SOIL KNOWLEDGE FOR FARMERS,
FARMER KNOWLEDGE FOR SOIL SCIENTISTS

The case of acid sulphate soils in the Mekong delta, Viet Nam

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The case of acid sulphate soils in the Mekong delta, Viet Nam

M. E. F. van Mensvoort

Proefschrift
ter verkrijging van de graad van
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op gezag van de rector magnificus,
Dr. C.M. Karssen,
in het openbaar te verdedigen
op dinsdag 18 juni 1996
des namiddags te vier uur in de Aula
van de Landbouwuniversiteit te Wageningen

Aan Marja, Marieke en Hilde
In herinnering aan mijn ouders, die hun koeien wilden verkopen om me te laten studeren

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PROPOSITIONS

1. Further land and water development in the Mekong delta should give priority to better infrastructural provisions at farm level, not to an extension of the main infrastructure.

   NEDECO 1993 Master Plan for the Mekong delta in Vietnam, a perspective for sustainable development of land and water resources. NEDECO consultants, Arnhem, the Netherlands

2. In order to make computer models of the chemical and physical processes in acid sulphate soils research more applicable, priority should be given to the detailed modelling of a limited number of dominating processes rather than to aim at one model encompassing all processes.

   This thesis

   Bouma, J., M.E.F. van Mensvoort and L. V. Khoa 1993. Ways and means of modelling acid sulphate soils. In: D.L. Dent and M.E.F. van Mensvoort (editors) Selected papers of the Ho Chi Minh City symposium on acid sulphate soils. ILRI Publication 53, ILRI, Wageningen, the Netherlands p 331-340

   Bronswijk J.J.B. and J.E. Groenenberg 1993. A simulation model for acid sulphate soils I: basic principles. p. 341-357. In: D.L. Dent and M.E.F. van Mensvoort (editors) Selected papers of the Ho Chi Minh City symposium on acid sulphate soils. Pub. 53, Int. Inst. Land Reclamation and Improvement, Wageningen

   Wijk, A.L.M. van, I. Putu-Gedjer Widjaja-Adhi, C.J. Ritsema and C.J.M. Konsten 1993. A simulation model for acid sulphate soils II: validation and application for water management strategies. p 357-368 In: D.L. Dent and M.E.F. van Mensvoort (editors) Selected papers of the Ho Chi Minh City symposium on acid sulphate soils. Pub. 53, Int. Inst. Land Reclamation and Improvement, Wageningen

3. The future of the acid sulphate land in the Mekong delta is since 1987 back in the hands it can be best entrusted to: the hands of the Vietnamese farming women and men.

   This thesis

4. In the Vietnamese language the word 'nuoc' means both land and water. The reason why becomes clear after having travelled in the acid sulphate soil areas of the Mekong delta during the rainy season.

5. The plans for construction of bridges over the Tien Giang and Hau Giang branches of the Mekong are now in an advanced stage. Before engaging in construction, however, investments should take place into small scale industries creating sufficient job opportunities in the Mekong delta. If not, the bridges will mainly enhance urbanisation towards Ho Chi Minh City.

6. The fast growing stream of international tourists to Ho Chi Minh City and Hanoi should be a reason for the French government to support generously the maintenance of the French colonial architecture in Vietnam, since this cannot be requested from the Vietnamese.

7. By creating Education Institutes with the main aim to organise cheaper education for larger groups of BSc students, WAU endangers its international MSc programmes.

8. The PhD sandwich programme of WAU should change name. It only consists of two slices of bread.

9. For reasons of sensible land evaluation and conservation of typical Dutch nature reserves, the Knot Arnhem/Nijmegen (KAN) should seek its extension either north of Arnhem or South of Nijmegen, but not in between.

10. The increasing replacement by Vietnamese farmers and farming women of the traditional conical hat made of palm leaves by baseball caps and floppy plastic hats is regrettable for economic, esthetic and practical reasons.

M.E.F. van Mensvoort
Soil knowledge for farmers, farmer knowledge for soil scientists. The case of acid sulphate soils in the Mekong delta, Viet Nam.
Wageningen, 18 June 1996

ACKNOWLEDGEMENTS

This thesis is the result of a long period of co-operation with a large number of people. They all, in their way, have contributed over the last 15 years to the project VH 10 which has been the inspiration for this thesis.

First of all I thank my promotor, Johan Bouma, for pushing me over the threshold and for continued pushing over the last two years. I needed it. During our one-and-only joint trip to Vietnam in 1992 you convinced me that the story of VH 10 was worth writing down.

I am deeply indebted to my co-promotor, prof. Vo-tong Xuan. It has been a great privilege to work side-by-side with you for all these years. Your knowledge of the Mekong delta and your life-long commitment to its people have been my source of inspiration. We are at the dawn of a new challenge together. I will try my best not to disappoint you.

I thank my co-authors David Dent, Le Quang Tri, Nguyen Van Nhan, Tran Kim Tinh and Herman Huizing for their contributions to this thesis.

A special word of thanks goes to the two godfathers of the VH 10 project, profs. Leen Pons and Eize Stamhuis. Leen Pons, my teacher since 1965, you showed me my first acid sulphate soil in the Bangkok Plain (Rangsit series !!), and I thank you for your warm commitment to the VH 10 project and particularly for your incredible mental and physical enthusiasm during fieldwork. Eize Stamhuis designed and supervised the construction of the research station Hoa An and lectured a number of times in Can Tho. Eize, your beautiful, meticulous drawings and the accompanying lecture notes on traditional Dutch methods and materials of civil engineering deserve more than the state they are in now: stencils or photocopies.

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I am deeply indebted to my Vietnamese colleagues of Can Tho University. I thank the former rector and vice rector, Mr. Pham Son Khai and Mr. Nguyen Kim Quang, and rector Tran Phuoc Duong for their support.

Most Vietnamese colleagues started in VH 10 as newly graduates and made a 15 years commitment to the project. The "hard core" consisting of Mrs. Do Thi Thanh Ren, Mrs. Nguyen My Hoa, Mrs. Vo Thi Guong, Tran Kim Tinh, Le Quang Tri and Le Quang Minh were engaged from day 1 of the project in January 1980 till this very day. Others joined and stayed committed to the project: Duong Van Ni, dr Truong Thi Nga, Nguyen Bao Ve, Vo Tong Anh, Tran Minh Thuan, Nguyen Nang Hung. In fact it is largely your story that I have written here and I am very grateful to you all.

I thank dr. To Phuc Tuong, now at IRRI but formerly at the University of Agriculture and Forestry of Ho Chi Minh City for his contributions to the VH 10 research in the field of water management. You were the only knowledgeable water management specialist with a farmers heart in the early years of VH 10 and: good company!

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I thank the other staff members of the Soil Science Department and the Water Management and Rural Engineering Faculty, and I thank the farmers of the Mekong delta and their local leaders in districts and provinces, who played such an important role in the VH 10 project.

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Chapter 1:

GENERAL INTRODUCTION

Upon drainage, acid sulphate soils produce sulphuric acid that brings down the soil pH below 4, leaks into surface water, corrodes steel and concrete and attacks clay, liberating aluminium which is toxic to plant growth. Half of the Mekong Delta, Vietnam, is to some degree affected by the problem of acid sulphate soils, covering an area of about 2 million hectares or half the size of the Netherlands. This is one of the largest occurrences of acid sulphate soils in the world. Until the early sixties this land was virtually unused. Population pressure was low. The Southern Vietnamese population could easily be fed by produce from the excellent land elsewhere in the delta. Vietnam was a rice exporting country at that time.

During the Vietnam war the acid sulphate land served as a hideout for the resistance forces and was heavily shelled and sprayed with defoliants. The few agricultural activities going on there came virtually to a standstill. After the war, in the late seventies, Vietnam experienced serious food shortages. This was caused by unfavourable weather conditions and international boycotts resulting in lack of funds for fertilisation and crop protection. However, also the resistance of the Southern Vietnamese farming community to the new centralised agricultural policy played a role.

The government gave high priority to development of the unused parts of the Mekong delta. The land seemed ideal for agricultural development: warm climate, high rainfall, flat land, reasonably easy access and close to the most densely populated part of the country. Besides, the population of the area had earned the support of the central government by its role during the war. The empty parts of the delta also needed to be settled because of threatening claims to the Mekong delta by the Pol Pot regime, at that time in charge in neighbouring Cambodia. Because it was so thinly populated, the land was ideal for the establishment of large scale state farms. Some 60 farms were established, varying in size between 1000 and 10,000 hectares each. Lack of experience in management of these extremely difficult soils, shortage of staff and funds, and harsh living conditions made most of these state farms a catastrophic failure.

Due to increased population pressure, land hunger and a dramatic economic liberalisation in the second half of the eighties known as the "doi moi" policy (which meant the end of the state farm policy) tens of thousands of hectares of acid sulphate land have been reclaimed and taken into cultivation by small farmers.

