la part du forestier et présentent un aspect intensif contraignant, nous en sommes conscients.

Cette formation végétale spécialisée à vocation multiples, si l'on veut satisfaire les besoins exprimés, doit être traitée avec soins et les paramètres de réalisation redéfinis en fonction des données nouvelles aquises par l'expérience du terrain et consignées par les inventaires. La pérennité de la mangrove est l'objectif prioritaire. Il serait souhaitable de maîtriser la régénération naturelle avant d'intervenir par voie de plantation.

L'aménagement proposé vise à promouvoir la croissance optimale du Rhizophora racemosa G.F.W. Meyer. A ce propos, nous nous référons aux travaux de Christensen (1983). '...généralement, la longueur de la révolution varie entre 20 et 40 ans (mangroves asiatiques). Divers systèmes de coupes progressives de régénération ont été expéri-

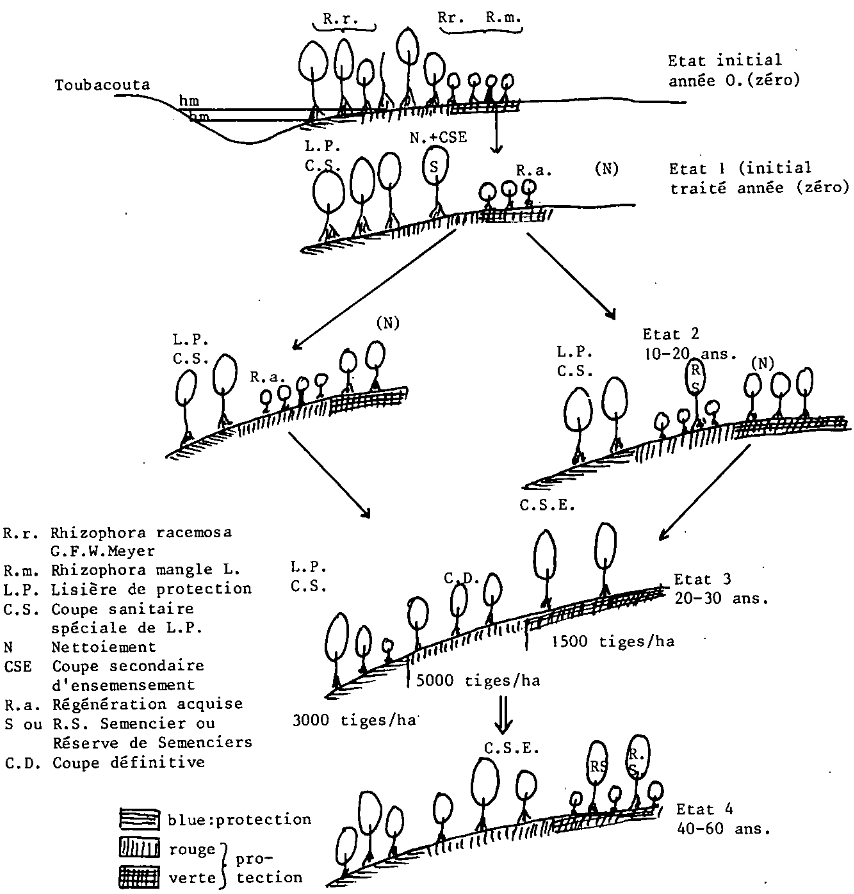


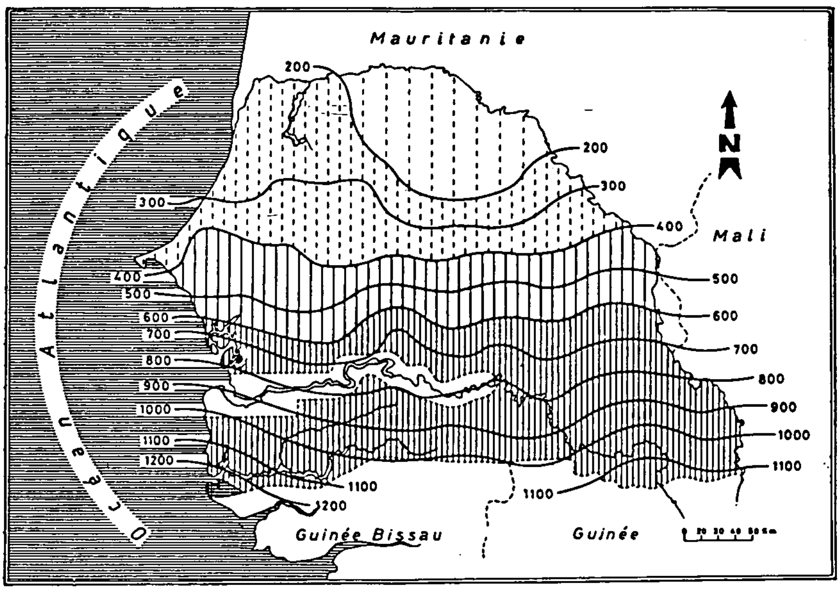
Figure 5 Proposition de planification des interventions sylvicoles en mangrove

mentés. Il convient en effet d'ouvrir le couvert pour accroître la taille des arbres. Par contre, de longues révolutions sont préférables dans les zones susceptibles de s'assècher. Les vieux peuplements tendent aussi à être plus clairs et la régénération préexistante des essences de lumière (Rhizophora sp.) est plus importante. De longues révolutions favorisent le Rhizophora. Le traitement préconise 3 éclaircies systématiques à 15-19, 20-24 et 25-29 ans. L'abbatage final est une coupe à blanc de tous les arbres de plus de 7,5 cm de diamètre ou 2 cm de circonférence à la base, juste au dessus des racines. On procède à la replantation sur presque toute la superficie. Dans les peuplements équiennes, les semenciers doivent être épargnés à raison de 80 arbres/ha'. Corpuz 1972; Liew, Diah et Wong 1977, insistent sur la nécessité de conserver 'un rideau abri de 10 m de large...le long des côtes, des rives des estuaires et des cours d'eau, de façon à prévenir l'érosion et à constituer une source de grains'.

Ces analyses doivent être adaptées aux conditions de notre zone d'étude. Il semble d'après nos observations que la régénération soit suffisante. Ceci est un facteur de succès.

Nous insisterons cependant sur la concertation nécessaire avec les populations locales, les décideurs locaux et les administrations compétentes. La conservation, la gestion des ressources naturelles et le développement de ces terroirs ne seront opérationnels et efficaces qu'avec le concours et la participation des populations intéressées.

Un volet formation professionnelle et valorisation des produits ligneux récoltés, doit être envisagé afin d'intégrer la forêt en amont et l' 'industrie' en aval.



Source : GOUDIABY, A. (1984) et SAMBOU, B. (1985).

Légende :

Zone d'étude (TOUBACOUTA)

Domaine Sahélien
- Secteur sahélo-saharien
- Secteur sahélo-soudanien

Domaine Soudanien
- Secteur soudano-sahélien
- Secteur soudano-guinéen

Domaine Guinéen

Isohyète (moyenne décennale : 1971-1980).

Carte 2 Domaine forestiers –isohyètes (moyenne décennale: 1971-1980) et zone d'étude

10 Conclusions générales

Les recherches de l'équipe 'écologie forestière', entreprises au sein de l'atelier d'étude des mangroves et de l'estuaire du Saloum, Sénégal, sous l'égide de UNESCO (Unité Rosta du Breda), avec le concours de l'Institut des Sciences de l'Environnement (I.S.E.) de Dakar, de la Station de Technologie Forestière de l'Etat à Gembloux, Belgique, et du Laboratoire de Pédologie de l'ORSTOM, Dakar, mettent en évidence les fonctions multiples et les potentialités, naturelles, sociales, économiques et culturelles de la mangrove de la zone de Toubacouta, Bolon du Bandiala de l'estuaire du Saloum au Sénégal.

Ces travaux s'intègrent dans les objectifs de la Stratégie Mondiale de la Conservation (1980).

Nous pensons que le statut particulier de conservation proposé par le MAB (Man and Biosphere): 'la réserve de biosphère' pourrait apporter un concours positif à l'amélioration des conditions de vie des populations locales par leur participation active à l'exploitation durable de leur ressource, susceptible de leur fournir un revenu numéraire non négligeable.

Comme Christensen (1983), nous soulignons que: '...l'écosystème mangrove fournit des alevins notamment pour l'élevage (pisciculture) et maintient la bonne qualité de l'eau. L'effet brise-vent est bien connu. L'ostréïculture est une activité importante. L'exploitation forestière est généralement considérée comme étant compatible avec les intérêts de la pêche et de l'aquaculture en eau libre à condition que le caractère de la forêt soit préservé et la régénération suffisante'.

Mangrove – faune – pêche – aquaculture en eau saumâtre – aquaculture en eau libre: pisciculture, algoculture, production de sel – agriculture (au succès assuré là où le sol contient suffisamment de chaux pour empêcher la formation de sols sulfatés acides) et les interactions entre ces pôles d'activités socio-économiques, sont autant de valorisations de l'écosystème étudié.

Le rôle économique de la mangrove à Rhizophora racemosa G.F.W. Meyer de Toubacouta n'est pas négligeable, même si nous avons constaté que son état végétatif moyen nécessite une exploitation parcimonieuse et respectueuse des facteurs écologiques stationnels. Sa régénération actuellement suffisante, reste néanmoins le problème le plus préoccupant. Notons que: '...des essais sylvicoles entrepris au Sénégal par le C.T.E.T. depuis 1968, sur les sols salés du Siné-Saloum permettent de penser qu'il serait vraisemblablement possible de remplacer certaines portions de la mangrove par des plantations de Melaleuca après édification de diguettes pour contrôler la submersion et favoriser le déssalement du sol'. (Giffard 1974).

Notre approche est globale et la plantation d'essences exotiques ne peut suffir à satisfaire les besoins multiples exprimés, ni assurer le fonctionnement de l'écosystème sans perturbations.

Or, nous sommes conscients de son importance écologique au sein de la chaîne alimentaire de détritus. Les fonctions de production, de protection, scientifiques, écologiques, de conservation et culturelles ont été mises en exergue, la mangrove est bien une formation forestière à usages multiples.

Cette formation s'adapte physiologiquement à son milieu spécifique par la concentration du Na dans les feuilles âgées qui participent ainsi au dessalement de la sève (Diallo 1984).

La mangrove du Siné-Saloum et de la zone de Toubacouta n'est pas aussi luxuriante que ses consoeurs asiatiques ou d'Amérique du Sud. Ceci est principalement dû à la teneur importante en sel de l'eau, toujours supérieure à celle de l'eau de mer (42 g/l à 75 g/l) (Saos et Pages 1982). La pluviosité varie entre 600 et 850 mm. Nous constatons une péjoration climatique par rapport aux précipitations normales comprises entre 900 et 1000 mm. Les sols sont peu évolués et d'apports non climatiques avec tendance sulfaté-acide vers l'intérieur des terres. Les vasières sont caractérisées par leur salinisation et leur acidification. L'estuaire du Saloum pourrait être confondu avec une ria sillonnée par de larges bolons aux multiples ramifications.

La mangrove observée présente la structure d'une futaie jardinée par groupes de hauteur homogène généralement monospécifique, constituée de Rhizophora racemosa G.F.W. Meyer en bordure des bolons et de Rhizophora mangle L. vers l'intérieur.

A titre indicatif, un palétuvier rouge Rhizophora racemosa G.F.W. Meyer de taille moyenne possède les caractéristiques suivantes: hauteur totale 7,35 m; circonférence à la base 23,8 cm; circonférence au milieu 14,5 cm; circonférence fin bout 4,5 cm; volume 12.324 cm^3, densité fraîche 1.379 kg/m^3 poids frais de la tige 17 kg, des racines 39 kg, des feuilles 2.470 gr, des fruits et fleurs 800 gr des pédoncules 460 gr, soit une biomasse aérienne de 24 kg (poids frais) et une biomasse souterraine de 39 kg (pois frais).

La teneur en eau par rapport à la matière sèche est estimée à 88%.

L'inventaire complet de placettes échantillons dans un peuplement dominant monospécifique à Rhizophora racemosa G.F.W. Meyer a mis en évidence les caractéristique suivantes (Doyen 1984): densité 3000 tiges/ha, volume sur pied: 62 m_3/ha, volume bois fort tige: 46 m_3/ha, hauteur dominante: 9,6 m hauteur maximale observée: 10,6 m, circonférence moyenne à la base: 33 cm, âge moyen: 28 ans, surface terrière: 22 m^2/ha surface foliaire simple: 1,4 ha/ha, biomasse aérienne totale 60 T/ha matière sèche, productivité primaire nette totale 2145 kg matière sèche/ha/an, biomasse des feuilles: 6651 kg matière sèche/ha, biomasse aérienne ligneuse 52 T/ha matière sèche: productivité primaire nette ligneuse: 1855 kg matière sèche/ha/an ou 3,638 m^3/ha/an à l'état vert. Le pouvoir calorifique inférieur d'un ha de mangrove est estimé à 223.10^6 Kcal ou 935.10^3 MJ/ha. La quantité charbon de bois qui pourrait être produite après coupe à blanc serait de 10 T/ha, soit 78.10^6 Kcal/ha ou 326.10^3 MJ/ha pour un rendement calorifique de 34,9%.

Le valorisation énergétique d'un ha de mangrove par carbonisation, combustion ou densification montre un rendement par rapport à la matière initiale variant entre 5 et 30%.

Nous avons estimé par m^3 de bois empilé à l'état vert, le poids des écorces à 70 kg. Plusieurs tarifs de cubage peuplement ont été élaborés (Delaye 1984) pour le gestionnaire forestriere. Les tarifs à une et deux entrées sont joint en annexe.

Les caractéristiques anatomiques et mécaniques du bois analysées, (Leclercq 1984) ont montré qu'il est préférable d'utiliser le Rhizophora racemosa G.F.W. Meyer, bois dense et durable sous forme de bois rond. Les billes de dimensions suffisantes pourraient trouver un usage dans le domaine de la charpente. C'est un matériau de choix pour la construction en zone tropicale, de même que pour tous les travaux hydrauliques. Diverses qualités telles que l'adhérence, la dureté, la finesse du grain font encore de cette espèce un matériau convenant pour des usages spéciaux: tournerie, fabrication de poulies, engrenages... C'est un excellent combustible. La densité élevée permet d'obtenir d'excellents rendements lors de sa transformation en charbon de bois.

La régénération de la mangrove semble suffisante et dynamique.

L'état sanitaire est bon. Néanmoins, nous avons constaté des nids aériens d'isoptères sur bois sénile ou mort. Ils ont fait l'objet d'une étude spécifique (Agbogba 1984) Microcerotermes fuscotibialis Sjöstedt se nourrit du bois de Rhizophora racemosa G.F.W. Meyer.

Une sylviculture écologique, soucieuse de la fonction de protection de la mangrove, tampon crucial entre l'océan et le continent, débouche sur un plan d'aménagement conservateur dans le sens dynamique du terme.

Il a pour objectif d'utiliser au mieux les ressources ligneuses disponibles et d'assurer la pérennité de l'écosystème.

Un schéma d'intervention est proposé en vue d'une gestion durable et de satisfaire les besoins multiples exprimés par les populations locales.

Ecosystème spécifique, la mangrove doit figurer comme un élément essentiel de l'aménagement du territoire. A ce titre, sa conservation doit être assurée.

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Conséquences sur l'environnement aquatique et la pêche d'un barrage-écluse anti-sel en Casamance (Sénégal)

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1 Résumé

Un barrage-écluse a été construit sur un petit affluent de l'estuaire de la Casamance pour essayer de gagner à la riziculture les terres salées situées en amont. Nous étudions les conséquences de cet ouvrage sur deux paramètres de l'environnement aquatique (salinité et chlorophylle a) ainsi que sur les poissons et crustacés.

Summary

A dam was built across a Casamance tributary in order to reclaim salted upstream lands for rice culture. Consequences for aquatic environment (salinity and chlorophyl), fishes and crustaceas are examined.

2 Introduction

La sécheresse qui sévit depuis plus de quinze ans au Sahel s'est traduit, dans l'estuaire de la Casamance, au sud du Sénégal, par une augmentation continue de la salinité. De ce fait, des terres du lit majeur autrefois utilisées ou utilisables pour la riziculture sont devenues impropres pour cette activité.

Un barrage écluse a été construit sur le petit bolon (marigot en Casamance) de Guidel, en amont de Ziguinchor, pour tenter de récupérer un peu plus d'un millier d'hectares de terres salées. Ce projet a valeur de test pour l'ensemble de la Casamance.

Un programme pluridisciplinaire a pour objectif d'apprécier les divers effets du barrage sur l'environnement en vue d'assurer la gestion la plus rationelle possible de l'ouvrage.

Nous étudions ici les effets du barrages sur les espèces pêchées.

3 Description de la zone d'étude

3.1 Cadre géographique

Aucune étude n'ayant été faite avant la construction du barrage il était difficile d'apprécier les impacts de celui-ci sur l'aquifaune. Nous avons tenté de pallier cette difficulté en comparant la zone amont du barrage (zone 2) d'une part avec la zone aval (zone 1), d'autre part avec un petit bolon non aménagé situé une quinzaine de km en amont, le bolon de Sindoné (zone 4). Il faut cependant noter que la hauteur d'eau peut attein-

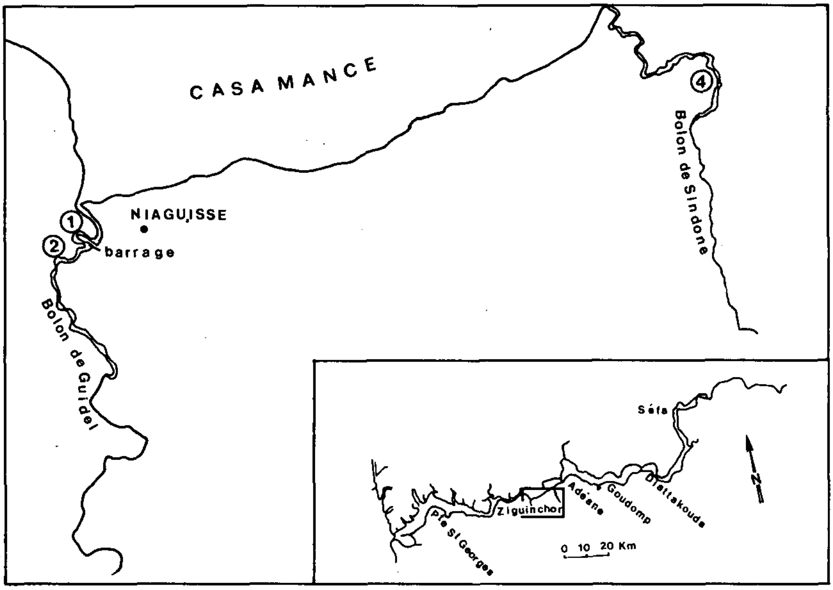

Figure 1 Zone d'étude

dre près de 4 m dans le bolon de Guidel dans sa partie la plus profonde (au niveau du barrage) alors qu'elle ne dépasse pas 1, 50 m dans celui de Sindoné.

3.2 Description et fonctionnement du barrage-écluse

Le barrage est en béton armé et comprend quatre ouvertures équipées de vannes glissant verticalement. En outre, du côté aval, des portes fonctionnent comme clapets; lorsque les vannes sont ouvertes les portes s'ouvrent automatiquement pendant le jusant et se ferment pendant le flot; elles peuvent cependant être maintenues continuellement soit en position fermée soit en position ouverte.

En période des pluies, en amont du barrage, l'apport d'eau douce est très supérieur à l'évaporation. Pour assurer le lessivage des sols et maintenir le niveau à une certaine côte, des vidanges sont réalisées. En saison sèche au contraire des admissions d'eau sont effectuées. Pendant la saison des pluies 1984 (juin à octobre) il y a eu quatre vidanges. Pendant la saison sèche 1984-1985 deux admissions ont été réalisées le 7 février et le 6 mars 1985. Pendant la saison des pluies 1985, quatre vidanges ont été faites, le 28 juin, le 24 juillet, le 8 août et le 8 septembre.

3.3 Caractéristiques du milieu

Nous ne considérons que deux paramètres, la salinité et la chlorophylle a: la salinité car elle est certainement, du fait de l'amplitude des ses variations, un facteur de sélection entre espèces; la chlorophylle a, car elle peut être considérée comme un indice de la richesse trophique du milieu. Nous suivrons les variations de ces paramètres dans les trois zones entre octobre 1984 et septembre 1985.

3.3.1 Salinité (Figure 2)

Dans les trois zones la salinité augmente entre septembre et juin; elle chûte très brutalement ensuite. Si l'on considère la salinité de surface elle a varié entre 9 et 66% en aval du barrage, entre 4 et 68% en amont, entre 3 et 58% dans le bolon de Sindoné. Une stratification très nette est observée dans le bolon de Guidel, de part et d'autre du barrage, en saison des pluies. A Sindoné, la faible profondeur devient inférieure à 2 m, vers l'amont.

3.3.2 Chlorophylle a (Figure 3)

D'une manière générale les valeurs sont élevées dans les trois zones; la zone 1 est néanmoins un peu moins riche que les deux autres. Les valeurs les plus élevées (30 µg/l dans la zone 1, 62 µg/l dans la zone 2, 40 µg/l dans la zone 4) sont observées en saison fraîche et sèche; une valeur élevée (30 µg/l) est cependant observée également en juillet dans la zone 4. Les valeurs d'octobre et novembre sont très faibles dans les trois zones.

4 Espèces pêchées

Les pêches ont été effectuées avec trois types de filet:
- Un filet en forme de chalut, à maille de 8 mm de côté, manoeuvré comme une senne de plage à partir des berges pour capturer les juvéniles;

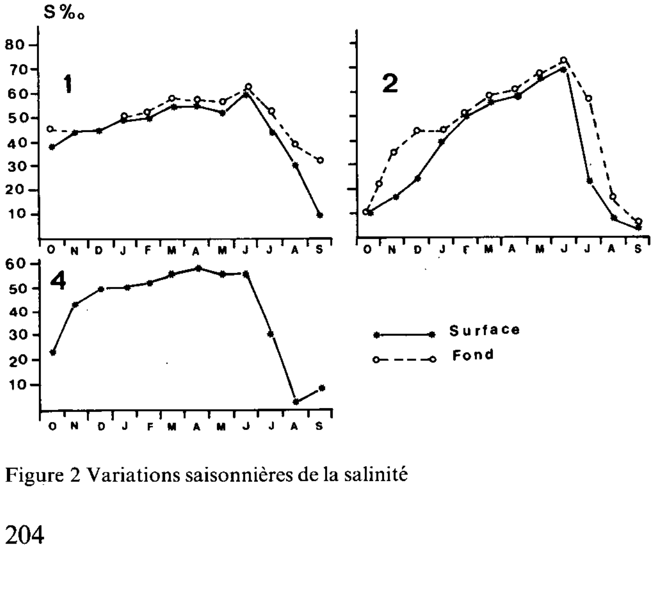

Figure 2 Variations saisonnières de la salinité

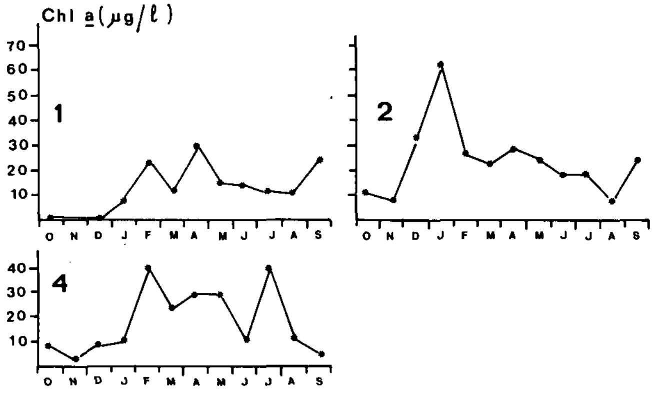

Figure 3 Variations saisonnières de la chlorophylle a

- Deux filets maillants à maille de 25 mm et 30 mm de côté pour capturer les subadultes et adultes des espèces les plus fréquentes; le premier plus spécialement adapté pour la pêche des mulets, le second pour la pêche des tilapies.

Suivant le type de filet et la zone, les pêches ont commencé entre juillet et septembre 1984. Les pêches ont lieu la nuit. Une série de pêches est réalisée, chaque semaine, dans chaque zone et pour chaque type de filet. Les résultats ont été standardisés en les rapportant à une unité d'effort de pêche: 50 coups de filet pour les juvéniles; 1 coup de filet à maille 25 + 1 coup de filet à maille 30 pour les subadultes et adultes.

Pour rendre compte des résultats du filet à maille 8 qui peut capturer des individus de tailles différentes, nous avons tenu compte des effectifs; pour ceux des filets maillants, qui capturent des individus assez bien calibrés, nous avons tenu compte des poids.

4.1 Juveniles

4.1.1 Abondance moyenne dans chaque zone

Nous avons tenu compte de tous les résultats disponibles, du début des pêches (juillet à septembre 1984) à novembre 1985 inclus. Les résultats par espèce et par zone sont présentés dans le Tableau 1.

C'est dans la zone 4 que l'effectif moyen total est le plus élevé (1747). Il est nettement moindre dans la zone 1 (1060) et tombe à 779 dans la zone 2.

Qualitativement il y a peu de différence entre les zones puisque les cinq espèces les mieux représentées leur sont communes: Sarotherodon melanotheron, Ethmalosa fimbriata, Tilapia guineensis, Penaeus notialis et Geres melanopterus.

On peut seulement noter la plus grande dominance des tilapies dans la zone 2 (75%) alors que dans les deux autres zones, bien qu'ils soient encore très largement dominants, ils ne représentent que 63% de l'effectif total. Inversément G. melanopterus qui ne représente que 2,4% des effectifs dans la zone 2, en représente 5, 2% dans la zone 1 et 10, 9% dans la zone 4. De même Benaeus notialis passe de 4,5% dans la zone 2 à 5,8% dans la zone 1 et 12,5% dans la zone 4.

Tableau 1. Abondance moyenne par unité d'effort de pêche avec le filet à maille 8 pour l'ensemble de la période d'étude

Espèces	Zones		
	2	1	4
Liza falcipinnis	7	29	5
L. grandisquamis	3	20	49
L. dumerili	3	5	14
Mugil bananensis	1	8	5
Elops lacerta	19	15	24
Ethmalosa fibriata	85	175	74
Sarotherodon melanotheron	532	596	1 045
Tilapia guineensis	55	67	55
Hemichromis fasciatus	6	5	2
Geres melanopterus	19	55	191
Sphyraena piscatorum	1	1	2
Polydactylus quadrifilis		1	1
Galeoïdes decadactylus	1		
Pomadasys jubelini	3	3	2
Psettus sebae	5	7	2
Cynoglossus sp.		4	4
Calinectes sp.	4	8	54
Penaeus notialis	35	62	218
Total	779	1 060	1 747

Les jeunes mulets sont très peu abondants dans les trois zones. Toutes espèces réunies, leur pourcentage est toujours inférieur à 6%.

4.1.2 Variation saisonnières de l'indice d'abondance

- Toutes espèces confondues dans chacune des trois zones.
  Ces variations ont été étudiées entre octobre 1984 et septembre 1985 et sont présentées dans la Figure 4. Elles sont peu perceptibles dans la zone 2, légèrement marquées dans la zone 1 et très marquées dans la zone 4. Dans les deux dernières zones la période de plus grande abondance se situe d'octobre à avril. Les différences dans l'effectif total qui avaient été notées au paragraphe précédent ne porte en fait que sur cette période; de mai à septembre l'abondance est identique dans les trois zones.

- Principales espèces dans la zone 2 (Figure 5)
  Ce n'est que pour S. melanotheron et E. fimbriata que les effectifs sont suffisants pour permettre de discerner des variations susceptibles d'être significatives. Les effectifs les plus importants sont trouvés en octobre-novembre et d'avril à juillet pour la première espèce, de janvier à mars pour la seconde.

- Principales espèces dans la zone 4 (Figure 6)
  S. melanotheron est surtout pêché d'octobre à avril avec un maximum en décembre. Pour P. notialis et E. fimbriata les maxima sont observés en octobre.

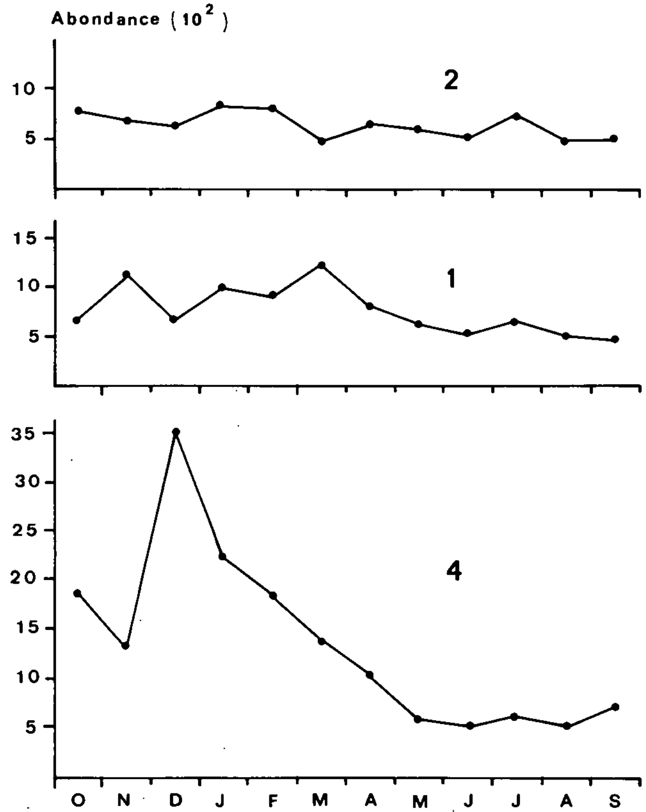

Figure 4 Variations saisonnières de l'indice d'abondance totale des juvéniles dans les trois zones

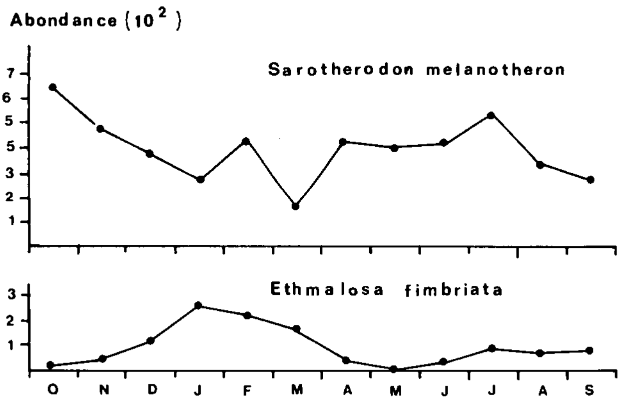

Figure 5 Variations saisonnières de l'indice d'abondance des juvéniles des deux principales espèces dans la zone 2

4.2 Subadultes et adultes

4.2.1 Rendement moyen dans chaque zone

Ici encore nous avons tenu compte de tous les résultats disponibles, entre juillet-août 1984 et novembre 1985. Les résultats par espèces et par zone sont présentés dans le Tableau 2. Les rendements globaux différent peu d'une zone à l'autre. En revanche, la composition des prises varie beaucoup.