In the late seventies the Vietnamese authorities solicited assistance on how to manage the acid sulphate soils in the Netherlands. Knowledge on acid sulphate soils was present at Wageningen University, particularly at the Department of Soil Science and Geology. Staff from that Department had investigated these soils in several countries in the tropics (Thailand, Indonesia, Guyana, Surinam). Their knowledge, however, was focused on fundamental aspects of genesis, spatial distribution, and chemical processes of pyrite formation and acidification after drainage. Vietnamese priorities were to find simple field methods to distinguish and improve the acid sulphate soils, and make them more productive.

Assistance from the Netherlands was granted in the form of a project of co-operation between the University of Can Tho (CTU), central city in the Mekong Vietnam, and the Wageninge Agricultural University (WAU). The project, coded VH 10 (project number 10 in a series of co-operation projects between Dutch and Vietnamese Universities) was also of interest to the Dutch: their fundamental knowledge could be used in the context of more practical, applied project on improvement and management of acid sulphate soils. Furthermore, the approach to solving the problems would have to be multidisciplinary, with contributions not only by soil science, but also by water management, agronomy and civil engineering. Until the start of the project in 1980, existing knowledge was mainly restricted to soil scientists. The goals of the project were threefold: train staff of CTU, supply CTU with the necessary facilities and carry out research for the management of acid sulphate soils.

This thesis is a reflection of the way in which the project developed and operated. Not only does it address part of the new knowledge generated in Vietnam, it particularly emphasises the nature of the co-operation, and its core activity: the strong interaction between the various land user groups: *farmers*, local *experts* such as district officers in charge of agricultural extension or land use planning and staff of Vietnamese research institutions, and the *specialists*, in our case scientists of CTU and WAU.

The political landslide of the late eighties also had implications for the VH 10 project. The recommendations from research, generally of a small scale nature due to the high short range variability in the soil properties of acid sulphate soils, which were unacceptable for large scale state farms, became of direct interest to the small settlers and thus much more applicable. The economic liberalisation caused a strong increase in agricultural production in the entire Mekong delta, from 5.3 million tons of paddy in 1980, 7.3 million ton in 1985, 10.9 million ton in 1992 to 12 million ton in 1995 (Anonymous 1993 and Vo-tong Xuan, pers. comm.). Vietnam became a rice exporting country again since 1989 with 1.67 million ton. In 1995, export was 2.2 million ton, making Vietnam the fourth largest rice exporter after Thailand, India and the USA.

The aims of this thesis are:

1. to supply a review of recent developments in acid sulphate soils research with emphasis on methodological developments for survey, chemical analysis, modelling, management and land evaluation;
2. to screen the literature for practical applicability;
3. to describe the research development over time and the special organisational aspects of the VH 10 project;
4. to give examples of studies integrating the knowledge of all groups involved with acid sulphate soils: farmers, local experts and specialists.

This is not the only thesis on acid sulphate soils in the Mekong delta being completed at this time, the middle of 1996. The work of Le Quang Tri (1996) and Le Quang Minh (1996) also develops and applies the research approach used in VH 10.

Tri carried out a comprehensive study of the land use systems in four districts with acid sulphate soils. The districts differ in severity of soil acidity, but also in hydrological regimes (deep or shallow floods in the wet season, salt water intrusion in the dry season) which make different land use systems possible. He not only describes the surprisingly wide variety of land use systems applied by Vietnamese farmers at this moment, but also explains the land use history and the measures farmers took when land use changed from extensive to more intensive. An example: land use may have changed from exploitation of *Melaleuca* forest, to growing acid tolerant upland crops such as yams or cassava, to double rice cultivation now. Tri used the information on farmers' activities and land use history to evaluate the land and present decision trees for land users and land use planners. Research for management optimisation was also carried out covering irrigation supply, fertilisation and soil management for upland crops such as yams and pineapples.

Minh (1996) concentrated on soil physical and water management aspects of land use on acid sulphate soils. He investigated measures to curtail accumulation of acid salts at the soil surface during the dry season and recommended early ploughing, mulching and also irrigation in the early rainy season. He thoroughly investigated the construction of raised beds, a farmers technique to stimulate leaching of toxic solutes and prevent water logging, widely used in the Mekong delta. In rice fields he studied the effectiveness of harrowing, puddling, ploughing and flushing techniques. The study was not limited to maximisation of economic return, but also included environmental side effects of farmers' activities by investigating the chemical composition of drainage water and proposed measured for reduction of surface water pollution.

The sequence of chapters of this thesis follows its aims.

Chapter II supplies a review of recent literature on acid sulphate soils with emphasis on methodological developments for survey and identification, for chemical support in field and laboratory, for simulation and mathematical modelling of the soil processes, for management and land use and for evaluation of acid sulphate land.

Chapter III screens recent literature, particularly information supplied by the world's leading specialists in acid sulphate soils as presented in three proceedings of scientific conferences. Screening was focused on evaluating the practical applicability of research for other groups involved with acid sulphate soils such as farmers and local experts.

Chapter IV describes the way the project VH 10 carried out research for improved management of acid sulphate soils and shows how emphasis in research shifted from a technology-driven, top-down approach to a methodology with a much more prominent role for local farmers' knowledge. The project moved to a balanced exchange of knowledge between the three groups of people involved with acid sulphate soils: farmers, local experts and specialists. The chapter also describes the way the VH 10 project operated in view of its strong commitment to outreach activities towards farming communities and its special ways of operation.

Chapter V gives two examples of studies in which the expertise of farmers, local experts and specialists is integrated to evaluate acid sulphate land in the Mekong delta.

Chapter 2:

REVIEW OF RECENT DEVELOPMENTS IN ACID SULPHATE SOILS RESEARCH

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I. INTRODUCTION

Acid sulphate soils generate sulphuric acid that brings their pH below 4, sometimes below 3, leaks into drainage and floodwaters, corrodes steel and concrete, and attacks clay, liberating soluble aluminium. Dissolved aluminium kills vegetation and aquatic life or, in sub-lethal doses, stunts growth and breaks down resistance to diseases. The weathering of sulphidic mine spoil and overburden presents the same problems as acid sulphate soils. In addition, mine drainage may be enriched in heavy metals. The off-site environmental implications command greater public attention even than the severe soil degradation that follows drainage or excavation.

The hazards presented by acid sulphate soils are magnified by their location, predominantly in coastal wetlands where land hunger and commercial development pressures are greatest. In 1975 Kawalec reported 7.5 million ha in the tropics; in 1986 Dent estimated 12 million ha world wide but mostly in the tropics, with perhaps twice this area of sulphidic sediments at shallow depth beneath peat and non-sulphidic alluvium. Soil survey data are still sketchy but aggregation of the most recent estimates suggests a total of about 24 million ha where acid sulphate soils and potential acid sulphate soils are a dominant feature of the landscape.

The source of acid sulphate problems is pyrite, FeS_2, less commonly other iron and organic sulphides, originally accumulating in waterlogged saline or brackish environments, especially in tidal swamps. Formation of pyrite is following:

$$Fe_2O_3 + 4\ SO_4^{2-} + 8\ CH_2O + 1/2\ O_2 \rightarrow 2\ FeS_2 + 8\ HCO_3^- + 4\ H_2O \qquad (1)$$

The requirements for pyrite formation are: a source of iron (from sediment), a source of sulphur (from sea water), reducing bacteria (present in all coastal systems), an energy source (organic matter from mangroves), tidal movement (to take away the basic component, which is bicarbonates, resulting from turning a neutral system into a potentially acid and a basic part; tides also provide a brief period of aerobic conditions at neap tide for oxidation of FeS to FeS_2, *inter alia* Berner 1984, van Breemen 1976). These requirement are optimally met in tidal swamps with mangroves, but pyrite may also be formed elsewhere (see page 10: Land forms).