Tableau 2. Rendement moyen (g) pour deux coups de filet (un avec la maille 25 et un avec la maille 30) pour l'ensemble de la période d'étude

Espèces	Zones		
	2	1	4
Liza falcipinnis	1 488	610	781
L. grandisquamis	404	824	496
L. dumerili	280	93	307
Mugil bananensis	75	468	516
M. cephalus	13	69	23
Elops lacerta	260	89	186
Ethmalosa fimbriata	148	434	953
Sarotherodon melanotheron	1 301	1 074	190
Tilapia guineensis	26	38	9
Hemichromis faciatus	25	14	9
Geres melanopterus	1	10	21
G. nigri		3	36
Syphyraena piscatorum	100	32	36
Polydactylus quadrifilis		3	17
Pomadasys jubelini		6	4
Pseudotolithus typus			13
P. brachygnatus	37	107	26
P. elongatus	23	29	46
Arius gambiensis	19	100	99
Calinectes sp.	52	8	1
Total	4 252	4 011	3 769

On notera tout d'abord l'énorme prépondérance de L. falcipinnis et S. melanotheron dans la zone 2 alors que dans les autres zones la décroissance de la biomasse en fonction du rang est plus progressive.

Les pourcentages des trois principales familles dans les rendements sur les trois zones sont les suivants:

	Zone 2	Zone 1	Zone 4
Mugilidae	53	51	56
Cichlidae	32	28	6
Clupeidae	3	11	25

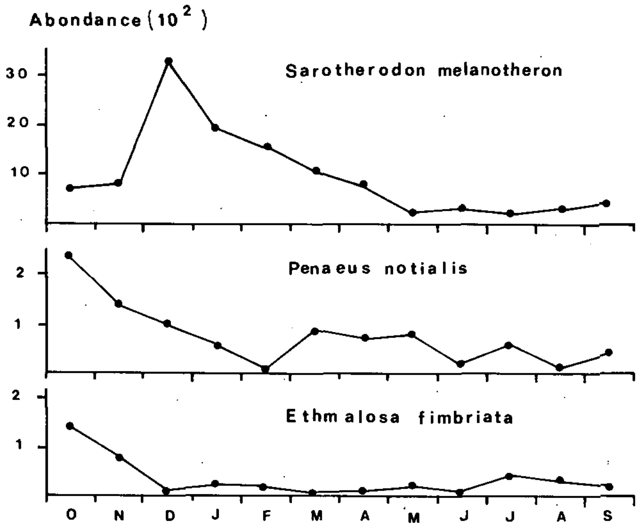

Figure 6 Variations saisonnières de l'indice d'abondance des juvéniles de quelques espèces dans la zone 4

Si les mugilidae constituent le groupe prépondérant dans les trois zones on constate en revanche une tendance au remplacement des cichlidae (essentiellement S. melanotheron) par les clupeidae (E. fimbriata) de la zone 2 à la zone 4 en passant par la zone 1 qui présente des caractéristiques intermédiaires.

4.2.2 Variations saisonnières du rendement

– Toutes espèces confondues, dans chacune des trois zones.
Elles ont été étudiées entre octobre 1984 et septembre 1985 et sont présentées dans la Figure 7. Les courbes sont très différentes d'une zone à l'autre. Dans la zone 2 on observe un important maximum en octobre-novembre. Aucune trace de ce maximum n'apparaît dans la zone 4 où l'on observe en revanche des rendements élevés en février et mars. La zone 1 présente une physionomie intermédiaire avec des rendements légèrement supérieurs à la moyenne à la fois en octobre et mars.

– Principales espèces dans la zone 2.
Les variations de L. falcipinnis et S. melanotheron sont présentées dans la Figure 8. La première espèce est pêchée de mai à novembre avec un maximum en octobre. La seconde est capturée essentiellement entre août et mars, avec un pic en décembre; les rendements ont cependant été nuls en octobre.

– Principales espèces dans la zone 4
Les variations de E. fimbriata, L. falcipinnis et M. bananensis sont présentées dans la Figure 9. La première espèce est abondante seulement de février à avril. Les autres espèces, moins abondantes, ne montrent pas de maxima bien marqués.

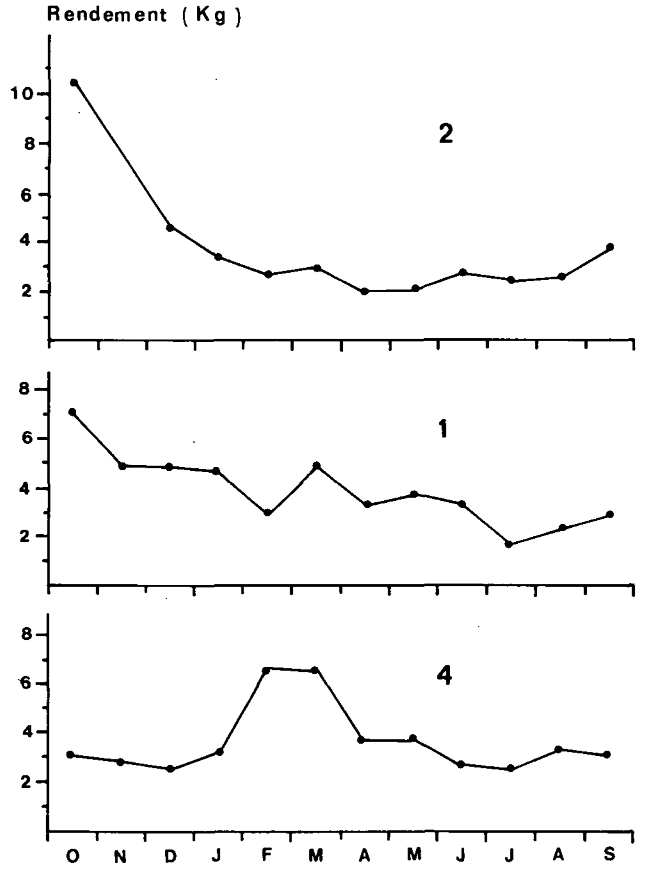

Figure 7 Variations saisonnières du rendement des subadultes et adultes pour l'ensemble des espèces dans les trois zones

5 Discussion

5.1 Conséquences du barrage sur l'environnement aquatique

Si nous prenons comme zone de référence la zone 4 et que nous caractérisions la zone 2 par la moyenne fond-surface, la différence de salinité S2-S4 passe de $-12^0/_{00}$ en octobre 1984 à $+14\%$ en juin 1984. En septembre 1985, la différence entre les deux zones est insignificante. Si la zone 4 avait été aussi profonde que la zone 2 il est probable qu'elle aurait été un peu moins dessalée en saison des pluies (cf. zone 1); il n'est pas certain qu'elle eut été moins sursalée en saison sèche si on se réfère à la zone 1. On peut donc affirmer que le barrage a entraîné en amont une augmentation de l'amplitude de variation de la salinité. Il en résulte des variations considérables par unité de temps, dont l'effet sur les organismes est souvent plus important que la valeur de la

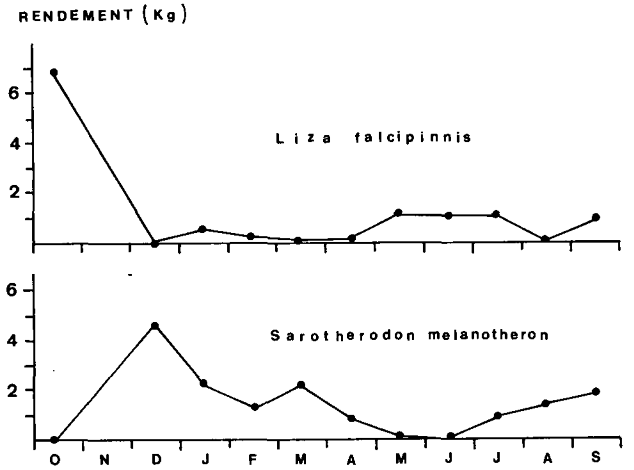

Figure 8 Variations saisonnières des rendements en subadultes et adultes des principales espèces dans la zone 2

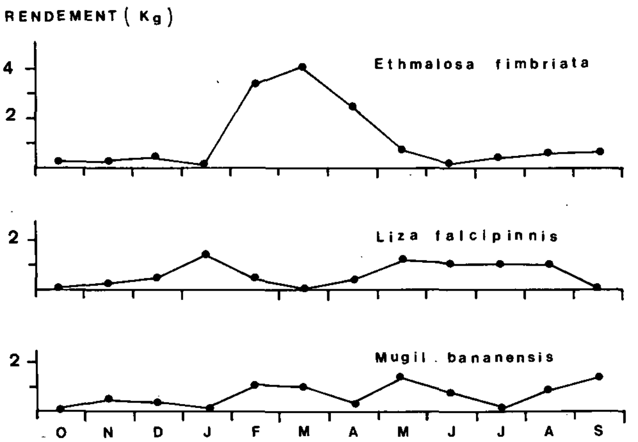

Figure 9 Variations saisonnières des rendements en subadultes et adultes des principales espèces dans la zone 4

salinité en elle-même: augmentation de 6, $7^0/_{00}$ par mois entre octobre et juin; diminution de $22^0/_{00}$ par mois entre juin et septembre.

Si nous nous référons toujours à la zone 4, le barrage a par ailleurs entraîné une légère augmentation de la chlorophylle a en amont et une nette diminution en aval. Il semblerait donc que la zone amont du bolon soit une source d'enrichissement trophique. Il est difficile d'identifier l'origine de cet enrichissement; ce pourrait être, au moins en partie, le guano des très importantes colonies d'oiseaux (pélicans notamment) qui existent sur le bolon de Guidel, en amont du barrage tout comme dans la partie amont du bolon de Sindoné.

5.2 Conséquences du barrage sur les espèces pêchées

Le barrage a entraîné un appauvrissement en jeunes poissons. Cela n'a cependant eu aucune conséquence sur la population de sub-adultes et adultes c'est-à-dire sur la pêche; les rendements en effet, sont aussi élevés dans la zone 2 que dans la zone 4.

Simplement, E. fimbriata est remplacé par S. melanotheron. Cela n'est pas une conséquence du peuplement en juvénile car les jeunes ethmaloses sont aussi abondantes en amont du barrage que dans la zone de référence (4) alors que les tilapies sont nettement moins nombreux. Il faut donc admettre que la mortalité naturelle des ethmaloses, derrière le barrage, est élevée. Quant aux tilapies, qui doivent probablement migrer vers l'aval quand ils grandissent, dans les conditions normales, ils semblent se développer sans problème derrière le barrage où ils restent bloqués. Cela n'est pas surprenant puisque sur le cours principal de la Casamance, Albaret (1984) avait noté, en fin de saison sèche, des populations très abondantes de S. melanotheron pour des salinités dépassant $80^0/_{00}$ alors qu'E. fimbriata cessait d'être abondant au-delà de $66^0/_{00}$ Ce n'est peut être pas tant la salinité elle-même qui est mal supportée par les ethmaloses, puisque la plupart du temps elle est inférieur à $66^0/_{00}$, que ses brutales variations.

Il est probable que dans la zone 2 les juvéniles proviennent de pontes in situ puisque les deux maxima d'abondance sont observés à des dates très éloignées des dates d'admission d'eau.

Les mugilidae posent un problème inverse de celui des ethmaloses; les juvéniles sont extrêmement rares alors que les subadultes (et adultes?) sont abondants. Ce phénomème, nous l'avons vu, n'est d'ailleurs pas particulier à la zone 2. Cependant dans les zones 1 et 4 on peut supposer que les grands individus viennent de l'aval; cette explication ne peut être invoquée pour la zone 2 car les bons rendements, en particulier le maximum d'octobre 1984 sont très décalés par rapport aux dates d'admission d'eau.

Il semblerait donc que la petite population de juvéniles (provenant de rares pontes ou ayant pénétré à l'occasion des admissions d'eau) ait un excellent taux de survie dans la zone 2. Cela n'est pas très étonnant puisque la principale espèce pêchée, et de très loin, est Liza falcipinnis qui, sur l'axe principal de la Casamance, demeure abondant pour des salinités de l'ordre de $80^0/_{00}$ (Albaret, op.cit.).

Nous avions vu à propos des juvéniles que Penaeus notialis et Geres melanopterus comptaient parmi les espèces principales dans la zone 4; en revanche nous n'avons pas mentionné de gros individus. Cela ne signifiait pas obligatoirement leur absence car les filets maillants que nous avons utilisés étaient inadaptés pour les capturer. Le chalut à petites mailles était cependant susceptible de capturer la crevette P. notialis. Cela n'a pas été le cas dans la zone 4 ce qui permet de penser que les bolons, s'ils abritent des nourisseries, sont peu favorable à la croissance des crevettes au delà de quelques grammes. Il nous est arrivé en revanche de pêcher des individus de bonne taille avec le chalut à petites mailles dans la zone 2. Nous avons même pu suivre assez bien le développement d'une cohorte. Les crevettes, qui pesaient en moyenne une dizaine de grammes en septembre 1984, dépassaient 20 g en octobre et atteignaient une trentaine de grammes en novembre; nous n'avons pas pêché de gros individus en décembre mais en avons pris trois pesant une quarantaine de grammes en janvier. C'est là une croissance très satisfaisante. On ne saurait cependant affirmer que le taux de survie est aussi élevé que sur le cours principal de la Casamance. Comme par ailleurs l'abondance des juvéniles est moindre dans la zone 2 que dans la zone de référence, il y a un risque, que si les barrages anti-sels se multiplient, les captures de crevettes de taille commercialisable ne diminuent.

En l'absence de connaissances sur le cycle biologique des différentes espèces en Casamance il est difficile de commenter les variations saisonnières que nous avons observées.

On constate néanmoins, si on compare ce qui se passe dans les zones 2 et 4 que la période décembre-avril est marquée par un déficit en poissons dans la première. Ce déficit traduit plus particulièrement celui des juvéniles de S. melanotheron et des subadultes d'E. fimbriata. Or, la salinité en amont du barrage se situe entre les limites 32 (moyenne fond-surface) et $60^{0}/_{00}$ à cette époque, ce qui ne semble présenter rien de prohibitif par rapport à celles observées dans la zone 4 ($45\text{-}58^{0}/_{00}$). Quant à la biomase phytoplanctonique, elle est au moins aussi élevée dans la zone 2 que dans la zone 4. Peut-être faut-il accuser, comme nous l'avions déjà suggéré précédemment, la variation continue et rapide de la salinité.

6 Conclusion

Il apparaît que le barrage n'a pas eu de conséquences néfastes sur la pêche en amont puisque les rendements et la valeur commerciale des prises sont équivalents à ceux obtenus dans la zone de référence.

Par ailleurs il va de soi que le barrage d'un bolon aussi petit que celui de Guidel ne peut avoir de conséquences sur l'écosystème casamançais. En revanche, si les barrages anti-sels devaient se multiplier et notamment si de grands bolons étaient barrés, il est à prévoir que la production de crevettes et d'ethmaloses diminuerait.

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Reclamation and management of brackish water fish ponds in acid sulfate soils: Philippine experience

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1 Summary

The rapid reclamation technique described by Brinkman and Singh in the last Acid Sulfate Soils Symposium in 1981 was applied in several experimental and commercial fish ponds in Panay and Negros Islands in the Philippines. The basic concept in this technique was to remove the source of acidity from the upper 15 cm pond bottom soil and preventing further diffusion of acids, and aluminium and ferrous salts from the sub-soil to the pond water during fish rearing period. To do so, it required a repeated sequence (4-5 times) of drying, tilling, flooding and draining of the pond bottom, and leaching of relatively big dikes. Subsequently, a small amount of lime (< 500 kg/ha) was also needed to counteract the diffusion of acidity from underneath.