When aerobic conditions are introduced by drainage or excavation, pyrite is oxidised to sulphuric acid. A sequence of reactions is involved:

$$FeS_{2(s)} + 7/2\ O_{2(aq,g)} + H_2O \rightarrow Fe^{2+}_{(aq)} + 2SO_4^{2-}{}_{(aq)} + 2H^+_{(aq)} \qquad (2)$$

$$Fe^{2+}_{(aq)} + 1/4\ O_{2(aq,g)} + H^+_{(aq)} \rightarrow Fe^{3+}_{(aq)} + 1/2H_2O \qquad (3)$$

$$FeS_{2(s)} + 14Fe^{3+}_{(aq)} + 8H_2O \rightarrow 15\ Fe^{2+}_{(aq)} + 16H^+_{(aq)} + 2SO_4^{2-}{}_{(aq)} \qquad (4)$$

$$Fe^{2+}_{(aq)} + 1/4O_{2(aq,g)} + 3/2H_2O \rightarrow FeO.OH_{(s)} + 2H^+ \qquad (5)$$

The latter equation can be split into two equations:

$$Fe^{2+} + 2/3\ SO_4^{2-} + 1/3\ K^+ + 1/4\ O_2 + 3/2\ H_2O \rightarrow 1/3\ KFe_3(SO_4)_2(OH)_6 + H^+ \qquad (6)$$

leading to the formation of jarosite, a mineral typical for acid sulphate soils, which is hydrolysed with time according to:

$$1/3\ KFe_3(SO_4)_2(OH)_6 + H_2O \rightarrow 1/3\ K^+ + Fe(OH)_3 + 2/3\ SO_4^{2-} + H^+ \qquad (7)$$

Initial oxidation of pyrite by oxygen is slow (equation 2). Fe^{3+} is the preferred oxidant (Singer and Stumm 1970, Moses *et al.* 1987, 1991) and oxidation of pyrite by Fe^{3+} (equation 4) is not only much faster but, also, much faster than the oxidation if Fe^{2+} to Fe^{3+} (equation 3). This potentially rate-limiting step is mediated by iron oxidising bacteria, in particular Thiobacillus ferrooxidans (Temple and Colmer 1951, Wakao *et al.* 1982, 1983, 1984) so that the optimum conditions for pyrite oxidation are the same as the optimum conditions for iron oxidation by Thiobacillus ferrooxidans: oxygen concentration > 0.01 Mole fraction (1%), temperature 5-55 °C, optimally 30 °C, and pH 1.5-5.0, optimally 3.2 (Jaynes *et al.* 1984).

Environmental problems for organisms other than Thiobacilli arise when the rate of acid generation is greater than the rate of neutralisation. To anticipate and avoid or manage these problems, we need to know exactly where acid and potentially acid sulphate soils are, their total actual and potential acidity, the rate and duration of acid generation, the pathway of the acid through the environment, and the sensitivity of the environment to the influx. Usually, a cruder approach has been adopted, and mining engineers have worked mostly independently of soil scientists. Different approaches and methods of analysis are dealt with in the subsequent text under the heading of diagnosing the problem, soil survey and field laboratory support, acid : base accounting, simulation and modelling, management and land use systems and methods for evaluating acid sulphate land.

II. DIAGNOSING THE PROBLEM

Usually, the first indications of the problem can be seen in the wider environment.

A. Land forms

- Coastal wetlands. Acid sulphate soils are most common in tidal swamp and marsh, former tidal areas now built up into deltas or flood plains, and the beds of brackish lakes and lagoons. Pyrite contents are very much higher in sediments that have accreted slowly and under lush vegetation than in those that accumulate quickly. Within any particular wetland, backswamps are more sulphidic than levees and clays more sulphidic than sands. Pyrite does not accumulate in fresh water, which contains little sulphate, but peat - mostly a freshwater deposit - can become very sulphidic if it is subsequently flooded by brackish water. Dent (1986) gives several examples of soil patterns in coastal wetlands.

- Inland marsh and swamp. Significant concentrations of pyrite occur only locally where the land is flushed by sulphate-rich water (Chenery 1954, Fitzpatrick *et al.* 1996). Formation of pyrite in former fresh water swamps has also been reported, and is due to increased sulphate influx from atmospheric deposition (Marnette 1993).

- Excavations and mines. On dry land sites, acid sulphate conditions develop in sulphidic overburden and spoil from coal and lignite workings, from sulphide ores, and in cuttings in sulphide sediments.

B. Vegetation

In wetlands, relief is subdued and it can be difficult to see the land form elements that determine the hydrology and the soil pattern. But this variation is subtly picked out by the mosaic of plant communities or, where there are few species, by difference in growth. These vegetation patterns can be seen on air photos. However, vegetation indicators must be used with caution because vegetation responds to the present conditions of flooding, salinity and sedimentation, whereas the soils may have accumulated over hundreds or thousands of years during which the conditions may have changed significantly (Diemont *et al.* 1993). For example, freshwater paper bark (*Melaleuca* spp.) or reed swamps may appear on strongly sulphidic soil that accumulated under a previous mangrove swamp. Mangrove vegetation in its infinite variety indicates tidewater but in different regions we have to look to different species to indicate different stages of sedimentation and, by association, differences in soil texture, ripeness and pyrite concentration.

Once drainage has taken place and extreme acidity has developed, then the vegetation, or lack of it, picks out the scalded areas in great detail.

In Viet Nam *Acanthus ebracteatus* and *Acrosticaceae* are seen as indicators for potential acid sulphate soils. In acidified conditions farmers recognise the presence of *Eleocharis dulcis* or *Eleocharis equisetia* as a sure indicator of acid sulphate conditions. Other indicators of acidity, in declining frequency, are: *Phragmites karka* (reed), *Lepironia mucronata* or *Lepironia articulata* (reed mace), *Scleria poaeformis* and *Saccharum spontaneum.*

C. Drainage

If the natural hydrology of the wetland remains undisturbed, sulphidic materials remain reduced. Only during exceptional droughts may there be significant lowering of the water tables in areas that are remote from tidal influence. This phenomenon may have happened in the Sahelian zone during the great drought of the seventies (Sadio and van Mensvoort, 1993). But when the land is drained or sulphidic material is excavated, then potential acid sulphate soils become actual acid sulphate soils. Obviously, knowledge of local disturbance can help to pinpoint the source of acidity. The water table may also be affected by the land use and management in the wider catchment which can lead to lower water flows in the dry season (Dent and Pons 1995).

Drainage may occur naturally through a gradual diminution of tidal influence as the shoreline progrades, leading to a lowering of the water table in the dry season, and through isostatic or tectonic uplift of the land. Deeper drainage of these soils which still have sulphidic subsoils can restart the cycle of acidification.

Most actual acid sulphate soils in the world, however, are man-made. Drainage schemes in coastal areas have initiated the acidification, mostly without realising the consequences.

D. Water Quality

Surface waters usually give the first warning of acid sulphate conditions, especially following a dry spell when the water table may be lowered, leading to generation of acid that is flushed out of the soil by the next rains. Drain water pH values as low as 1.5 have been recorded. Red rainwater, scummy or gelatinous ochre deposits and an oily-looking film on the water surface all indicate very high concentrations of iron having precipitated in more oxidising and, usually, less acid conditions (equation 5) but oxidation of pyrite (equation 2) is not the only possible source of acidity in the water. More telling is crystal-clear or blue-green water where it should normally be muddy, a phenomenon caused in extremely acid conditions by flocculation of suspended material loaded with aluminium. Vietnamese farmers call these two kinds of water 'warm' (iron) and 'cold' (aluminium), expressing a clear preference for the former.

Slugs of acid, aluminium-rich water, though they may persist for only a few hours or days, cause fish kills and red spot disease in fish (Callinan *et al.* 1993, Sammut *et al.* 1995). Frequent acid episodes reduce the diversity of aquatic life, although species of rush (Juncus spp., Eleocharis spp, *Lepironia mucronata*) and water lily (Nymphea spp.) are remarkably resistant and may become dominant in these habitats.

Acid sulphate drainage waters corrode concrete and galvanised metal fencing, sluices, culverts and pumps. They are generally avoided by livestock, taste bitter and make eyes sting.

Chemical tests can be performed in the field with indicator papers. Acid sulphate conditions are flagged by a pH value <4 with >0.5 mol Fe^{2+} m^{-3} or 0.05 mol Al^{3+} m^{-3} (>0.1 mg l^{-1}). Standard water quality analyses invariably record the concentrations of chloride and sulphate. A chloride : sulphate ratio less than that of sea water (7.2 :1) indicates enrichment with sulphates, possibly from pyrite oxidation (equation 2).

E. Soil and Spoil

1. Morphology

Examination of the seat of the problem in soil or excavated sediment is usually definitive, at least where acidity has already been formed. Then the soil matrix is grey or sometimes, in the initial stage of severe acidification and high organic matter content, the pinkish colour of chestnut puree (beurre marron). Usually, there are yellow mottles and coatings of jarosite: very pale in colour, almost cream, when fresh but ageing to yellow and often associated with crusty ochre. Except for the latter, these feature develop quickly, within a few weeks, in spoil dumped on the surface and indicate a raw acid sulphate soil in which active acid generation is taking place. Field pH is typically around 3.8 but may be lower than 3.0. Occasionally, organic-rich soils that remain wet do not develop jarosite mottles although they become very severely acid, as was found in the Mekong delta, Viet Nam and in Kalimantan, Indonesia (van Mensvoort and Tri 1988, Andriesse 1993). The phenomenon is attributed to complexation of iron to organic matter, thereby making jarosite precipitation impossible. In this raw stage, toxicity inhibits rooting so clay and peat soils remain unripe, with the soft consistency of camembert cheese.

Once the pyrite is spent and the free acid is leached, rooting takes place and extraction of water by the vegetation brings about physical ripening. Jarosite slowly hydrolyses to iron (hydr)oxides so that ripe acid sulphate soils are characterised by strong brown goethite or dark red hematite mottles. Usually, pyrite is no longer found in brown- or red-mottled soils, mottling indicating oxidising conditions under which pyrite would oxidise or not accumulate in the first place. But ripening and oxidation are not always necessarily connected. A physically ripened substratum, full of pyrite, directly underlying the red mottled zone, was found in Surinam (Pons 1963).