The results obtained from this study have been very encouraging and successful both in terms of improving soil and water quality, and fish yields. Based on the results obtained, a technology package was prepared and disseminated for the use of farmers. Because of its simplicty, practicality and high effectiveness at economic costs, many farmers in Panay and Negros islands, and elsewhere in the country have adopted this technique and benefitted from it.

After reclamation, soil properties indicated a general decrease in the concentrations of sulfates (from 6145 to 630 ppm), aluminium (160 to 12 ppm) and pyritic iron (3300 to 1800 ppm) and an increase in pH of dry soil by about 1.1 to 1.4 units (from 3.5 to 4.8). Similar improvements were also recorded in water properties. The pH increased form 3.9 to 6.5 and alkalinity from 22 ppm to 47 ppm while the levels of aluminium, iron and sulfate decreased to 0.18, 1.35 and 773 ppm from 2.9, 3.5 and 1800 ppm, respectively.

In all crop seasons, the growth of fish-food organisms (Lab-Lab) in reclaimed ponds was four times more than in unreclaimed ones, although both received similar productions inputs. Likewise, milkfish and prawn production in reclaimed ponds was five times higher (530 kg/ha milkfish and 32 kg/ha prawns) than in unreclaimed ponds (112 kg/ha milkfish and no prawns). In reclaimed ponds fish mortalities were less and weight gains/fish were higher than in unreclaimed ponds.

After the first season, there was further improvement in the soil and water quality and fish production in reclaimed ponds. Details of these results and economic analysis of reclamation, are presented and discussed in the paper.

Résumé

La technique d'assainissement rapide décrite par Brinkman et Singh lors du dernier symposium sur les sols sulfaté-acides, tenu en 1981, a été employée dans plusieurs viviers à poissons de types expérimental et commercial à Panay et Negros Islands, aux Philippines. Le concept sur lequel repose cette technique consistait à éliminer la source d'acidité présente dans la couche supérieure de sol – d'une épaisseur de 15 cm – du lit du vivier et à empêcher toute autre remontée d'acides et de sels aluminiques et ferreux du sous-sol dans l'eau du vivier, pendant la période d'élevage des poissons. Pour ce faire, il fallait procéder à des séances répétées (4 à 5 fois) de séchage, de labour, d'inondation et de drainage du lit du vivier, ainsi qu'au lessivage de digues de taille relativement importante.

Ensuite, il fallait appliquer une petite quantité de chaux (500 kg/ha) afin de contrecarrer la diffusion d'acides contenus dans les couches inférieures du sol.

Les résultats obtenus à la faveur de cette étude ont été très encourageants et on fait leurs preuves en termes d'amélioration de la qualité des sols et de l'eau et de rendements dans la production de poissons. A partir des résultats obtenus, on a donc préparé, puis disséminé un ensemble de techniques à l'usage des paysans. Cette technique étant simple, pratique et hautement efficace, a séduit de nombreux pisciculteurs de Panay et des Negros Islands pour ensuite être adoptée dans d'autres régions du pays, où elle porte ses fruits.

Après l'assainissement, les caractéristiques des sols indiquaient une régression générale de la concentration de sulfates (de 6145 à 630 ppm), d'aluminium (de 160 à 12 ppm) et de fer pyritique de (3300 à 1800 ppm), et une augmentation du pH du sol sec de l'ordre de 1,1 à 1,4 unités (de 3,5 à 4,8).

Des améliorations similaires ont également été constatées dans les caractéristiques de l'eau. Ainsi, le pH a augmenté, passant de 3,9 à 6,5 unités et le taux d'alkalinité de 22 à 47 ppm tandis que les niveaux d'aluminium, de fer et de sulfate ont baissé, passant respectivement de 2,9 unités à 0,18, de 3,5 à 1,35 et de 1800 ppm à 773.

Dans toutes les campagnes de production, la croissance de la biomasse alimentaire (Lab-Lab) dans les viviers a été de quatre fois supérieure à celle qui a été observée dans les viviers non-assainis et ce bien que les uns comme les autres aient reçu les mêmes intrants de production. De même, la production de 'milkfish' et de crevettes dans les viviers assainis a été de cinq fois supérieure (530 kg/ha de 'milkfish' et 32 kg/ha de crevettes) à celle des viviers non-assainis (112 kg/ha de 'milkfish' et pas de crevettes du tout). Dans les viviers assainis, le taux de mortalité des poissons a été inférieur et le gain pondéral à l'unité de poisson supérieur à ceux qui ont été relevés dans les viviers non-assainis.

Après la première campagne de production, on a constaté une nouvelle amélioration tant de la qualité des sols et de l'eau que de la production de poissons dans les viviers assainis. Les détails concernant les résultats de cette enquête et de l'analyse économique de l'assainissement sont présentés et discutés en détail dans la présente étude.

2 Introduction

Acid sulfate soils develop strong acidity upon drainage and drying. They are common in brackish water mangrove tidal swamp areas. With the rapid expansion of fish ponds, in potential and actual acid sulfate soil areas, the problems of high acidity,low productivity, poor fertilizer response, fish kills and high levels of iron, aluminum, sulfate and in some cases manganese, have become acute and more pronounced.

Whenever these soils are subjected to oxidation by excavation or by drainage and drying, the two inevitable operations in establishing and managing fish ponds, the result is strong acidity with the above mentioned adverse effects. The problems have been commonly observed in many countries in Southeast Asia, Africa and in Latin America. In the Bangkok symposium on acid sulphate soils of 1981 the phenomena involved were analysed in detail and presented by Brinkman and Singh (1982), Singh (1982 a and b). Brinkman and Singh (1982) reviewed the earlier reclamation efforts and prepared a rapid reclamation technique for brackish water fish ponds in acid sulfate soils. Since then this technique has been tested and adjusted in several experimental and commercial fish ponds in Panay and Negros islands, Philippines and the results have been very encouraging.

After two years of verification, a technology package was prepared and disseminated for the use of farmers. Because of its simplicity, practicality and high effectiveness at economic costs many farmers in these islands and elsewhere in the country, have adopted the technique and benefitted from it. The details of reclamation results are presented and discussed in this paper.

3 Nature and magnitude of problems in fish ponds with acid sulfate soils

Various problems faced by farmers in fish ponds with acid sulfate soils have been summarized by Potter (1976), Singh (1980), Brinkman and Singh (1982), Poernomo (1983), and Singh and Poernomo (1983).

3.1 General

The most common phenomena observed in the ponds are poor fertilizer (especially-P) response, dark brown or clear brown water with little and poor natural fish food production, slow growth of fish, soft shelled prawns, in severe cases fish kills especially during heavy rain after long dry periods and erosion of pond dikes.

Fish mortalities are also observed in the canals that receive water drained form acidic ponds or acid sulfate areas.

3.2 Algae growth and fertilizer response

The growth of algae is observed to be restricted or inhibited by low pH, low phosphate concentration (Figure 1) and high aluminium and high iron (Figure 2) content. At

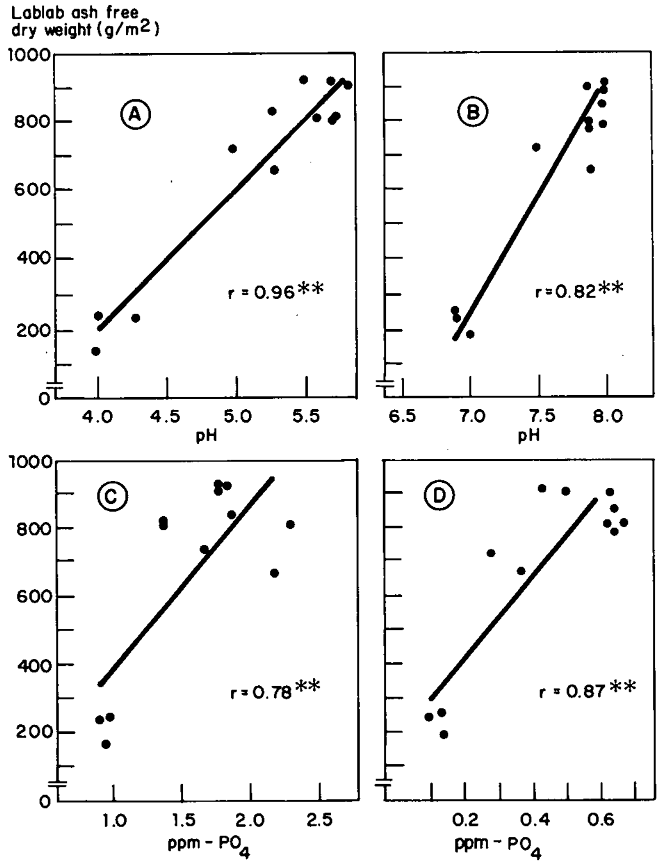

Figure 1 Relationships of Lab-lab production with soil pH (A) water pH (B), soil available-P (C) and dissolved-P in water (D)

low pH the solubility of aluminum, iron, and sulfate is high (Figure 3). These high concentrations of aluminium and iron render the phosphate unavailable (Figure 3) as it is fixed into insoluble aluminum and ferric-posphate compounds. This leads to severe phosphate deficiency for algae growth.

Stum and Morgan (1970) reported that high concentrations of aluminium and iron render silicates and molybdenum unavailable which affect nitrogen metabolism and cellular function in algae. The high concentration of iron and aluminium are also reported to inhibit cell division (Clarkson 1969) and disrupt the activities of protenaceous enzymes in the cell wall (Woolhouse 1970). However, other than the general decrease in biomass production and changes in species composition of the biomass, directly observable effects (symptoms) of acid sulfate on algae have not been established.

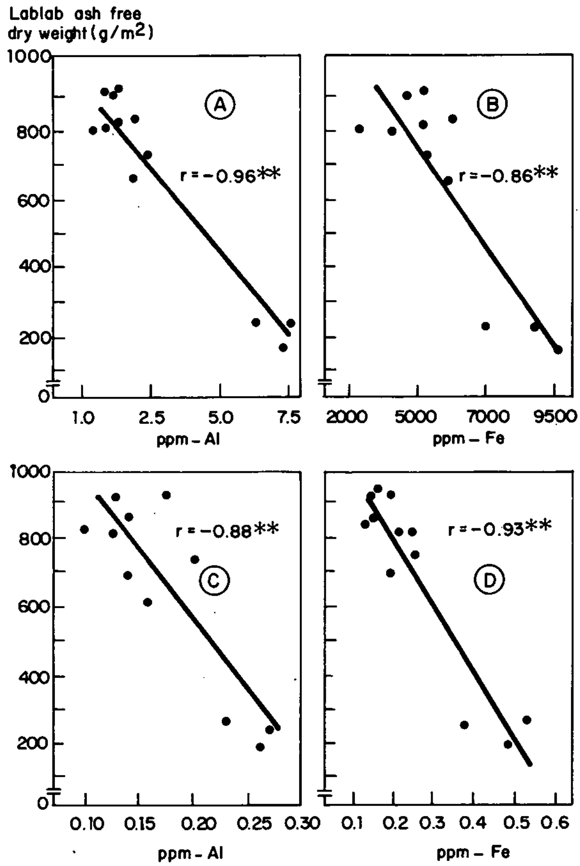

Figure 2 Relationships of Lab-lab production with soil-Al (A), soil active- Fe (B), aluminum in water (C) and iron in water (D)

3.3 Fish health

High concentrations of aluminum and iron together with low pH become toxic to fish and result in fish kills. This is more pronounced and evident when there is a sudden influx of acid water washed down from the dikes during the early rainy season. In most fish ponds with acid sulfate soils, the concentrations of iron and aluminium reach beyond the tolerance limit to most fishes. The tolerance limits for iron and aluminium to most fishes are reported to be 0.2 and 0.5 ppm, respectively (Nikolsky 1973).

In less severe cases, marginal for fish health, these elements create chronic stress trough ionic imbalance in the fish body and as a result fish becomes more susceptible to diseases and parasites.

Prawns grown in these situations face an even worse problem; besides being soft-shelled due to lack of calcium and other essential elements for shell formation their gills are clogged with finely suspended ferric oxides and hydroxides.

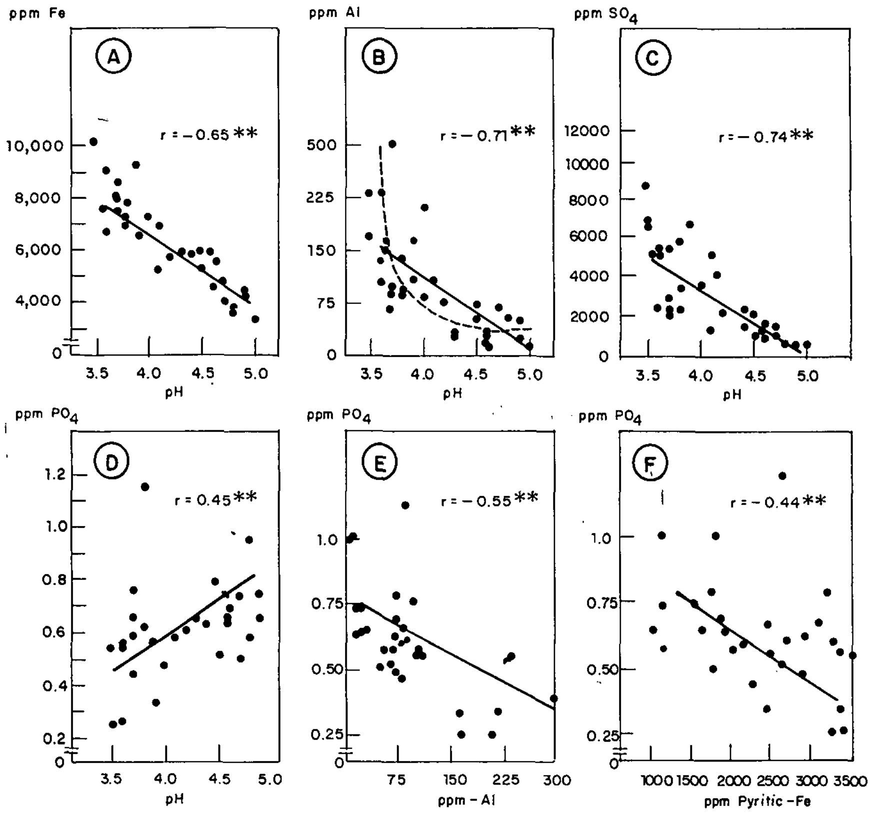

Figure 3 Relationships of soil pH with active-Fe (A), exchangeable-Al (B), sulfate (C) and available-P (D), and soil available-P with exchangeable-Al (E) and pyritic-Fe (F)

3.4 Dike erosion and pond siltation

A lesser problem due to the lack of vegetative cover is the very rapid erosion of dikes and siltation in the pond. Grasses hardly survive on the acidic dike soil. Thus, aside from being detrimental to the pond biota (fish and fish food organisms), acid sulfate soil conditions add to the cost of physical maintenance of dikes and pond desiltation.

4 Reclamation of acid sulfate fish ponds in the Philippines

4.1 Reclamation procedures

The basic concept in this technique is to remove the source of acidity by oxidizing the pyrites from the upper 15 cm. pond bottom soil and preventing further diffusion of acids, and aluminium and ferrous salts from the sub-soil to the pond water during fish rearing periods. This requires a repeated sequence (4-5 times) of drying, tilling, flooding and draining of the pond bottom, and leaching of relatively big dikes. Subsequently, a small quantity (500 kg/ha.) of finely ground (60-100 mesh) agricultural lime is also needed to counteract possible diffusion of acidity from underneath. The details of this procedure can be read in Brinkman & Singh (1982).