Identification of sulphidic (potential acid sulphate) soils is more problematic. They are still waterlogged and not acid. They are dark grey or dark greenish grey in colour but so are other strongly reduced soils. They are usually unripe, and they stink of H_2S but so do other recent alluvial materials that do not contain a dangerously high concentration of pyrite. But dark grey or dark greenish grey, stinking unripe mud that contains abundant rotted organic matter and which blackens on exposure to the air is always strongly sulphidic. In nearly every case, it is the combination of characteristics that leads to the diagnosis.

2. Field tests

a. Hydrogen peroxide

A simple field test for sulphidic material is to apply 30 per cent hydrogen peroxide to the fresh sample. Within a couple of minutes it will froth and its pH falls from near neutral to <4. Take care! 30 per cent hydrogen peroxide is a hazardous reagent and should be kept leak proof. When using it, protect your skin and eyes and wash off any splashes immediately.

b. Azide-soap test

Another sensitive field test for sulphide can be prepared in a test tube by mixing 1 cm^3 soap solution and 0.5 cm^3 of sodium azide (1.27 g iodine, 2.4 g KI in 100 cm^3 distilled water, add 3 g NaN_3, dissolve, and keep in a dark bottle). In the field, add 0.5 cm^3 sample and stir gently to avoid making bubbles. Nitrogen gas is formed by catalytic action of sulphides. The amount of froth indicates the amount of sulphide present, for example 20 mm high $\cong$ 1.4% sulphide-S; 3 mm high and covering the whole surface of the liquid $\cong$ 0.8 %S; 3 mm high only at the margin $\cong$ 0.4 %S (Edelman 1971). The calibration must be carried out for each locality. Again, caution: sodium azide is poisonous.

c. Red lead paint

Stakes painted with red lead provide a very simple test for sulphide. The paint blackens within an hour in presence of H_2S, one of the products of sulphate reduction. This indicates the depth and thickness of soils that might be accumulating pyrite, but gives no indication of pyrite content.

d. Calcium carbonate

Calcium carbonate and exchangeable bases are quick-acting neutralising agents that will counteract acidity generated by oxidation of sulphides. A field estimation of carbonate content may be made by dropping 10 per cent hydrochloric acid onto the fresh soil sample and noting the effervescence:

$\%CaCO_3$	Audible effect (hold close to ear)	Visible effect
0.1	None	None
0.5	Faintly audible	None
1.0	Audible	Slight effervescence, confined to individual grains
2.0	Distinctly audible away from the ear	Effervescence visible on close inspection
5.0	Easily audible	Moderate effervescence, bubbles to 3 mm diameter
10.0	Easily audible	Strong effervescence, bubbles to 7 mm diameter

e. Moist incubation

If time is available, the best simple test is to leave a moist sample to incubate for some weeks in a thin-walled polythene bag. Oxidation and neutralisation take place within the sample at a near-field rate which allows for the neutralising activity of coarse carbonate fragments and more slowly weatherable minerals. A fall of pH to <4 on incubation is usually diagnostic and, if acid sulphate conditions do develop, yellow mottling is visible in the sample.

The problem here is to choose an appropriate period of incubation. Sometime, acidification is delayed for up to 60 days in samples rich in organic matter and relatively undecomposed roots, even though the total S-content is very high (Ahmed and Dent 1996). Dent (1986) recommends incubation of 500 g samples for 3 months; Keys to Soil Taxonomy (1994) specify incubation of a 1 cm thick layer under moist, aerobic conditions for 8 weeks; Burch and Fanning (in press) propose shaking a 50 g sample with an equal amount of water in a bottle at 45 °C to accelerate the oxidation of pyrite.

III. SOIL SURVEY

A. Field relationships

Having established that there is an acid sulphate soil problem, the next step is to determine its extent, distribution, severity and time span in enough detail to avoid or manage the problem. Significant variation in the distribution of pyrite and of potentially-neutralising minerals is characteristic of acid sulphate soils. Most commonly, pyrite accumulates within rotting roots as tight clusters of spherical nodules, each < 0.02 mm in diameter but composed of hundreds of individual cubic crystals (Figure 2.1). The intervening matrix may be quite free of pyrite. In other cases, a different mode of sulphide precipitation or reworking of the sediment may produce a more uniform distribution of nodules or individual crystals of pyrite. At a broader scale, there may be order of magnitude variations in pyrite concentration between pedologic horizons and sedimentary facies related to the environment of accumulation and time available (Brinkman *et al.* 1993). The same applies to the distribution of potentially neutralising minerals, especially to calcium carbonate as shell.

Soil survey is needed to establish the pattern of variation, to provide a framework for sampling for any costly and time-consuming analyses that may be required, and a basis for modelling and management of any problems. For potential acid sulphate soils, the key variables are depth to the sulphidic material, the thickness of the sulphidic layer and its pyrite content. For actual acid sulphate soils, the keys are the depth to severe acidity, the thickness of the acid layer and its total acidity. If reclamation is contemplated, it is also necessary to know bearing strength and hydraulic conductivity of the different soil horizons and the hydrology of the site.

The trouble with acid sulphate soils is that:

1. The land is inaccessible because of tidal or seasonal flooding, the maze of creeks and river channels, impenetrable vegetation, and the attention of mosquitoes and snakes!
2. Conventional soil mapping units have proved unsatisfactory. Pyrite is unevenly distributed at the smallest scale between pore fillings and the soil matrix, vertically between different soil horizons, and laterally between different facets of the landscape. It has proved difficult to match field characteristics with chemical data so a large number of samples is needed to make a reliable map;
3. Conventional laboratory techniques are time-consuming and require specialist laboratories. This is costly and may involve delay between sampling and analysis during which period significant changes can occur in the samples;
4. The dynamic nature of these soils (changing with tides, with wet and dry seasons, and following drainage) defies simple, straightforward characterisation.

Broad scale soil survey depends on surface expressions of soils in land forms and vegetation which are visible on air photos and satellite imagery. Certainly, areas at risk from acid sulphate soils can be distinguished easily from areas not at risk, since acid sulphate soils are confined to wetlands. But within the dynamic environments of flood plains and tidal wetlands, important patterns of soil texture, ripeness and, above all, acidity or potential acidity are not always clearly expressed by surface patterns. Repeated sedimentation and erosion, here overlaying older materials, here erasing them; and changes in flood regime and salinity, that are followed by a succession of natural vegetation and land use, leave only a palimpsest of earlier conditions that may have determined the key features of the soils.

Even so, given the difficulties of access, geomorphologic interpretation of air photos or satellite imagery remains the only feasible method of broad-scale soil mapping. Individual land forms such as levees, back swamps and beach ridges, or aggregations of these into flood plains, erosional platforms, chenier plains, are useful first order mapping units at scales of 1:20,000 and 1:100,000 respectively (Dent 1986, Andriesse 1993). A recent example of this approach is the set of acid sulphate hazard maps of New South Wales which present a qualitative assessment of the likelihood of acid sulphate hazard and the likely depth below the surface at which the hazard will occur (CALM 1995).

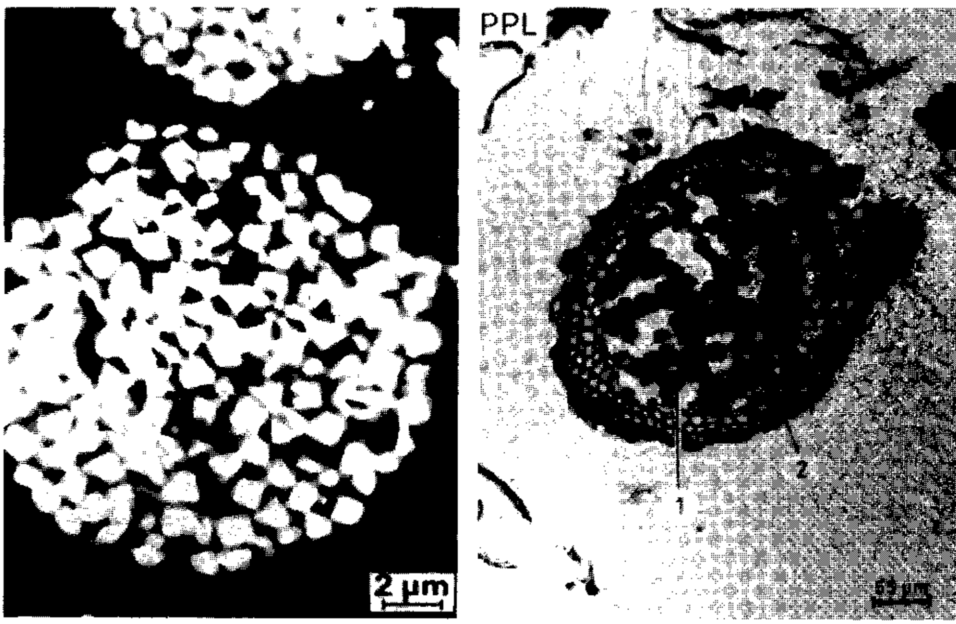

Figure 2.1: Spherical nodules of pyrite associated with organic matter remnants (right) and showing individual cubic crystals (left) Photos: E. Marnette

Inspection and sampling within mapping units has to be intensive enough to establish the relationships between land form and soil profile morphology, and between morphology and the key physical and chemical characteristics, so that the acid sulphate hazard can be specified in enough detail for the job at hand. Because each locality has a unique history, this calibration has to be undertaken independently in each locality. For Northland, New Zealand, Dent (1980) presents the key physical and chemical characteristics of 8 diagnostic soil horizons based on some 1200 profile inspections and analytical data from 250 samples. These horizons are generalised in Table 2.1. Under natural hydrology and vegetation, there is a bottom up sequence of accumulation of horizons in the sequence Grp Grs Gro Go. Within the sulphidic (Grs) horizons, total S content increased from 1.5 ± 0.7% at latitude 36°40'S to 3.5 ± 1.3% at latitude 35°S in response to increasing temperature and the luxuriance of mangroves. Expressed in terms of potential acidity, this is an increase from 500 ± 200 mol acidity m^{-3} to 1100 ± 400 mol acidity m^{-3}.

Table 2.1 : Standard horizons of acid sulphate soils (Dent 1980, Diemont *et al.* 1993)

Horizons of unripe saline soils under natural conditions	
G	unripe surface layer
Grp	permanently reduced, containing primary pyrite (<1% pyrite S = < 320 mol H^+ m^{-3}); unripe or half ripe; uniform grey or dark grey colour
Grs	permanently reduced, accumulating secondary pyrite (>1% pyrite S = > 320 mol H^+ m^{-3}); unripe or half ripe; dark grey, greenish grey, brownish grey, blackening on exposure to air; abundant rotting organic matter; stinks of H_2S
Gro	partly oxidised, little or no pyrite; half ripe; grey or greenish grey with pipes & coatings of iron oxide
Go	oxidised, no pyrite; nearly ripe; mottles, nodules, pipes and coatings of iron oxides
Horizons developing after drainage	
Gj	Severely acid with a reserve of pyrite; unripe to half ripe; black, dark grey or pinkish brown, usually with pale yellow jarosite mottles
Gbj	Severely acid; nearly ripe; grey with pale yellow jarosite mottles
Bj	Severely acid; ripe; strongly mottled grey with reddish iron oxide and yellow jarosite
Hj	*Severely acid peat or muck with a reserve of pyrite; usually without jarosite*

Most marine sediments contain some pyrite, which may be called primary pyrite (Pons 1973). Pyrite formed in situ, associated particularly with root remnants may be called 'secondary pyrite'. Its accumulation leads to sulphidic horizons, dubbed Grs in table 2.1. There is an obvious difficulty in distinguishing between Grp and Grs horizons and their field relationships have to be established for each survey area. Janssen *et al.* (1992) working in Kalimantan defined sulphuric horizons by a total actual acidity of ≥ 26 mmol (+) per 100 g soil, and sulphidic material by total potential acidity of ≥ 32 mmol (+). Table 2.2 summarises the field relationships of acid sulphate soils in Pulau Petak, South Kalimantan, based on the scrutiny of 2500 inspection sites. The pyrite content of sandy Gr horizons is always much lower than that of associated muddy sediments and sands often contain shell or coral fragments that will neutralise any acid produced. However, in the absence of calcium carbonate, sulphidic sands develop extreme but short-lived acidity if they are drained or dumped on the surface.

The difficult question of short range variation in soil characteristics was addressed by Burrough *et al.* (1988) who applied a nested sampling scheme in order to perform an analysis of semi-variance on a large number of properties in 192 soil profile inspections in two districts of the Mekong delta. The only useful criteria for soil mapping proved to be the presence/absence of jarosite, depth to the jarosite, depth to pyrite and the position of the groundwater table. pH and EC turned out to be useless criteria. To avoid the confusion of background short-range variation, they suggested using average values from multiple, closely-spaced samples to characterise each site.

Table II.2: Relationships between field characteristics and chemical parameters of acid sulphate soils in Pulau Petak, Kalimantan (Janssen *et al.* 1992)

Field characteristic (layer)	Total actual acidity (TAA)	Total sulphidic acidity (TSA)	Description
Matrix colour: - stability	-	+	If matrix colours are stable (greyish) brown (hues 7.5YR and 10YR, chroma>1): TSA<32 mmol; for all grey colours (hues 10YR/chroma 1, and hues 2.5Y, 5GY and N) and for unstable (greyish brown colours: TSA ≥ 32 mmol.
- hue	+	-	If dominant hue or sub-dominant hue 5GY: TAA < 26 mmol.
Mottles colour	+	+	If hue 5YR: TSA < 32 mmol; if hue 5GY or N: TSA ≥ mmol; jarosite mottles indicate horizons with most active oxidation of pyrite; TAA relatively high
Iron coatings	-	+	If reddish brown coatings occur on ped faces: TSA < 32 mmol
Reaction with peroxide:			
- time lapse	-	+	If time lapse till reaction ≤ 15 seconds: TSA ≥ 32 mmol If time lapse till reaction ≥ 99 seconds: TSA ≤ 32 mmol
- intensity	-	+	If no reaction: TSA < 32 mmol; if strong reaction: TSA ≥32 mmol
- pH of foam	-	+	If pH of foam ≥ 4: TSA < 32 mmol
- colour of foam	-	+	For specified colours of foam: TSA ≥ 32 mmol
pH (paper: field)	+	-	If field pH < 3.6: TAA > 26 mmol

Field characteristics (profile/site)	Depth to the sulphidic layer	Description
Altitude	+	Altitude is a very rough indicator only
Land form	+	In levees and coastal ridges: DSL ≥ 50 cm: in alluvio-marine plains and on old river beds: DSL may be < 50 cm
Vegetation	+	In Nipa-Plai complex (*Nipa fruticans, Achrosticum aureum):* DSL<50 cm and TAA< 26 mmol; in Alang alang (*Imperata cylindrica*): DSL ≥ 50 cm
Flooding	+	If no flooding: DSL ≥ 50 cm
Thickness of brown layer	+	Sulphidic layer generally starts below or at the base of the brown layer (hues 7.5 YR and 10YR; chroma > 1)
Depth to grey layer	+	Sulphidic layer generally starts above or at the top of the grey layer (hue 10YR; chroma 1 and hues 2.5Y, 5Y, N and 5GY)

+ indicates some relationship

- indicates no relationship

Pons *et al.* (1986) developed a refined version of Soil Taxonomy to create a legend for the soil map at 1 : 250,000 of the Trans Bassac, the western half of the Mekong delta. Besides the well-established criteria for Sulfaquents (potential acid sulphate soils with sulphidic material within 50 cm depth), Sulfaquepts (acid sulphate soils with a sulphuric horizon within 50 cm depth), and sulfic Tropaquepts (acid sulphate soils with a sulphuric horizon below 50 cm depth), they also distinguished soils with and without a strongly organic surface soil, and also recognised pale sulfic Tropaquepts, i.e. soils with a sulphuric horizon below 80 cm.

B. Spatial statistics

Detailed quantification of pyrite distribution can be achieved by combining classical survey technique with spatial statistics. Spatial statistics depend on the relationship between the similarity of a soil property at any two points and the distance between the points so that, knowing the value of the property at the sampled point, the values at any

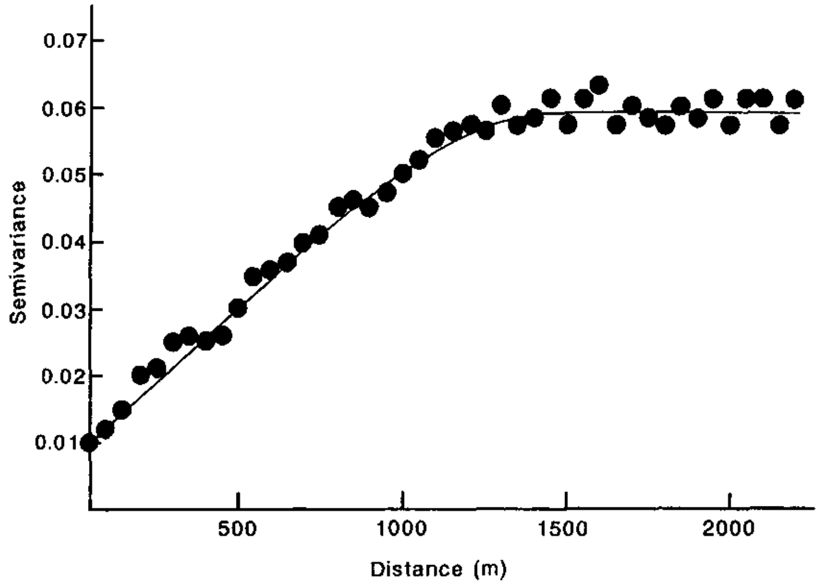

Figure 2.2: Semi-variogram of %-S over the Gamiba floodplain (Ahmed and Dent, in press)