In the last five years this procedure has been applied in several experimental and commercial fish ponds in Panay and Negros island, Philippines. Depending on the prevailing conditions like weather (mainly rainfall), amount and distribution of pyrites, texture, structure and moisture in the soil and the presence of compounds like calcium carbonate, the entire reclamation work is completed in about 3-4 months. Leaching of dikes is done only in a few cases where primary dikes were relatively big or where large secondary dikes surround nurseries and fingerling ponds of relatively small size.

Reclamation in considerably easier in a distinct monsoon and dry climate than in perennially even climatic conditions. The maximum effect of reclamation is expected if carried out in the dry season with soil moisture of about 30-40%.

Heterogeneous distribution of pyrites in the soil has to be taken into account . In the large root remnants pyrite concentrations are oxidized relatively fast due to easy access of oxygen. The acid formed upon oxidation is also leached rapidly. With limited sponge structure on the other hand in soil the oxidation front moves downward very slowly after drainage so that soluble acids are also leached out slowly. Tilling the pond bottom thus creates a situation in which the greater surface area exposed after tilling leads to faster oxidation and the wider pore space facilities the leaching of oxidation products.

Pyrite sediments rich in $CaCo_3$ do not give rise to acid sulfate soil conditions when their lime content matches the equivalent acidity potential of the pyrite. Smaller amounts of lime may slow down the initial oxidation of pyrite and the completion of the reclamation operation.

4.2 Management of reclaimed fish ponds

In the experimental and commercial fish ponds that were reclaimed with the described method, preparation for growing natural fish food (benthic algae and other microorganisms that grow in the pond bottom, locally called lab-lab) and fish rearing was started immediately after completing the reclamation. The lime application as recommended earlier was done at the rate of 500 kg/ha after completing reclamation or just in the beginning of pond preparation. Growing of fish food (lab-lab) was practised by following the standard pond preparation and management practices. Only milkfish was grown in the first season. The prawns were tried in poly/mix culture with the milkfish in the second season and thereafter also by following the standard fish growing techniques.

All fish pond operations except the fertilizer management were carried out in the usual manner as that practised in normal fishponds. A total of 48 kg N and 60 kg P_2O_5/ha was applied in six bi-weekly split applications during the entire fish growing period which ranged from 90-120 days. The fertilizer management and other suggestions for reclaimed fish ponds in acid sulfate soils are presented in another paper of this symposium (Singh et al. 1986).

5 Reclamation experiences and results

The results of fishpond reclamation with the described technique at different locations in the Philippines have been very encouraging and successful. Similar satisfactory results have also been reported from trials conducted at experiment stations and privately owned fish ponds by Poernomo 1983, Poernomo and Singh 1982, Bantala 1983, Singh and Darvin 1983, Singh and Poernomo 1984, Neue and Singh 1984, Soveyanhadi 1985 and Singh 1985.

Based on these results a technology package has been prepared and disseminated for the use of farmers. In the following the results of a specific representative case are presented and reviewed.

The properties of the pond bottom and dike soil and pond water before and after reclamation are shown in Tables 1, 2 and 3. The results of lab-lab and fish production are shown in Table 4.

5.1 Soil properties

In the beginning the low pH (3.6) combined with high concentrations of exchangeable Al, (160 ppm) active Fe, (7800 ppm) and acetate soluble SO_4 (6100 ppm) (Table 1) indicate extremely acidic condition. Because of the intense oxidation of pyrites, the dike soil was even more acidic than the pond bottom.

The concentrations of aluminium and iron in the pond soil due to low pH are very high and are far beyond the tolerance limits for most fishes, which generally are about 0.5 ppm and 0.2 ppm, respectively (Nikolsky 1973). The extremely low concentration of available phosphorus (0.30 ppm) in the pond bottom soil is attributed to the high binding capacity of excess amounts of aluminium and iron (Table 1).

Table 1. Some properties of pond bottom soil before and after reclamation and after the harvest of first crop (after Singh 1985)

Property*	Before reclamation		After reclamation		After harvest	
	Control	Treated	Control	Treated	Control	Treated
pH - Wet	5.8	5.7	5.6	6.0	5.8	6.8
pH - Dry	3.7	3.6	3.7	4.8	3.8	5.7
Eh (mV)	230	220	70	10	-120	-150
Exch. Al	160	135	85	12	63	10
Active Fe	7845	7600	7910	3630	7670	2960
Pyritic Fe	3350	3320	3140	1865	3200	1620
Active Mn	15	16	12	10	7	0
Acetate sol. SO_4	6145	5612	2075	630	2000	700
Avail. PO_4	0.30	0.25	0.66	1.03	1.13	1.43

* Except the pH and Eh, all others are in ppm (mg/kg)

In the tilled pond bottoms vigorous oxidation resulted in the formation of bright-red ferric-oxides and brown ferric hydroxide with an efflorescent film of aluminum sulfate. These colorations became clearly visible in two days after shallow flooding (2.5 cm).

The formation of colored deposits gradually decreased with repeating the sequence of drying, tilling, flooding and rush draining. At the end of the reclamation, no reddish coloration was noticeable in the reclaimed ponds. In contrast the bottom of unreclaimed ponds remained evenly red throughout. The red color in control ponds was evident even after harvesting the first fish crop. During and after reclamation there were significant improvements in soil quality.

After 3 months reclamation both potential and actual acidity had decreased as expressed (Table 1) in decrease of pyritic iron (from 3320-1865 ppm) acetate soluble sulfate (6100-630 ppm) and exchangeable aluminium (160-12 ppm) and by the increase of pH of dry soil with 1.2 units (3.6-4.8). The available PO_4 in treated ponds increased from 0.25 to 1.03 ppm. In contrast, there was little change in the pH and other properties of control ponds and such change this was due to superficial washing by rains.

The dry soil pH (4.8) attained after reclamation (Table 1) was enough to maintain and ideal pH wet (6.8) of the submerged reduced pond bottom soil and (7.0 to 8.5) of pond water during lab-lab and fish growing. The lab-lab growth further helped in maintaining these pH levels. This situation in turn was optimal for the solubility and availability of phosphate for lab-lab growth; fixation of phosphorus is known to be minimal at these pH levels.

In the control ponds where the concentrations of aluminium and iron were high and the soil pH low, phosphate fixation was apparently vigorous. That is why in these ponds even just after fertilizer application the levels of phosphate remained constantly low. Singh (1982 a) and Soveynhadi (1985) noted that after application of 100 kg P_5O_5/ha., the available P level in acid sulfate soils was almost gone in about 2 days; while in neutral and reclaimed soils applied with the same rate, it remained above 2 ppm for several weeks. A similar trend in the changes of soil properties was also observed for dike soil (Table 2).

After fish harvest from the reclaimed and control ponds both treated with chicken manure and 48 kg N and 60 kg P_2O_5 per ha as a standard operation practice the analytical results indicated that the reclaimed pond soils attained a higher dry pH (5.7); and also had lower concentrations of aluminium (10 ppm), active and pyritic iron (2960 ppm and 1920 ppm, respectively), and sulfates (700 ppm) than the control ponds in

Table 2. Some properties of dike soil before and after reclamation (after Singh 1985)

	Before reclamation		After reclamation	
Property*	Control	Treated	Control	Treated
pH – Wet	3.6	3.6	3.6	4.1
ph – Dry	3.0	3.1	3.6	4.1
Eh (mV)	370	360	340	290
Exch. Al	360	330	250	118
Active Fe	9850	9650	9160	5285
Pyritic Fe	2330	3120	1770	1360
Active Mn	17	15	11	6
Acetate sol. SO_4	9440	8720	7000	1080
Avail. PO_4	0.40	0.40	0.55	0.80

* Except pH and Eh, all others are in ppm (mg/kg).

which these concentrations were at least twice as high (Table 1). In the treated ponds the level of available phosphorus (1.43 ppm) was higher than in the control ponds (1.13 ppm).

5.2 Water properties

Before reclamation the chemical properties of water in both the control and treated ponds, had similar magnitudes. Water pH was 3.9, alkalinity 22 ppm, aluminum 3.5 ppm, iron 9.3 ppm and sulfate 1800 ppm (Table 3). Due to low pH and high aluminum, iron and sulfate levels, the dissolved phosphorus in water was essentially zero. These conditions indicate a very highly acidic and unfavorable situation for growing milkfish and prawns.

After the 3 months reclamation period, the water quality in ponds improved significantly. The water pH increased to 6.5, alkalinity to 47 ppm (Table 3) and the levels of aluminum, iron and sulfate decreased to 0,18 ppm, 1.30 ppm and 770 ppm, respectively (Table 3). Dissolved phosphorus improved from 0.0 to 0.02 ppm. Slight improvements also occurred in the control ponds but these were mainly due to occasional overflow of water from previously dried ponds because of heavy rains during the reclamation period (Table 3).

Table 3. Some properties of pond water in acid sulfate soils before and after reclamation and after harvest of first crop (after Singh 1985)

	Before reclamation		After reclamation		After harvest	
Property*	Control	Treated	Control	Treated	Control	Treated
pH	3.9	3.9	4.2	6.5	6.9	8.0
Alkalinity	20.3	23.1	23.1	47.3	49.0	98.5
Aluminium	2.9	4.1	1.7	0.18	0.04	0.02
Iron	9.3	9.3	3.9	1.35	0.40	0.16
Sulfate	1720	1930	1060	770	1070	680
Phosphate	0.0	0.0	0.01	0.02	0.02	0.20

* Except pH, all others are in ppm (mg/l).

During the fish growing period and thereafter, water quality in the reclaimed ponds further improved significantly. After harvesting the fish grown in the control as well as reclaimed ponds (both had received the same fertilizer and other inputs) the improvement in water quality of the reclaimed ponds was remarkably better than that in the control. Aluminium and iron in reclaimed ponds decreased to negligible levels, sulfate decreased considerably and pH, alkalinity and phosphorus levels increased significantly (Table 3).

5.3 Lab-lab and fish production

5.3.1 Lab-lab

The significantly lower production of lab-lab in the control ponds (Table 4) compared with that in reclaimed ones is attributed to the constantly low concentration of the available phosphorus. In the reclaimed ponds, fixation of phosphorus by the soil seems to have been much less because of high pH and reduced concentrations of aluminium and iron.

Table 4. Lab-lab production (ash free dry wt. g/m^2), fish survival (%), weight gain (g/fish) and yield (kg/ha) in control and reclaimed ponds with acid sulfate soils (after Singh 1985)*

Treatment	Lab-lab production g/m^2	Milkfish Survival %	Milkfish Weight gain g/fish	Milkfish Yield kg/ha	Prawn Survival %	Prawn Weight gain g/prawn	Prawn Yield kg/ha
First season							
Control	198	43	108	112	–	–	–
Reclaimed	672	93	124	442	–	–	–
Second season							
Control	230	45	110	150	2	8	3
Reclaimed	780	90	178	500	15	13	32
Third season							
Control	248	50	107	150	7	10	15
Reclaimed	800	90	175	550	28	18	60

* Lab-lab and milkfish values are over a period of 90 days, while those for prawns over a period of 120 days; prawns were not stocked in the first season. In control ponds they are generally soft shelled.

The growth of lab-lab in control ponds in all seasons was about four times less than that in the reclaimed ponds (Table 4) although both received the same amount of fertilizer and other management inputs. Even in the second and third seasons after reclamation the growth of lab-lab in reclaimed ponds was significantly higher than that in control ponds, although the total amount produced remained almost the same as in the first season.

The lab-lab mat which grew evenly on reclaimed pond bottom seems to have acted as a barrier and prevented the phosphorus fixation into the soil. After establishing lab-lab growth, subsequent application of fertilizer also provided ideal condition for utilization of P by lab-lab because the fertilizer ultimately settled on the lab-lab and in the water column. Lab-lab growth in all the reclaimed ponds was so thick that thinning was done to avoid the danger of sudden decomposition.

The dominant component species of lab-lab in the reclaimed ponds were different from those in the control ponds. In reclaimed ponds dominated Nitzachia, Anabaenopsis, Oscillatoria, Lyngbia, Rotatoria, Copepods and Nematodes. In the control ponds Pleurostigma and Gyrostigma were the dominant species of lab-lab.

5.3.2 Milkfish

Despite of equal inputs reclaimed ponds produced more milkfish (442 kg/ha in the first season) than the control ponds (112 kg/ha, table 4).

Twice in the first season there were mortalities in the control ponds leaving only 43% survival. The survival in the reclaimed ponds was 93%. Also in the succeeding seasons, the number of fish that died in control ponds was about twice that in the reclaimed ones.

Theoretically, fishes in the control ponds should have gained more weight than in the reclaimed ones (because of fewer fish and less competition in the controls as a result of high mortality), buth the results were otherwise. The fish in the reclaimed ponds weighed about 50 g more (av. 160 g/fish) than the ones in the control (av. 110 g). This indicates that the supply of natural food in the control pond was not sufficient and the water quality was poor. This observation was further confirmed by the length-weight analysis. Fish production in both treatments was significantly correlated with lab-lab growth.

5.3.3 Prawns

In the first season after reclamation prawns were not stocked in any of the ponds. In the second and third season they were stocked together with milkfish. This was done in both the reclaimed and control ponds.

They were not fed with any artificial/synthetic feed.

The survival of prawns in the second season was rather low in both ponds but it was significantly higher (15%) in reclaimed ponds (Table 4) than in the control ones (2%). Again, even with the poor survival the weight of prawn was lighter than normal. In control ponds it averaged 8g/ prawn in the reclaimed ponds 13 g/prawn. At the end of the culture period, total production in the control ponds was only 3 kg/ha; while in the reclaimed ponds it was 32 kg/ha.

In the third season after reclamation i.e. the second season of prawn growing, the survival, weight gain and production of prawns increased markedly in the reclaimed ponds to 28%, 18 g/prawn and 60 kg/ha, respectively (Table 4); against only 7% 10 g/prawn and 15 kg/ha in the control ponds.

Besides low survival and production, prawns in the control ponds were soft shelled apparently due to the lack of calcium and phosphorus, as normally observed in acid sulfate soils.

5.4 Effects of forced leaching of dikes

The technique of fishpond reclamation includes forced oxidation and leaching of larger dikes with potential acid sulfate soil material, to prevent contamination of pond water by acids washed from the dike body in the rainy season. The effect of preventive dike leaching on the lab-lab and fish production was not apparent in the first season of fish growing. It became significant and more pronounced in the subsequent growing seasons especially during distinct rainy periods. The ponds with unleached dikes showed higher fish mortality and lower production than the ponds with leached dikes even if the bottoms of both were reclaimed. The unleached dikes had more acidic water seeping out, thus, represented more potential hazards of fish kills.

6 Returns

Based on an improved fish yield of 330 kg/ha per crop over control, gross revenue increased by $215.8 (Table 5) for the first season after reclamation. The net income in the first season increased by about $124.40/ha equal to a return of $1.35 per dollar invested in the reclamation. It should be noted however,that the cost of reclamation is incurred only once while the benefits of reclamation are expected to last several fish growing seasons or forever. At present it is the sixth season after reclamation and there is no indication of reoccurrence of the problem. The cost of reclamation therefore, should be amortized over at least six fish growing seasons.

Moreover, the results indicate that in the succeeding seasons after reclamation there is further increase in production especially of prawns. Therefore, the returns are supposed to increase further and the cost benefit-ratio of reclamation to improve.

Table 5. Cost and returns* of reclaiming fishponds in acid sulfate soils for one fish growing season (after Singh and Darvin 1983)

Particulars		Value ($/ha).
Cost of reclamation**		
– Tilling of the pond bottom (three times at $12 each)		36.00
– Construction of levees at the top of dikes ($0.05/m)		20.00
– Fuel cost to run a water pump for dike leaching (three to four times)		15.36
– Labor cost (8-10 men days at $2/day)		20.00
	Sub total	91.36
Returns		
– Increase in Gross returns: increase in fish production (in reclaimed less in control = 330 kg/ha) multipield by price of fish ($0.65/kg)		214.50
– Net returns: increase in gross returns minus the cost of reclamation (214.50 – 91.36)		123.14
– Benefit-cost Ratio***		1.35

* All computations are based on the data from first season after reclamation.
** Except for the reclamation other costs were same in control and reclaimed ponds.
*** The benefits of reclamation appear higher in the subsequent seasons after reclamation.