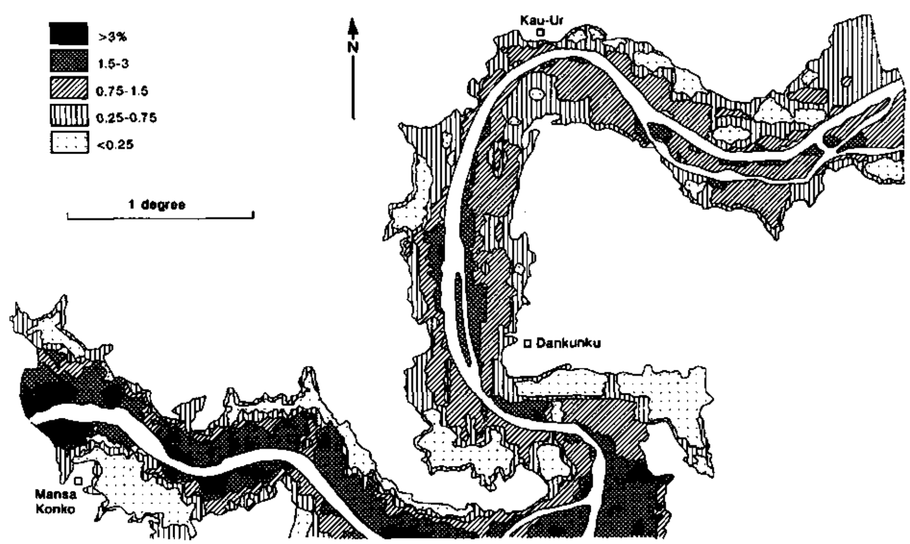

Figure 2.3: Map of %-S produced by kriging of the Gambia flood plain (Ahmed and Dent, in press)

unsampled point can be predicted (Webster and Oliver 1990). This so-called distance-decay relationship may be calculated from the semi-variance of the property in question over a range of distance separation. Figure 2.2 shows semi-variance of %S in the 50-75 cm layer plotted against the distance separation of sample points for the tidal flood plain of the Gambia. Three features are of interest: the 'nugget variance' at the closest distance separation that cannot be mapped; the 'sill' at 1350 m separation that indicates that sampling at a greater distance than this will not reveal the soil pattern; and a distinct wave pattern (the grain or repetition size) with a wavelength of 250 to 400 m indicating a cyclical soil pattern which, in this area, is directly related to the close and regular spacing of tidal creeks. Similar grains have been identified in Viet Nam, where for the south-western part the Mekong delta the grain amounts from 500 to several km (Burrough *et al.* 1988), while in the adjacent Saigon river delta the pattern may be some 5 to 10 times smaller (Brinkman, pers. comm.), similar to the examples from the Gambia and Pulau Petak, Kalimantan, where sedimentation is also fine grained (see below).

The detailed map of %S (Figure 2.3) was produced by kriging between a grid of sample points using the unique distance-decay relationship between the nugget variance and the sill, computed for each individual soil landscape unit.

Spatial statistics used in conjunction with a geographic information system (GIS) offers a way of handling the sheer mass of data from a large soil survey and can reveal previously unsuspected field relationships. In the Gambian example, manual analysis of the 5000 data points revealed only a general decrease in total S content upstream and the sharp distinction between the terraces and tidal flood plain. Kriging using the GIS highlighted more complex patterns within each landscape unit that are significant in terms of management. But spatial statistics produces spurious patterns if applied over large tracts without first dividing the area into landscape units that have their own soil patterns (Ahmed and Dent, in press).

Sylla (1994) applied a multi-scale approach in a study of West-African mangrove ecosystems which was based on the pre-conditions of acid sulphate soil formation and showed that climate and coastal morphology can be used for classification at catchment scale; hydrology, physiography and vegetation complexes are best used for unit distinction at the scale of one catchment, and topography, vegetation species, tidal flooding and sedimentation rate are best used at micro scale.

Some perhaps surprising conclusions emerged from an intensive survey based on a grid of 820 observation points by Bregt *et al.* 1993 in Pulau Petak, Kalimantan, Indonesia.

For the property "depth to pyritic layer':

1. Variation is so great and the pattern so complex that there is no advantage to be gained by increasing the sample density from 22 per km^2 to 200 per km^2. This is equivalent to a difference in survey scale from 1:30,000 to 1:10,000 and a 5-fold increase in the cost of survey.
2. The accuracy of prediction of the conceptually difficult kriging procedure was no better than with the simple procedures of local mean and inverse distance.

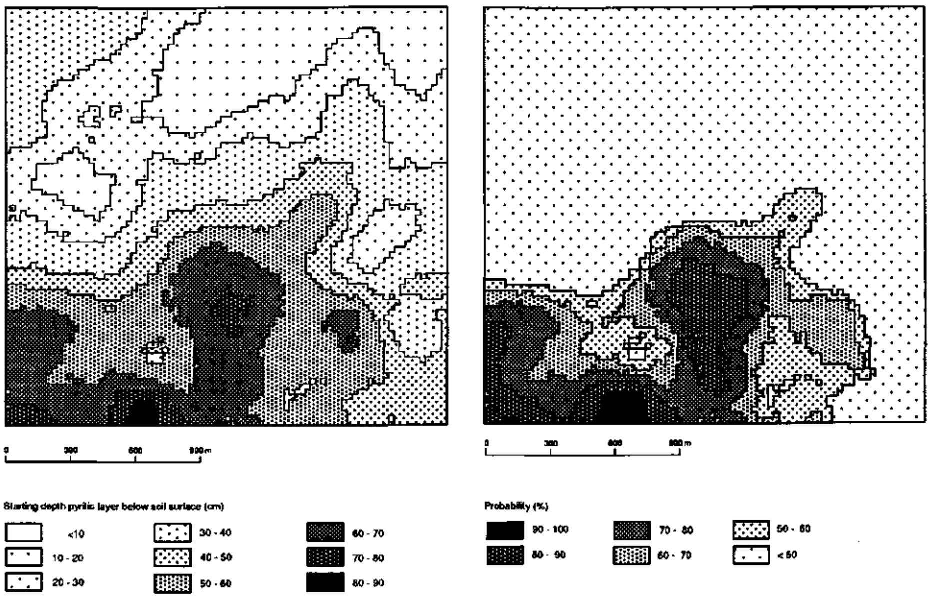

Figure 2.4: Comparison between depth to sulphidic material (cm) predicted by kriging (left) and by calculation of the probability (in %) that the depth to the sulphidic material exceeds 50 cm. Data for the Belawang area, Pulau Petak, Kalimantan (Bregt *et al.* 1993).

Since depth to pyrite, pyrite concentrations (potential acidity) and total actual acidity show such high spatial variation, conventional soil boundaries depicting these properties are not very reliable. A more robust procedure is to map their conditional probability calculated by spatial statistics (Figure 2.4). Such maps enable planners to build in safety margins.

Experience with spatial statistics has been mixed. It is clear that no less insight is needed in applying this approach than with classical survey methods and that the high sampling density and still rare skills needed to apply spatial statistics have to be justified case by case.

C. Field laboratory support

Quantitative data on acidity and potential acidity can only be obtained by laboratory determinations. Because of the local variability of these key soil characteristics and the uncertainty of matching them with soil morphology, it is necessary to test many samples. Because sulphidic materials oxidise and acidify rapidly, delay between sampling and analysis should be kept to a minimum. Therefore, a field laboratory can provide valuable support, to both soil survey and ongoing management, particularly if the area is remote.