Based on these results, the application of this reclamation procedure seems not only practical but economically highly feasible and profitable as well. The cost of reclamation is only about $90.0/ha with a return of 150% in one season.

7 Conclusions

Acid sulfate soils are undoubtedly detrimental when excavated for fishponds, but they can be rapidly improved to become productive pond bottom soils with the proper method of reclamation.

A repeated sequence of drying, tilling and flushing (with sea water or brackish water) of the pond bottom combined with leaching of relatively big dikes preferably during the dry season, is a cheap, fast and economically feasible method of reclamation for areas with a distinct monsoon and dry climate.

A moderate and low rate application of powdered lime (500 kg/ha) broadcast on the pond bottom immediately after reclamation or during pond preparation would help speed up soil reduction, and suppress the concentrations of aluminum, iron and acids that may be released into the soil. This would also reduce the fixation of phosphate into the acid sulfate bottom soil. Application of waste materials like mudpress from sugar mills and burnt rice hulls on the wet pond bottom are also effective in reducing phosphate fixation.

To further avoid excessive phosphate fixation in pond bottom soil,small weekly dressings of preferably slow release fertilizers, are recommended.

Instead of prefingerling, post fingerling size of milkfish or other hardy fishes should be stocked in the first or second season after reclamation. Prawns should be tried afterwards in polyculture with milkfish on an experimental basis before embarking on the intensive commercial monoculture after several years.

Acknowledgement

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Soil reclamation: a technical or a social-economic problem? Reclaiming the acid-sulphate soils in the tidal swamps of Basse Casamance, Senegal

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1 Summary

Recent reclamation by the State of the acid-sulphate soils in the Basse Casamance region of Senegal has turned out into a fiasco. This is partly due to technical/climatological factors and partly to social-economic ones. Local farmers are not keen to join the project. A lack of economic incentive among the farmers is said to be the reason for this. Such an explanation is based on a Western market model, in which State and farmer are part of one socio-economic system. In this paper a different model is used: the state that wants the land reclamation, and the local population that carries out this reclamation, are seen as two different factors, each with its own goals. We conclude that the problems connected with this type of land reclamation are more political than technical.

Résumé

La situation de la nourriture qui s'aggrave depuis quelques décennies dans les pays de l'Afrique Occidentale, a incité les gouvernements à essayer d'augmenter les superficies agricoles. C'est dans ce souci que le gouvernement du Sénégal a entrepris une large campagne de récupération de terres.

Au sud du pays, en Basse Casamance, de nouvelles superficies ont été mises en valeur. C'étaient des sols de mangrove sulfaté-acides et souvent hypersalés, situés dans une région où depuis des siècles la population locale Diola fait une riziculture traditionnelle. Comme les projets ont généralement abouti à des échecs, des explications surtout climatologiques et techniques ont été données.

Le présent article a pour but de confronter ces explications à celles d'ordre socio-économique, que nous considérons comme plus importantes.

L'abandon des rizières en Basse Casamance a ses racines dans l'administration coloniale. Traditionnellement les paysans Diola produisaient des quantités considérables de riz qui étaient destinées non seulement aux nécessités locales (autosuffisance alimentaire, cérémonies), mais aussi à l'échange. Cet échange était fait avec les commerçants Mandinkos qui apportaient du bétail et des textiles de la Moyenne Casamance et de la Gambie, et les échangeaient pour du riz et des esclaves, conformément à un système bien établi. Les deux produits, bétail et textiles, étaient des biens acquis uniquement pour les cérémonies. Particulièrement pour la cérémonie de 'bukut' (circoncision), qui joue un rôle central dans la vie réligieuse et socio-économique des villages Diolas, où un groupe restreint 'd'aînés', contrôle tous les moyens de production et dirige la

masse paysanne. Pour qu'un tel système puisse subsister, il faut que de temps en temps, les 'aînés' soient remplacés par de nouveaux membres plus jeunes. Ceci se fait dans la cérémonie de 'bukut'. Ce n'est qu'après avoir satisfait à cette exigence, qu'un homme acquiet le droit de se marier et reçoit de la terre, gagnant en même temps l'indépendance politique, économique et réligieuse.

La création de l'Etat colonial a perturbé profondément cet état des choses. Les grandes maisons de commerce françaises n'étaient pas intéréssées à la culture du riz (qu'on importait à bas prix de l'Indochine) mais l'étaient par contre, dans la culture d'arachides. C'est ainsi que les Mandinkos cessèrent le troc avec les Diolas et commencèrent à produire et à échanger l'arachide pour du riz venant de l'Indochine. Ainsi les Diolas furent exclus de l'approvisionnement en bétail et en textiles, biens essentiels pour leur système socio-économique. Il en résulte, que les jeunes furent envoyés comme ouvriers saisonniers dans les cultures d'arachides pour gagner l'argent nécessaire à l'achat de ces biens. Bientôt ils introduisirent l'arachide dans leur village comme culture monétaire et la riziculture perdit de plus en plus pied se résumant à n'être plus qu'une culture d'autosuffisance alimentaire.

Maintenant que la main-d'oeuvre était devenue de plus en plus rare, suite à la migration des jeunes vers les villes, là réhabilitation de la riziculture devint elle aussi de plus en plus difficile. Pourquoi les Diolas voudraient-ils cultiver plus de terres? A part l'autosuffisance alimentaire, une production plus élevée pourrait certes les aider à entretenir leurs rizières (digues, barrages, etc.), mais ne pourrait pas contribuer à leur donner du profit, car l'Etat n'est certainement pas capable dans les circonstances actuelles, de leur offrir un meilleur prix pour le riz. Et n'y trouvant pas d'intérêt, les Diolas réfusent la collaboration avec l'Etat. C'est pourquoi des méthodes de contraintes ont été utilisées (comme la mésure de diminution de la migration urbaine ou la loi nr. 64-46 relative au Domaine National par laquelle les terres ont été nationalisées) et une violente protestation en a été la reponse (1982, 1983).

Tout celà montre que tant que l'intérêt de l'Etat ne coïncide pas avec l'intérêt de la population locale, tout projet de mise en valeur aboutit à un échec. Connaître l'interêt de la population locale, signifie connaître son mode d'organisation et ses aspirations. Cela pourra contribuer à introduire des réformes agricoles avec moins de difficultés politiques et moins de risques financiers.

2 Introduction

There has been a growing food shortage in Africa over the past decennia. An increasing amount of the national budgets is swallowed up by food imports. To cope with this situation, the national governments have planned increased food production.

The government of Senegal, in this context, is promoting the reclamation and improvement of tidal lands for rice cultivation in the Basse Casamance. These areas have salinity and acid sulphate problems. In the precolonial period they have been reclaimed successfully for rice growing by the local population: the Diola. In that time the Diola produced rice surpluses. At present, most of these rice fields have been abandoned and the surpluses disappeared. Recently, the government started a program for the recuperation of these abandoned fields and the reclamation of new ones. In the beginning of the seventies nearly one thousand ha of new fields were reclaimed.

The project was not a success. None of these fields are cultivated now. Reasons for this failure are both climatological/technical and social-economic. The present paper deals with the social-economic factors and more specifically with the circumstances that in the recent past have led to a decline in rice production and in the present to a lack of interest among the Diola to increase production in the newly reclaimed fields. The mode of production of the Diola i.e. the way land, labour and output are used will be described in a historical context. The case of the village of Diatock will illustrate this. In this way we shall be able not only to consider the factors and mechanisms which have caused the present developments, but through them we may also understand the difficulties and problems which will face the government in its efforts to implement the policy of increasing rice production in the Basse Casamance amongst the Diola.

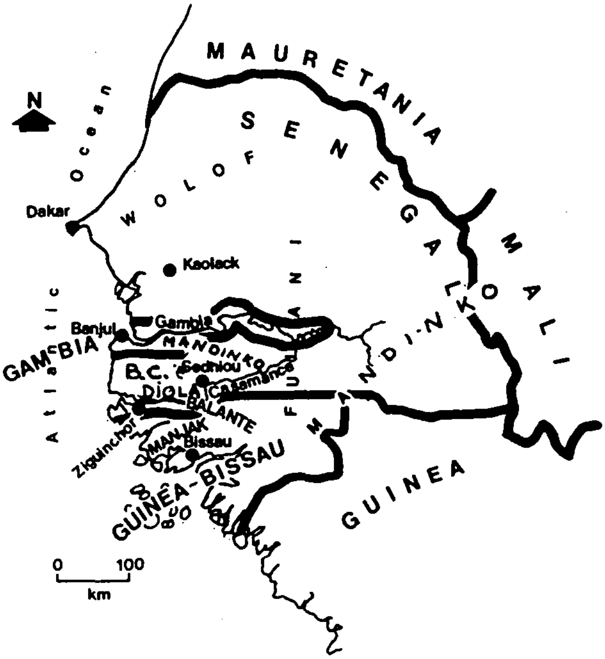
3 The Basse Casamance and the Diola

The Basse Casamance includes the 'Départements' of Oussouye, Bignona and Ziguinchor in the 'Région' of Ziguinchor. It is an area covering 100 km^2 at the estuary of the river Casamance. The population is 350,000 of whom 100,000 are living in the regional capital of Ziguinchor. In African terms this is a dense population. This is largely due to the fertility of the soil, an annual rainfall of 1,400 mm (June-October) and to the fact that rice has been cultivated here for centuries. Rice is grown along the tidal river and its countless tributaries. There are two different types of rice fields: those that are on the relatively higher grounds (the 'fresh water rice fields') and the low-lying fields which by empolderment in the past have been reclaimed from the mangrove swamps (the 'saline rice fields').

In the countryside live 200,000 people, largely Diolas, scattered over about 300 villages. Until the French colonialization (1920) these villages were largely autonomous and rice cultivation was the main economic activity. Then they became part of Senegal and started participating more or less in the market economy by the cultivation of a cash crop (groundnuts) and by labour migration. World religions (Islam and Christianity) penetrated the villages and drove away some local beliefs and customs. In spite of all this, the Diola villages have retained by and large the essence of their social system where the young depend on and have to support their elders.

The Diola territory borders that of the Mandinkos to the north and east, and to the south that of various small groups (such as the Balantas, Mancagnes and Manjaks), similar to the Diola in many ways e.g. their practices of rice cultivation.

There are certain characteristics which apply to any Diola village. They all lie near the bank of a river, just beyond the rice fields which border the water. The 'fresh water rice fields' are still cultivated; most of the 'saline fields' no longer. Behind the villages, on the higher plateaux, the groundnut is cultivated. Each village consists of at least three family units (fank). The different households of a fank help each other in agriculture and other activities. In the rainy season the village bustles with activity of all sorts. After this period, the young people (in the age group of 15 to 30), leave for the cities, looking for jobs (girls) and further education (boys). At the onset of the following rainy season, they return once again to their villages. Once every 25 to 30 years, each village celebrates an important ceremony. It is a male initiation ceremony, lasting for months, and involving enormous expenses.



The Diola in their environment

4 The village of Diatock

Diatock lies in the centre of the Basse Casamance ('Département' of Bignona and 'Sous-Préfecture' of Tendouck). It has a population of about 2,000, composed of 290 households. The territory of the village covers about 2,100 ha of which 540 ha are rice fields (310 ha 'fresh' and 230 ha 'saline' rice fields). Besides this, the village has about 700 ha for peanuts, of which a quarter can be cultivated annually. During the dry season, almost the entire 15-30 year old age group leaves (about 25% of the total population). This seasonal migration began in the '20s. In the past, some of these migrants settled down elsewhere, thus becoming permanent migrants. Together with their offspring, these number about 2,000. They still maintain their ties with Diatock for ceremonies such as marriage or initiation and as a lodging address for young migrants (Van der Klei 1985c).

5 Land, labour and output: authority of the elders and dependance of the young

5.1 Ricefields

In theory the land is divided between the families who reclaimed it in the past; in practice it is divided between the married male members of these families. On the occasion of his marriage, a son is given a portion of his father's part. He may then cultivate this land and so support his wife and children. Women and unmarried men cannot own land. Those who have inherited too little land to support their households, can supplement their land sufficiently by borrowing from relatives (Van der Klei 1978). There are no landless households.

5.2 Groundnut fields

Over the past 60 years forest has been reclaimed for cultivating groundnuts, which are marketed. Unlike the rice fields, these fields cannot be re-used each year, but have to lie fallow for some years. Thus the annual production of groundnuts occupies only 200 ha of the total 700 ha. It is still possible to reclaim new areas for groundnut cultivation. The fields are divided amongst the heads of the households in about the same way as the rice fields.

5.3 Labour

The household is the basic production unit. Each household consists of the male head (hereafter refered to as elder), his wife/wives, unmarried children, and other dependents. Dependent young people account for the majority of the labour force as the age on which a man marries, thus founding his own household, is in his thirties. The elder controls the work of the members, organizing them as he sees fit.

As part of a larger family unit (fank) the household may benefit from the unpaid labour of fank members. Another source of extra help are the so called working groups. These are age groups of unmarried young men and girls.

The groups must be paid partly in kind and partly in money. The recompensation varies depending on the relation between the employer (the elder) and those hired. It is worth noting that this recompensation is determined by the council of family heads.

The vast majority of activites in the village, however, takes place within the framework of the household.

5.4 Output

Everything produced within the household framework belongs to the elder. The rice harvest is collected, and the part which is intended for food until the next harvest is stored by the wife/wives of the elder. If there happens to be a rice surplus (very rare nowadays) it belongs to the elder. Money income, from the sale of groundnuts and other marketed products, also belongs to him.

The unmarried young people, who leave the village for the cities as soon as they have contributed to the agricultural production of their household, are bound to return back to the village on pain of fine. This fine, and its precise amount, is determined by the council of elders in the village. The fact that these young people are away for about eight months, maintaining themselves at their own costs, represents a considerable saving for the elders.

5.5 Land, labour and output of Diatock in 1975

In the year 1975, only 260 ha of rice fields out of the 540 were used. These were almost entirely 'fresh water' rice fields. But not even all the 'fresh water' rice fields (310 ha) were used. Each household cultivated just as much rice as would be required to last through to the following rice harvest, and not more, as was evident from arable land that was left unploughed. Almost all households also cultivated groundnuts in that year. But not all the available fields were used. Several households, which had their groundnut fields cultivated in the previous year, decided to earn their money income this year in a different way e.g. the sale of fruit, palmoil etc. With these alternatives, each household was able to earn enough money to cover its financial requirements which were any way reduced as nothing needs to be spent on the young people who, for long periods each year, are away in the cities.

In the year 1975 there were even some elders who had a money income surplus which, typically, was spent in buying cattle. The possession of cattle is kept private. The cows are kept at some distance from the village and looked after by 'comrades'. The Diola do not sell their cattle, they do not use them as a beast of burden or for labour, nor do they keep cattle to produce milk. They are kept exclusively for their essential role in certain ceremonies. Most important of these are the burial of an elder, and the initiation of the young men.

From all this it is clear that the village of Diatock is not in need of extra rice fields. In spite of this, it was decided, by the government project for reclaiming acid sulphate soils in the Basse Casamance, that about 34 ha should be reclaimed from the land belonging to the village of Diatock. The people of Diatock were not interested, but afraid that they would permanently lose their rights to this land if it were reclaimed by others ('droit de hache'), and under government pressure, they did in fact reclaim these acid sulphate soils. That was all. The land has never been cultivated since. This is not at all surprising in view of the above. The project evaluations say it is due to lack of incentives.