Field laboratory methods have to be straightforward, requiring only simple equipment and readily-available chemicals. The most widely adopted method elaborated by Konsten *et al.* (1988) estimate total actual acidity (TAA) by quick titration to pH 5.5 with standard alkali, the sample being suspended in a 1 M NaCl solution. Subsequently NaF can be added to the suspension, precipitating all Al, and titrated back with HCl to get an estimate of the soluble plus exchangeable aluminium in the sample. Total potential acidity (TPA) is estimated by first oxidising all sulphides with 30% hydrogen peroxide, followed by quick titration to pH 5.5 as for TAA. In the case of TAA, the pH of the suspension continues to fall for some time after titration. A correction factor is applied to convert the value obtained by quick titration to a more stable value obtained after 24 or 48 hours but this correction factor depends on the speed of titration and the kind of soil, and has therefore to be established for each operator and soil type. Janssen *et al.* (1992) found factors between 1.4 and 2.3 for the same operator. Correction factors for TPA have proved even more problematic, depending on the efficiency of oxidation by hydrogen peroxide. Dent and Bowman (1996) found that, by adding a further aliquot of hydrogen peroxide to the suspension immediately when pH 5.5 was reached, and then completing the titration, no correction factor is necessary. Their modified procedure is as follows:

1. Total Actual Acidity, TAA

- Sample: 10 cm^3 field sample, packed air tight and analysed as soon as possible after sampling. A sawn-off syringe of a large diameter is an ideal sampler.
- Equipment: balance accurate to 0.1 g for preparation of standard solutions; pH meter and buffer solutions; plastic bottles and beakers; a burette; a shaker/stirrer.
- Reagents: Distilled water (if not available, any water will do, but its acidity should be determined); NaCl solution 1 mol l^{-1} (dissolve 59.6 g NaCl in a litre water or dilute saturated NaCl 6 times); Standard NaOH solution 0.1 M (dissolve 4.0 g NaOH in a litre water or prepare from and ampoule of analytical concentrate).
- Procedure: Make up 10 cm^3 sample to 100 cm^3 suspension with 1M NaCl (or add 5.9 g solid NaCl and make up with water). Shake for 2 hours. Measure the pH of the suspension. If pH is less than 5.5, titrate to 5.5 with standard NaOH. Depending on the equipment available, this may be done automatically, manually with continuous stirring, or stepwise with fixed aliquots of alkali. After each addition of alkali, stir the suspension and allow the pH to stabilise for one minute. The pH of the suspension will drop slowly after completion of the quick titration. A correction factor may be determined by resuming the titration after 24 hours for a representative range of samples, and for different operators since it also depends on the speed of titration.

2. Aluminium acidity

The TAA extract can also be used to estimate soluble plus exchangeable Al in the suspension, an important characteristic since Al is the most important toxin of actual acid sulphate soils (Begheijn 1980).

- Reagents: as for TAA plus: solid NaF; 0.1 M HCl as for residual quick neutralising capacity
- Equipment: as for TAA
- Procedure: add a few grams (excess) of solid NaF to the suspension after titration for TAA. Al will be precipitated as AlF_3, raising the pH of the suspension. Titrate back to pH 5.5 with 0.1 M HCl.

Al in mol m^{-3} = volume of titrant (cm^3 0.1 M HCl) x 10/3

3. Total Potential Acidity, TPA

- Sample: 10 cm^3 field samples. In contrast to the determination of TAA, oxidation of the sample does not affect the result.
- Equipment: As for TAA plus: protective gloves and spectacles; pyrex beakers 1 litre, water bath.
- Reagents: as for TAA plus: hydrogen peroxide solution 30 per cent, technical grade.
- Procedure: Make up 10 cm^3 sample to 50 cm^3 suspension with 1M NaCl (or add 5.9 g solid NaCl and make up with water). Stir until the suspension is homogenised, transfer to a pyrex beaker and make up to 100 cm^3 with NaCl solution. Mark the height of the suspension on the outside of the beaker. Put on gloves and spectacles. Carefully add 10 cm^3 H_2O_2 then transfer the beaker to the water bath or stand in sunlight till the sample begins to bubble. Remove from heat. Samples rich in organic matter or pyrite will froth strongly. When the peroxide is spent, add further aliquots of H_2O_2 till oxidation is complete, which may take a few hours or days. Up to 100 cm^3 H_2O_2 may be needed for peaty samples. Oxidation is complete when addition of H_2O_2 produced no further reaction, the mineral soil has become grey to light brown, and the supernatant solution is clear and transparent - not murky. Boil down the mixture to its original volume and wash the side of the beaker. Stir. Measure and record pH of the suspension. If it is below 5.5, titrate with 0.1 M NaOH solution to pH 5.5 as for TAA. Add a further aliquot of H_2O_2. If the pH falls, resume titration back to pH 5.5. Do a blank titration with each batch of samples to correct for acidity of reagents.

Total Potential Acidity (TPA) mol (+) m^{-3} = volume of titrant (cm^3) x 10.

TPA - TAA, mol (+) m^{-3} represents the acidity that will be released on drainage of the material and can be attributed principally to oxidation of sulphides.

4. Residual quick neutralising capacity

- Reagents: as for TPA plus: standard 0.1 M HCl solution (commercially prepared standard or dilute from a 10M HCl solution).
- Procedure: If the pH after peroxide treatment is greater than 5.5, titrate with 0.1 M HCl to pH 5.5. Measure the pH again after 3 hours and, if it has risen, resume titration to pH 5.5.

Residual quick neutralising capacity in mol (-) m^{-3} = volume of titrant (cm^3 0.1 M) x 10.

Coarse shell fragments may take some days to dissolve at pH 5.5, but in the field they would not contribute to quick neutralisation. If a measure of coarse shell is required, it may be separated by sieving and determined separately.

The TPA determination takes account of the in situ quick-neutralising capacity of the exchangeable bases and finely-divided carbonates, so TPA-TAA provides an estimate of the excess acid that might be released from the material as a result of complete oxidation of sulphides. By sampling of a known volume, TAA and TPA may be determined directly in mol m^{-3} of material, thus avoiding the need to dry large numbers of very wet samples, risking oxidation in the process and avoiding the need to weigh.

Analytical data are conventionally expressed at an oven dry mass basis, but this is difficult to interpret because unripe soils may contain up to 90% water and may be highly organic. If values on a mass basis are wanted for further analysis, they must be dried quickly to minimise acidification. This means small samples, spread thinly or diced, in a forced-draught oven. Oxidation during storage and drying does not affect TPA.

5. Peroxide-oxidisable sulphuric acidity

An alternative to the direct estimation of TAA and TPA is to determine soluble sulphate before and after hydrogen peroxide treatment (Lin and Melville 1993), sulphates being determined turbidimetrically after filtration (Rhoades 1982). By difference, potential acidity from oxidation of pyrite is then estimated from the peroxide-oxidisable sulphuric acidity (POSA), assuming all S is pyrite and oxidation according to equation 8. POSA does not take account of any *in situ* neutralising capacity.

IV: ACID: BASE ACCOUNTING

A. Principles and limitations

Acid : Base accounting is the most widely used assessment, certainly for acid mine spoil (e.g. Sobek *et al.* 1978), because it is simple, reproducible and relatively cheap. Acid-producing potential is assessed by determination of pyrite or some surrogate such as total S or oxidisable S. Neutralising potential is identified by determination of carbonates. The difference between the two potentials indicates the absolute magnitude of excess acid production from oxidation of pyrite, assuming:

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+ \qquad (8)$$

1 mol pyrite yields 4 moles acidity

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2\uparrow + H_2 \qquad (9)$$

1 mol carbonate neutralises 2 moles acidity

Crudely, one part by mass of pyrite S is neutralised by three parts by mass of calcium carbonate. Acid : Base accounting involves several assumptions:

- All determined S is pyrite;
- All "pyrite" is oxidised under the proposed conditions of management according to equation 8;
- All determined carbonate is $CaCO_3$ and this reacts completely with acidity in situ.

This budget does not take account of the differences in the rates of acid generation and neutralisation that depend critically on the surface area of pyrite accessible to oxidants, and the nature and surface area of weatherable minerals in contact with the acid produced. $CaCO_3$ and, also, exchangeable bases react quickly and completely, even close to neutrality, but there is usually a bigger reserve of neutralising capacity in silicate minerals that react more slowly by acid hydrolysis. Jarosite, the diagnostic mineral of acid sulphate soils ties up one mole acidity (see equation 6) which it will release upon hydrolysis (equation 7).

Significantly for the release of acidity into drainage water, pyrite in recent marine sediments is usually concentrated as pore fillings where it is easily accessible to oxidants and from which much acid can be leached quickly by through flow before it can be neutralised by minerals in the matrix. As a resultant of these uncertainties, treatment of acid sulphate soil or spoil that relies on Acid : Base accounting should include a substantial safety error.

B Methods of laboratory analysis.

1. Storage and pre-treatment of samples

Field-laboratory methods use samples directly taken from the field with simple precautions such as the use of thick-walled plastic bags to prevent rapid oxidation. For more detailed laboratory analysis samples may well have to be stored for longer periods. Freeze drying of the samples is a good way to avoid oxidation, especially when samples are stored under N_2 gas (Marnette 1993). Alternatively, samples may be collected in air-tight containers and bacterial oxidation inhibited by a drop of toluene, prior to rapid drying as described in on page 24.

2.S-fractions in acid sulphate soils.

Begheijn *et al.* (1978) developed a methodology yielding data on elemental-S, water soluble and exchangeable-S (present as SO_4^{2-}), jarosite-S, pyrite-S and Total-S in acid sulphate soils. Finely ground, freeze dried soil samples are subjected to a number of extractions. Extraction of a soil sample with acetone yields elemental-S. EDTA.3Na is used for the extraction of water soluble plus adsorbed sulphur. The remaining solid after centrifugation is extracted with 4M HCl for the determination of jarosite-S. Extraction by HF and concentrated sulphuric acid dissolves all free iron minerals except for pyrite. After centrifuging the HF/H_2SO_4 extract, the solid is treated with HNO_3 to oxidise pyrite, and iron determination in the HNO_3 extract can be used to determine pyrite-S. Total-S is determined by partial fusion with a mixture of Na_2CO_3 and KNO_3. Alternatively, total-S can also be determined by oxidation with an alkaline sodium hyperbromite solution, followed by reduction of the formed sulphate to H_2S by hydriodic acid. The H_2S is trapped in NaOH and colorimetrically determined using bismuth nitrate (Tabatabai and Bremner 1970). A third possibility is analysis of total-S by X-ray fluorescence spectrometry (Darmody *et al.* 1977). Subtracting the total of elemental, jarosite, pyrite and water soluble/exchangeable sulphur from the total S yields the remaining fraction, i.e. organic-S. Organic-S fractions such as ester sulphate-S (Kowalenko 1985), amino acid-S and carbon bonded-S (Freney 1970, Tabatabai 1982) can also be determined but may well be beyond the scope of most work in acid sulphate soils.