What circumstances incited in the past the Diola to produce rice surpluses, why don't they do so any longer and what circumstances might incite them in the future to do so? These are the questions we want to answer here.

6 Pre-colonial Diatock: the production of rice surpluses

Reports of 1902 (ANS, Dakar, 13 G 498 5) describe Diatock as a village with a population of 1,800 (in 1975 2,000). Its social structure, and its relations and methods of production in that period were basically similar to the present ones. In 1902 there were rice surpluses and large herds of cattle but no labour migration nor cash crops. Cattle censuses of the 1920's arrive at a ratio of one animal per eight inhabitants; today the figure has increased to one animal per four inhabitants. In the absence of labour migration, the consumption of rice must have been larger in that period and thus more rice fields must have been under cultivation.

In fact, in those years the Diola produced rice surpluses. These surpluses were partly bartered, mainly for handwoven textiles and cattle brought in by travelling traders (mostly Mandinko) from what is now the Gambia and Moyen- and Haute Casamance. This exchange of goods formed part of the internal African bartering system that also involved slave trade and was governed by a system of fixed exchange rates: for example, one cow was exchanged for a certain sized basketful of rice and a pile of loincloth was given in exchange for a slave (Van der Klei 1985). The Diola themselves did not hold markets and did not dare to leave their own village territory for fear of being captured and sold into slavery by the travelling traders. Then as now, the acquired cattle and loincloths were reserved for ceremonial use, such as at the occasion of the burial on an elder, and particularly at the initiation of the young men (bukut).

As we have seen, a Diola village consists of a small group of elders who control all means of production, and a large labour force of young people who are dependent on them and work for them. If this social structure is to continue, then from time to time, the elders need to recruit new members from the group of young people. This is done in the ceremony of the bukut. Indeed, only after going through this ceremony a man can marry and so receive land from his elder, with which he can establish an independent household.

Now, let us consider the above mentioned as part of a integrated system. Diola youth were forced by their elders to produce rice surpluses so that cattle and loincloth could be acquired. These were essential for the bukut ceremony. Only by going through this ceremony young men could get the right to marry, receive land and become independent from their elders. Thus, we see that this ceremony does not only play a role in local religion, but is also crucial to the social-economic system of the Diola. This kind of 'incentive' was behind the production of surplus rice by the Diola.

In this explanation the kinship-based relation of production between elders and dependents stands central and explains the old rice production policy of the Diola. In this model there is no room for an individual farmer aiming at maximizing his profits within a so-called market economy.

7 Diatock since colonialisation: disappearance of rice surpluses

In the beginning of this century the colonial administration introduced in the Casamance region an economic policy that promoted the production of groundnuts for the world market. To this effect rice from Indo-China was offered in exchange for groundnuts. French trading houses acted as intermediaries. At the same time colonial frontiers between Senegal, the Gambia and Portugese Guinea became effective and old trading routes were cut off or became smuggling paths. The Mandinko from the Gambia, who traditionally traded with the Diola for slaves and rice, turned to produce and trade groundnuts. Thus the traditional rice exchange of the Diola came to an end, and therewith the old means to secure cattle and loincloths, essential for the maintenance of their socio-economic system. The importation of these goods was revived with money earned by the young people sent by their elders to work as seasonal labourers in the groundnut areas of the Gambia. Thus labour migration and later on also local groundnut cultivation replaced the production of surplus rice as a means of acquiring exchange goods. As a consequence, first the 'saline' rice fields and gradually the other less difficult to cultivate rice fields were abandoned.

8 Concluding observations

From the foregoing, it may be concluded that the Diola of Diatock and also the Diola in general, have no strong motives to expand their rice production and even less to reclaim new 'saline' and acid-sulphate rice fields to that end, as long as their kinship based economic system prevails. This system is aimed at its own reproduction and organises the means of production to this end. It must be clear that this system has nothing in common with a so called market system where individual farmers try to maximize their profits. The remaining rice production of the Diola, as well as their recent participation in the market economy (cash crops and labour migration) are basically concerned with reproducing the old situation where the young people support their elders.

Under the prevailing socio-economic system, it is also not likely that technical improvements of the infrastructure and marketing facilities, will bring about a spontaneous reversal of the actual trend of young people to turn to schooling and beter paid jobs in the towns and drift away from the agrarian way of life in the village. Under the given circumstances, the national administration will have to take stronger measures to persuade the Diola to increase their rice production. One way would be to raise the price offered for rice, or else to use more or less subtle forms of coercion to discourage urban migration. This, however, would not necessarily imply a return to food production. As long as the village can produce enough food for itself, and is in control of its own land, it can remain immune to the wishes of the state concerning increased food production. In theory, the state has full control of the land since it nationalized by law all land in Senegal in 1964 (Loi no. 64-46, relative au Domaine Nationale). However, the implications of this law are hardly realised and still less understood by most of the local people (Van der Klei 1978, 1979 and Geschiere & Van der Klei 1985). It seems that the policy of the Senegalese government to increase rice production in this region has serious problematic aspects which escape solutions by mere technical and legal approaches.

This particular case of the 'non-cooperation' of the Diola in a soil reclamation project is examplary for similar governmental agricultural projects in this part of Africa. This case shows us that the economic aims of the state and the Diola in connection with land usage and production are not the same. In these and similar state projects, far too little attention is paid to the functioning of local societies and too easily it is assumed that local and national interests will coincide. This does not mean that more detailed knowledge of the internal logic of local societies would help all agricultural reforms to run smoothly and without friction. But greater attention and concern for how local societies are functioning, could contribute appreciably to lessening the political and financial risks involved in carrying out nationally desirable agricultural projects.

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Social and economic status of farmers in acid sulfate soil areas in The Philippines

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1 Summary

A study to compare the socio-economic status of farmers engaged in rice and fish farming in reclaimed with those in unreclaimed acid sulfate soil areas in the Northeast of Panay Island, Philippines was conducted in 1985.

Cluster random sampling technique was used in selecting the respondents. Before the interview and survey, the respondents, according to the size of land holding, were grouped in small, medium and large scale farmers and type of land holding indicated. Prior to the preparation of questionnaires and survey forms a few case studies were also conducted. To avoid the effect of differences in the size and type of land holding, comparisons were made within each category.

The economic changes brought by reclamation and associated improved management techniques in terms of changes in land use pattern, increase in land productivity, cropping intensity, and overall increase in farmers income are evaluated. The social status assessed in terms of farmer's contribution in satisfying the social needs of the community, standard and ways of his and his family's life, participation in communal activities, changes in social habits, leadership attainment, social recognition and job opportunities for family labor including women are presented and discussed.

The conclusion is that succesful reclamation of fish ponds and rice fields with acid sulfate soil problems, has enabled the farmers to establish financial independance and to gain social and economic influence and status in their rural community.

Résumé

Une étude comparative de l'état socio-économique des fermiers riziculteurs et pisciculteurs des superficies à sols sulfaté-acides, améliorées et non améliorées, de la partie nord-est de l'île Panay de Philippines a été réalisée en 1985.

Afin de sélectionner les répondants, la technique des sondages au hazard a été utilisée et les fermiers groupés en fermiers à exploitations de petite, moyenne et grande taille, d'après les dimensions de terrains possédés et du type d'utilisation.

Ensuite, un questionnaire concernant les interviews et les expertises à suivre a été mis au points. Pour eviter l'effet des differences de dimensions et type d'utilisation, les comparaisons ont été fait à l'intérieur de chaque catégorie.

Les avantages économiques apportées par l'amélioration, associés aux techniques d'aménagements perfectionnées exprimés en termes des changements dans le modèle d'utilisation des terres, de l'augmentation de la productivité, de l'intensité de la production et d'augmentation des profits des fermiers, ont été evalués et comparés. L'état social des impôts en terms de contributions de fermiers pour la satisfaction des nécessi-

tés de la communauté, le standard et les routes de leurs vie familiale, par participation aux activités communes, les changements dans des habitudes sociales, l'aquisition d'une conduite, la reconnaissance sociale de l'opportunité que la famille de l'agriculteur, inclusivement les femmes reçoivent une besogne, sont présentés et discutés.

2 Introduction

Acid sulfate soils are reported to occupy several millions ha in South and Southeast Asia. About 0.5 million ha are estimated to be in the Philippines (Brinkman and Singh 1982). Of these, 20 to 25 thousand ha, are reported to be in the island of Panay (Singh and Darvin 1983). Acid sulfate soils are characterized by low pH (less than 4) and the presence of yellow mottles of jarosite in the upper 50 cm of the soil profile. But according to Pons (1972), acid sulfate soils embrace all soil materials in which the low pH has a lasting effect on main soil characteristics.

In the Philippines these soils are generally associated with coastalsaline soils and they are mainly cultivated for brackish water fish production. Rice culture is practised if and when fresh water becomes available. For both these crops, acid sulfate soil condition are harmful and their productivity is low (Singh et al. 1985) but it can be increased by intensive reclamation (Singh and Darvin 1983; Poernomo 1983). A rapid reclamation technique for fishponds, proposed by Brinkman and Singh (1982), was extensively tested and disseminated for the farmers by Singh and co-workers. Many farmers are reported to have benefitted from this in terms of increase in production and income of the farmer (Singh 1985; Singh et al. this symposium).

Only little is known about the socio-economic impact of reclamation. Brinkman (1982) has outlined some features in this regard but quantitative date are scarce.

In 1985 in a first approach an attempt was made to register the socio-economic status of the farmers in reclaimed and unreclaimed acid sulfate soil areas in Panay Island, Philippines, in relation to the benefits of reclamation and difficulties in implementation of reclamation techniques. It was necessary to examine and compare the status of farmers engaged in rice as well as fish production because reclamation techniques for both crops were technically feasible. The study was limited to rice and fish farmers in the northeast coast of Iloilo province. Its results are reported in the following.

3 Materials and methods

This study was conducted in the towns of Barotac Nuevo, Barotac Viejo, Ajuy, Concepcion and San Dionisio of Iloilo province. In this area fifty respondents were picked at random in reclaimed and unreclaimed areas affected by acid sulfate soil conditions, as apparent from earlier surveys by Singh.

The respondents were known to be or have been engaged in rice as well as fish farming with varying sizes of land holding and period of farming.

Each of the respondents was interviewed for 25 predesigned questions and the interview recorded on a mini tape recorder for verification purposes. The questionnare had been tested and corrected previously by staying with some farmers and interviewing them, some responses of the farmers to the regular questionnaire were rechecked and verified by examining the tape recorder or reinterviewing.

The informations gathered were reduced to percentage of absolute number and grouped according to the farmer's general profile, social profile, soil and crop management practices, farm assets, and household assets, considered to be essential aspects of socio-economic status.

Comparisons were made within the simular size of land holding, types of crops grown and reclamation techniques employed. Prior to this interview the farmers and the interviewer were not known to each other.

4 Results and discussion

4.1 General

The results of some characteristics of the farmers general profile are presented in Table 1. The size of land holdings ranges from 1 to 288 ha and averages 20 ha. The majority (80%) of the holdings are small size (1-10 ha) and medium size (10-22 ha), with the smallest holdings occurring in the unreclaimed lands.

In unreclaimed areas, 36% farmers (9/25) grow fish, and 16% (4/25) rice. The remaining 48% (12/25) reported not to grow anything mainly because of continuous failures in rice as well as fish farming. On the other hand in reclaimed areas 92% of the farmers grow fish and the remaining 8% rice. In both areas, it is interesting to note that all rice farmers had small size land holdings.

In each area, the majority of respondents were titled land owners; 17 in unreclaimed and 15 in reclaimed areas. About 25-30% of the farmers cultivated land leased from private or public sources but such farmers were small size in the unreclaimed and medium to large size holder in the reclaimed area (Table 1). Of all farmers, only 1 owned the land with certificate of land transfer.

The amounts of lease payment to private sources in both areas varied from ₱ 1400 to 4000/ha per year; while to the public sources it was only from ₱ 20 to 30/ha per year (Table 1).

The higher lease cost in the private sector can be explained by the land being developed (cleared, levelled, diked), when development being absent in land leased from public sources.

In the unreclaimed land most lease was for rice production and in terms of share of production (0.25 of the gross), while in the reclaimed areas it was for fish production and always paid in cash mostly and in advance for one to five years. These trends indicate that the farmers have confidence in the reclamation procedure enabling economically successful fish culture.

The average family size in both reclaimed and unreclaimed areas is about 7-9 members per family The average age of the children in both areas ranged from 18-26 years. It is interesting to note that in both areas, farmers had their children of working age helping on the farm. But most frequently this occurred on small size land holdings in the unreclaimed area (Table 1).

The reasons for children working on the farm are apparently to assist the parents. But obviously in the unreclaimed areas children work on the farm because they don't have better opportunities outside. In the reclaimed areas the children assist on the farm because of more attractive remuneration than outside. The children working on unreclaimed farms are mainly engaged in physical labor while in the reclaimed areas they work in managerial capacities e.g. manager, overseer or taking care of the farm. The number of farmers receiving some monetary support from children was slightly less in the unreclaimed areas than in the reclaimed ones. Few farmers about (30%) in both cases take agricultural laons to support their farm operations most of them, being small size land holders.

4.2 Soil and Crop Management Practices

Table 2 indicates that all 25 respondents in the reclaimed areas tried to reclaim the land and succeeded in their efforts. In the unreclaimed areas only few respondents reported to have tried to reclaim their land but with very little success. Interestingly, it was noted that more farmers in the unreclaimed areas built dikes to stop sea water intrusion because they thought that the problem in the area was more of the sea water rather than acidity. According to the farmers, building dikes worsened the situation where soil surfaces turned red. Thereafter, they discontinued their efforts.

In general, the succesful techniques to reclaim the land included frequent draining, drying and flushing of the land in the dry season. In addition to this, farmers also reported to apply lime to neutralize the acidity. Two farmers also reported to till the fields in between drying and flushing periods. Only one farmer reported to apply normal soil or mud press to neutralize the acidity.

In the unreclaimed areas, diking, levelling of the field and filling of the depressions by bringing the soil from higher portions were more common. Draining, drying, tilling, and liming was practised rarely. More than 25 per cent of the farmers in this category, reported to drain and dry their land but did not apply flushing (Table 2). On the other hand in the reclaimed areas almost all farmers reported to sequentially first drain, dry and flush their lands and so improved the production capacity.

This indicates that apparently the farmers who are now in the reclaimed areas knew that the problem in their land was not so much of the sea water per se but it was a combination of acidity as well as salinity. Salinity appears to be a lesser problem, as farmers in the reclaimed areas mostly grow salt water fishes. The salinity tolerance of these fishes is very high, in fact, they can be grown in pure sea water.

Of the 23 fish farmers with reclaimed ponds, 10 reported that after reclamation they grow older fingerlings, while none of the 9 fish farmers in the unreclaimed area reported such an operation (Table 2). All fish farmers in both areas use inorganic fertilizers and pesticides, but organic fertilizers are only applied in the reclaimed ponds.

All the rice farmers in both areas reported to use modern rice varieties, herbicides, pesticides, irrigate fields and to replant dead seedlings. Apparently no difference in the rice cultural practices was noted among the farmers of both areas.

From Table 2, it is clear that presently the production of both rice and fish in the reclaimed area is significantly higher than in the unreclaimed lands. Before the new reclamation techniques were introduced, fish production was already higher in the now reclaimed area, indicating that the present superiority in fish production in this area is not a mere result of reclamation but also of better skill or more favourable natural conditions. All the same in the now reclaimed area fish production increased from an original 120-240 kg/ha/crop to 320-660 kg/ha, whereas in the unreclaimed area it remained on the original level of about 100 kg/ha.

An increase of 400 kg fish/ha/crops can be considered due to the reclamation itself.

As for rice, the increase from 0.5 to 2.6 t/ha of paddy in the reclaimed are is obviously mainly the result of the reclamation operation.

There is also a significant increase in the cropping intensity in reclaimed areas. In unreclaimed areas farmers usually grow two crops of fish or only one crop of rice per year. In the reclaimed areas they reported to grow three crops of fish or five crops of rice in about two years. This trend indicates that reclaimed areas are now normally productive. The levels of rice as well as fish production in all reclaimed areas (small, medium or large) is almost similar to the average production of the country or the average production in the province of Iloilo. Higher production levels and increased crop intensity clearly indicate that the farmers in the reclaimed areas are economically much better off than those in unreclaimed areas.

4.3 Social profile

In unreclaimed areas (Table 3) almost all farmers are engaged in off farm activites (fishing in the sea, small scale trading, carpentry, etc.). They are also engaged in other farm operations (backyard gardening, growing poultry, livestock, etc.), apparently to offset the monetary obligations and because their main farm income is not sufficient to meet all family requirements. In the reclaimed areas the number of farmers engaged in off-farm operations or having other farm income sources was less (Table 3). The majority of the farmers with alternative income sources in both cases belonged to the small land holding group.

In the unreclaimed areas the number of women working on the farm was 6, against 1 in the reclaimed areas. The women in the former case contribute to family income by working almost for the whole week while in the latter case they work occasionally. This trend indicates that in unreclaimed areas because of the lower income, all members of the family including the women need to help the family in generating more income. When investigated, the farmers in the reclaimed areas reported to have no need for the women to work to increase family income. They reported to prefer hiring the labor rather than asking the women of the household to work. Apparently they earn enough to support their family.

In reclaimed as well as unreclaimed areas many of the farmers are members of the local civic and government organizations but their number is highest for reclaimed areas (Table 3). Only half of the members from unreclaimed areas reported to have an officer's position in these organizations, whereas from the reclaimed areas almost all are officers in their organizations. This is apparently because the latter are economically more sound and socially/politically influential. It is interesting to note that in both cases the sampled farmers were from the same locality (town/municipality/barrio) as well as organization.

Almost all farmers from both areas reported to have a church (chapel), school, basketball court, and a plaza. This was to be expected as they live in the same community. They also reported to donate some money for church or school building but there was a remarkable difference in the amount donated between the two groups. From

Table 1. Farmers general profile* in unreclaimed and reclaimed acid sulfate soil are Iloilo, Philippines

Particulars	Unreclaimed Small (< 10 ha)	Unreclaimed Medium (10-20 ha)	Unreclaimed Large (> 20 ha)	Reclaimed Small (< 10 ha)	Reclaimed Medium (10-20 ha)	Reclaimed Large (> 20 ha)
No of respondents	16	5	4	9	10	6
Average farm size (ha)	2 (1-6)	13 (10-17)	107 (27-288)	5 (2-10)	14 (11-17)	37 (20-70)
Type of land possession:						
– Titled	10	4	3	7	5	3
– Leased from private sources in cash	1	0	0	1	5	2
– Leased from private source of share of production (0.25 of gross)	5	0	0	0	0	0
– Leased from public sources	0	1	1	0	0	1
– Certificate of land transfer	0	0	0	1	0	0
Amount of lease payment:						
– Private sources (₱/ha/year)	2000	0	0	1400	500–4000	2000–3000
– Public sources (₱/ha/year)	0	20-30	20-30	0	0	20-30
Average number of years:						
– In farming rice	20 (2-50)	0	24 (5-45)	20 (9-30)	0	0
– In farming fish	0	20 (10-35)	0	0	16 (3-50)	28 (10-40)
Number of farmers cultivating:						
– Rice	4	0	0	2	0	0
– Fish	4	4	1	7	10	6
– None	8	1	3	0	0	0
– Take Agricultural Loan	5	2	1	3	2	1
– With children working in farm	11	4	2	6	5	5
– With children providing financial help	6	2	0	3	5	2
– With college graduate children	10	1	2	6	2	6
– Average family size	9	8	7	9	6	7
– No of children/family	7 (1-13)	6 (4-8)	5 (1-9)	7 (3-11)	4 (2-8)	5 (1-10)
– Average age of children	22 (1-44)	18 (7-38)	26 (10-43)	22 (1-45)	17 (1-40)	22 (3-35)

* Values in parenthesis are ranges

Table 2. Soil and crop management practices of farmers in unreclaimed and reclaimed acid sulfate soils areas. Iloilo, Philippine

Particulars	Unreclaimed				Reclaimed			
	Small	Medium	Large	Total	Small	Medium	Large	Total
No of respondents	16	5	4	25	9	10	6	25
Number of farmers:								
– Successfully tried to reclaim the land	0	0	0	0	9	10	6	25
– Tried to discontinued	3	2	1	6	0	0	0	0
Land reclamation by:								
– Diking to stop seawater intrusion	5	1	0	6	0	0	2	2
– Levelling	4	2	1	7	0	0	1	1
– Filling	1	1	1	3	0	0	0	0
– Draining	2	4	1	7	7	9	4	20
– Drying	2	4	0	6	6	10	3	19
– Tilling	2	0	0	2	0	2	0	2
– Flushing	2	0	0	2	6	10	3	19
– Liming	2	1	1	4	3	8	2	13
– Using mud press/neutral soil	0	0	0	0	0	0	1	1
Growing fish with the:								
– Use older fingerlings	0	0	0	0	3	3	4	10
– Use inorganic fertilizer	4	4	1	9	7	10	6	23
– Use organic fertilizer	0	0	0	0	7	10	6	23
– Use pesticides	4	4	1	9	7	10	6	23
Growing rice with the use of modern varieties, pesticides, irrigation	4	0	0	4	2	0	0	2
Number of farmers reported production increase after reclamation/with time	6	4	0	10	9	10	6	25
Rice production (earlier) (before reclamation) (kg/ha/crop)	1150	–	–	1150	500	–	–	500
Rice production (now) (after reclamation) (kg/ha/crop)	1400	–	–	1400	2600	–	–	2600
Fish production before reclamation kg/ha	42	102	0	72	124	208	236	189
Fish production after reclamation kg/ha	88	115	0	102	318	658	632	536

Table 3. Social profile of farmers in unreclaimed and reclaimed acid sulfate soil areas. Iloilo, Philippines

Particulars	Unreclaimed				Reclaimed			
	Small	Medium	Large	Total	Small	Medium	Large	Total
No of respondents	16	5	4	25	9	10	6	25
Number of farmers with:								
– Off-farm income	15	5	2	22	6	5	3	14
– Other products of farm	11	2	4	17	5	1	2	8
– Women working in rice field as labor	4	0	0	4	1	0	0	1
– Women working in fish ponds as labor	1	1	0	2	0	0	0	0
– Work period of women (days/week)	4-5	4-5	0	–	4-5	1-2	0	–
– Salary of women (₱/day)	13-20	12	0	–	20	0	0	–
– Membership in civic/govt. organization	8	2	2	12	7	5	2	14
– Officership in civic/govt. organization	3	1	2	6	7	3	3	13
– People consulting them	9	3	4	16	7	8	5	21
– People call to pacify trouble	9	1	2	12	5	5	2	12
– Private transportation	2	2	2	6	2	3	3	8
– Use public transport	14	3	2	19	7	7	2	16
– Use private transport	0	2	2	4	1	3	3	7
– Give ride to others	0	1	2	3	1	2	3	6
– Have church, school, basketball court and plaza in their locality	16	5	4	25	9	10	6	25
– Donated money for the above	13	4	3	20	7	7	6	20
– Amount (₱)	2-200	50-200	2-5000		5-400	12-10000	50-500	
– Donated land for the above	0	0	1	1	5	0	1	6
– Area (ha)	0	0	1		1	0	10	
– Support school athletic activities	0	0	0	0	0	0	1	1
– Provided labor	2	1	0	3	1	2	0	3
– Celebrate fiesta	11	4	3	18	8	7	5	20
– Use leisure time in beer/wine drinking	3	2	2	7	4	4	4	12
– Cockfighting	2	1	1	4	2	3	0	5
– Playing basketball	3	1	3	7	2	2	1	5
– Listening radio	11	3	3	17	7	8	1	16
– Watching T.V.	4	3	2	9	4	3	5	12
– Visit and talk to friends	13	3	4	20	6	8	5	19
– Attend dancing	3	0	0	3	5	1	0	6

Table 4. Farm assets* of farmers in unreclaimed acid sulfate soil areas. Iloilo, Philippines

Particulars	Unreclaimed				Reclaimed			
	Small	Medium	Large	Total	Small	Medium	Large	Total
No of respondents	16	5	4	25	9	10	6	25
Number of farmers that own:								
– Bodega/Kamalig	12	2	3	17	6	1	2	9
	1(2)		1(2)				1(8)	
– Carabao	6	0	1	7	2	0	1	3
	1(2)				1(4)			
– Cattle	0	0	1(4)	1	0	0	0	0
– Goats	0	0	0	0	0	0	1(60)	1
– Tractors**	2	0	1	3	0	0	0	0
	1(2)		1(4)					
– Power tiller	0	0	1	1	0	0	0	0
– Irrigation pump	1	0	0	1	2	0	0	2
					1(2)			
– Thresher	0	0	0	0	1	0	0	1
– Sprayers	4	0	1	5	2	0	0	2
– Plows	13	0	2	15	3	0	0	3
	2(2)		1(2)		2(2)			
– Harrows	0	0	0	0	3	0	0	3
– Nets	4	2	1	7	7	6	4	17
	(1-2)	(2-5)			(2-6)	(2-4)	(2-5)	
– Sacks	4	1	0	5	4	2	3	9
	(25-400)	(80)			(300-1000)	(200-400)	(100-3000)	
– Basins	3	1	0	4	6	5	3	14
	(1-3)	(3)			(1-6)	(1-2)	(2-5)	
– Pails	4	0	1	5	7	5	6	18
	(1-3)				(1-4)	1(200)	(1-5)	
– Search lights	0	0	0	0	2	1	2	5
– Pump	1	0	0	1	0	0	3	3
– Aerators	0	0	0	0	1	0	0	1
– Wooden boxes	12	0	0	12	2	1	3	6
					(20-50)	(20-160)		
– Plastic boxes	0	0	0	0	0	0	1	1
							(25)	

* Values in parenthesis indicate number of units and preceeding numerical number of farmers
** Purchased on credit and used for custom services

Table 5. Household assets* of farmers in unreclaimed acid sulfate soil areas. Iloilo, Philippines

	Unreclaimed				Reclaimed			
Particulars	Small	Medium	Large	Total	Small	Medium	Large	Total
No of respondents	16	5	4	25	9	10	6	25
Number of farmers that own:								
– One house	15	3	2	20	8	7	4	19
– Two houses	1	2	2	5	1	3	1	5
– Three houses	0	0	0	0	0	0	1	1
– House and lot	12	5	3	20	7	8	5	20
– Sala set	2	3	2	7	8	5	4	17
		2(2)	1(2)		1(2)		(2-3)	
– Dining set	3	4	2	9	8	4	3	15
	1(2)	1(2)	1(2)					
– Radio	13	5	4	22	9	10	5	24
					2(2)			
– Television set	2	4	2	8	5	6	3	14
					1(2)		1(2)	
– Refrigerators	1	2	2	5	4	4	3	11
							1(2)	
– Stereo	1	2	1	4	3	4	1	8
– Electric fan	0	2	1	3	3	3	2	8
							(2-3)	
– Phonograph	1	0	0	1	2	3	1	6
– Sewing machine	3	4	1	8	8	6	4	18
– Gas range	0	0	0	0	1	0	1(3)	2
– Bathroom	4	4	2	10	8	5	3	16
		2(2)	1(2)		1(2)	1(2)	2(5)	
– Cassette	1	0	0	1	1	0	0	1
– Typewritter	1	0	0	1	0	0	0	0
– Betamax	2	0	0	2	1	1	1	3
– Generator	1	0	0	1	0	0	0	0
– Airconditioner unit	0	0	0	0	1	0	2	3
							1(2)	
– Vehicle	2	2	2	6	2	3	3	8

* Values in parenthesis indicate number of units and preceeding numerical number of farmers

the unreclaimed area the amount donated averaged ₱ 342, and varied from ₱ 2 to 200 with one exception: the farmer (large land holder) who donated ₱ 5,000 and one ha of land (Table 3). In the reclaimed areas the amount donated varied from ₱ 5 to 10,000 (average of ₱ 727) and 6 farmers donated some land which varied from 1-10 ha. In addition, one farmer from the reclaimed area also regularly supports the uniforms and equipment needed for school athletic activities. In both land groups, generally bigger donations came from large land holders.

As for social habits and leisure time activities, the number of farmers spending their time by watching T.V., drinking and attending dances were considerably higher in reclaimed than in unreclaimed areas. Farmers engaged in other leisure activities number the same in both cases (Table 3). Farmers in the reclaimed areas have their own T.V. set and other entertainment equipment while those in the unreclaimed areas ask favors from the neighbourhood. Farmers who succesfully reclaimed their land reported that ever since than they celebrate the annual fiesta with more extravagance.

4.4 Farm Assets

Farm assets of the farmers in both areas varied with the use and size of the land holding. The number of units owned varied with the type of land (Table 4). A total of 15 farmers in unreclaimed areas owned one unit of bodega (kamalig, generally a nipa house with cemented floor) and 2 farmers has 2 units each. In the reclaimed areas only 9 farmers had such bodegas of which 1 with 8 units. Seven farmers in unreclaimed areas had carabaos (water buffalow) against only 3 in reclaimed areas.

Apparently more farmers in unreclaimed areas have carabaos and more agricultural equipment such as plows, sprayers and tractors, because they are mainly rice farmers. In reclaimed areas, as they are mainly fish growers, they had more fish farming equipments: nets, bassins, sacks, pails and wooden or styrofoam boxes. In general, the farmers with small size land holding and in unreclaimed areas have insufficient farm assets while those in other categories have sufficient to meet the farm requirements.

4.5 Houses and Household Assets

In reclaimed as well as unreclaimed areas the number of farmers that had one house, was almost identical (Table 5).

About 5 farmers in both areas owned 2 houses. In the unreclaimed areas farmers with two houses belonged mostly to the medium to large scale land holding class. In the reclaimed areas it appears that the additional houses owned were paid mainly from the farm income while in the unreclaimed areas the additional house unit of some farmers was paid for with income other than from the land.

In addition, there is a remarkable difference in the quality and location of second houses between the two soil areas. The farmers in reclaimed areas have their second house in the city while those from the unreclaimed areas have it mostly in rural towns or barrios. Some of the people in reclaimed areas have even a house in a foreign country. Many farmers in the unreclaimed areas have abandoned the land and do not grow any crop, yet they were able to build two houses but mainly from income other than from the farm.

The types of household assets and the number of units owned varied considerably between the unreclaimed and reclaimed areas and the size of land holding. More farmers in the reclaimed areas owned radios, T.V. set, refrigerators, stereo sets, electric fans, phonographs, sewing machines, sala sets, dining sets, betamax, airconditioners, gas ranges, and even transportation (jeep, car, and tricycles) (Table 5). The number of units of these assets owned was also highest in reclaimed acid sulfate soil areas.

5 Conclusions

Reclamation of acid sulphate soils in Iloilo province by sequential draining, drying, tilling, liming and flushing, improved not only productivity of fish ponds and rice fields, but also increased the financial position and the socio-economic status of the land owners and their family. Farmers that did not try to or succeed in ameliorating their fields with adverse acid sulphate soil conditions tended to abandon their land or become dependant on off-farm sources of income and their social-status in the local rural community relatively lagged behind. Successful reclamation enables the farmers to establish a sound financial independance on the basis of agrarian activity only thereby widening the scope of options in the future for their families.

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