Where there is a significant FeS fraction, as in the Litornia sediments of the Baltic, this may be determined as acid-volatile sulphide following Berner (1963) and Georgala (1980) by treating the freeze-dried sample with 1M HCl, the H_2S evolved being trapped in 0.05M $CdCl_2$. The precipitated CdS is then filtered, dried at room temperature and weighed.

The analyses described above require well equipped laboratories, skilled laboratory staff and strict safety precautions in view of the dangerous chemicals used.

3. oxidisable acidity

Determination of oxidisable acidity by treatment with hydrogen peroxide and titration of the resultant acid, similar to the field-laboratory method, is a well-established assessment for the hazard of mine drainage but results can be variable because of the varying grain size of pyrite, certainly in overburden and mine spoil, so that oxidation may be incomplete. Similarly, the varying grain size of rock carbonates may result in only partial removal by acid washing. To ensure greater efficiency and reproducibility, O"Shay *et al.* (1990) adopted rigorous pre-treatment of samples: grinding to < 149 µm, acid washing to remove carbonates, followed by leaching with 1M $CaCl_2$ to remove residual acidity prior to oxidation with 30% hydrogen peroxide. After oxidation, a copper catalyst was used to decompose unused hydrogen peroxide, the free and exchangeable acidity produced by oxidation was leached with 1M $CaCl_2$ solution, and this leachate titrated with standard alkali.

In a slightly different approach to determine oxidisable acidity after oxidation with hydrogen peroxide, Lin and Melville (1993) including filtration and measurement of the resultant sulphate to estimate peroxide-oxidisable sulphuric acidity, POSA, as the difference between water soluble sulphate and the sulphate concentration after oxidation with peroxide.

4. Carbonates

"Calcium carbonate equivalent" may be estimated by treatment of a sample with 1 M HCl, to react with any carbonates, then titration of the residual acid with 0.5M NaOH using phenolphthalein as an indicator (van Reeuwijk 1986). Manometric methods measuring the CO_2 gas evolved on acid treatment (e.g. Martin and Reeves 1955, Skinner and Halstead, 1958) are more precise.

V. SIMULATION AND MODELLING OF PROCESSES IN ACID SULPHATE SOILS

A. Physical simulation

Weathering *in situ* of pyritic material may be simulated by periodic leaching of moist samples (Caruccio and Geidel 1981), instrumented lysimeter studies (van Wijk *et al.* 1993, Danh and Tuong 1993) or simply by moist incubation of samples in thin-walled polythene bags (Dent 1986). In either case, the end-products may be titrated to determine the net acid production. Simulated weathering takes some account of the relative weathering rates of the pyrite and neutralising materials, although it is difficult to assess the extent to which the laboratory situation corresponds to the uncontrolled situation in the field. Moreover, simulation takes a long time and remains one dimensional, at best two dimensional, so simulation models are a very attractive approach to assessing acid sulphate hazard over both time and space.

B. Simulation by means of dynamic models

The development of simulation models for predicting the chemical processes in acid sulphate soils was often recommended (van Breemen and Dost 1982, Dent 1986, Dost 1988). A first attempt at predicting the rate of pyrite oxidation in relation to drainage depth was made by Dent and Raiswell (1982). Their model was based on a calculated rate of pyrite oxidation determined by the speed of O_2 diffusion through the soil and the pyrite concentration. The rate of acid generation is calculated according to the diffusion of oxygen into cylinders representing the coarse prismatic peds produced by physical ripening, and the critical variables are the initial pyrite content (assumed to be uniformly distributed) and the ped size that determines the length of the diffusion path. The model was used to predict what would happen in case of lowering groundwater tables in the Gambia.

Jaynes *et al.* (1984), modelling acid generation from coarse mine spoil, took account of rates of diffusion of both O_2 and Fe^{3+} into fragmented material and, also, the activity of the bacteria generating Fe^{3+} which was calculated according to the energy available from the substrate and deviations from the ideal growing conditions (specifically temperature, solution pH and oxygen concentration).

Eriksson ('93) concentrated his modelling work on the flow of water and dissolved substances in already oxidised acid sulphate soils because in his study area, the Plain of Reeds, Mekong delta, Viet Nam, all acid sulphate soils are already oxidised to a substantial depth, and pyrite oxidation is not expected. The Eriksson model assumes two dimensional water flow and partitions the soil in an unsaturated and a saturated zone, using conventional water flow models for each. The model attributes fractions of the flow to micropores (**a**) and to macropores (**1-a**) whereby **a** is derived from soil structure. It is assumed that cation exchange only takes place in the micropore fraction, the flux of water then rejoining the mass flow through the macropores. The model seems particularly fit to predict the removal of soluble Al and SO_4^{2-} by leaching under conditions of saturated flow. Eriksson (1993) compared his predicted data with experimental results of Danh and Tuong (1993), who studied soil solution kinetics on column experiments, subjected to different leaching treatments and to water logging. Figure 2.5 shows that the spread in experimental points is wide, which is attributed to soil heterogeneity and sampling difficulties.

Although valid for oxidised conditions, the Eriksson model does not incorporate redox reactions and therefore does not consider the dynamics of one of the main toxins in acid sulphate soils, ferrous iron. In water management treatments including slow leaching and certainly in a waterlogged situation, Fe is important in acid sulphate soils.

An overarching model for simulation of the processes in acid sulphate soils called SMASS (Simulation Model for Acid Sulphate Soils) was presented by Bronswijk and Groenenberg (1993). Objective of the model is to predict the effects of water management strategies such as drainage and irrigation on acidification and de-acidification of acid

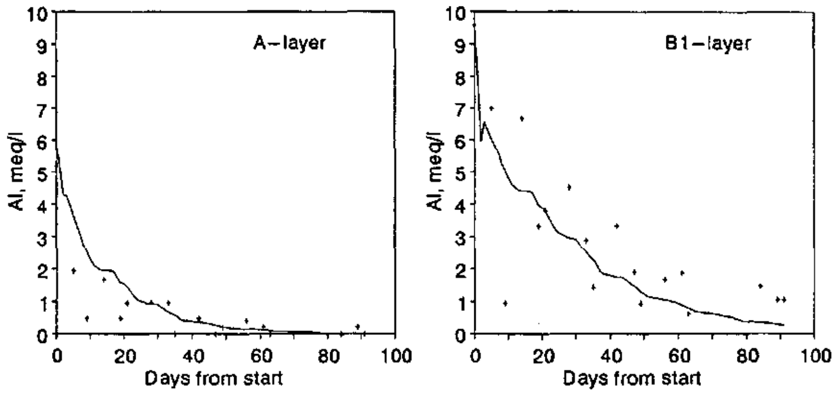

Figure 2.5: Simulated (fulldrawn) and experimental (crosses) values of aluminium in two horizons of a soil column kept permanently water saturated with a pre-set rate of leaching (Eriksson, 1993)

sulphate soils. In SMASS the soil profile is divided into uniform compartments, and chemical changes in the soil are computed over a number of time steps.

SMASS uses four sub-models (Figure 2.6):

1. a water transport sub-model, computing one-dimensional, vertical water flow based on the SWATRE model (Belmans *et al.* 1983), resulting in fluxes of water through the boundary of each compartment, thereby also indicating air content.
2. The oxygen transport and pyrite oxidation sub-model calculates oxygen diffusion in the air-filled pores and oxygen consumption by pyrite oxidation. The sub-model also converts oxidised pyrite into its oxidation products, Fe^{3+}, H^+ and SO_4^{2-}.
3. A solute transport sub-model, which computes the solute fluxes between compartments as indicated by the water fluxes from sub-model (1).
4. Finally, SMASS has a chemical sub-model which first calculates non-equilibrium chemical processes (e.g. Fe-reduction in submerged conditions) over a time-step.

Next SMASS sums, for each chemical component, the production/consumption terms, the inflow/outflow for each compartment and the amount present after the previous step. These new totals lead to the calculation of a new equilibrium for the composition of the soil solution, the soils' exchange complex and of precipitates formed. Most importantly the sub-model can predict pH and concentrations for the most important ions as Al^{3+}, Mg^{2+} and SO_4^{2-} at various depths for both potential and actual acid sulphate soils.

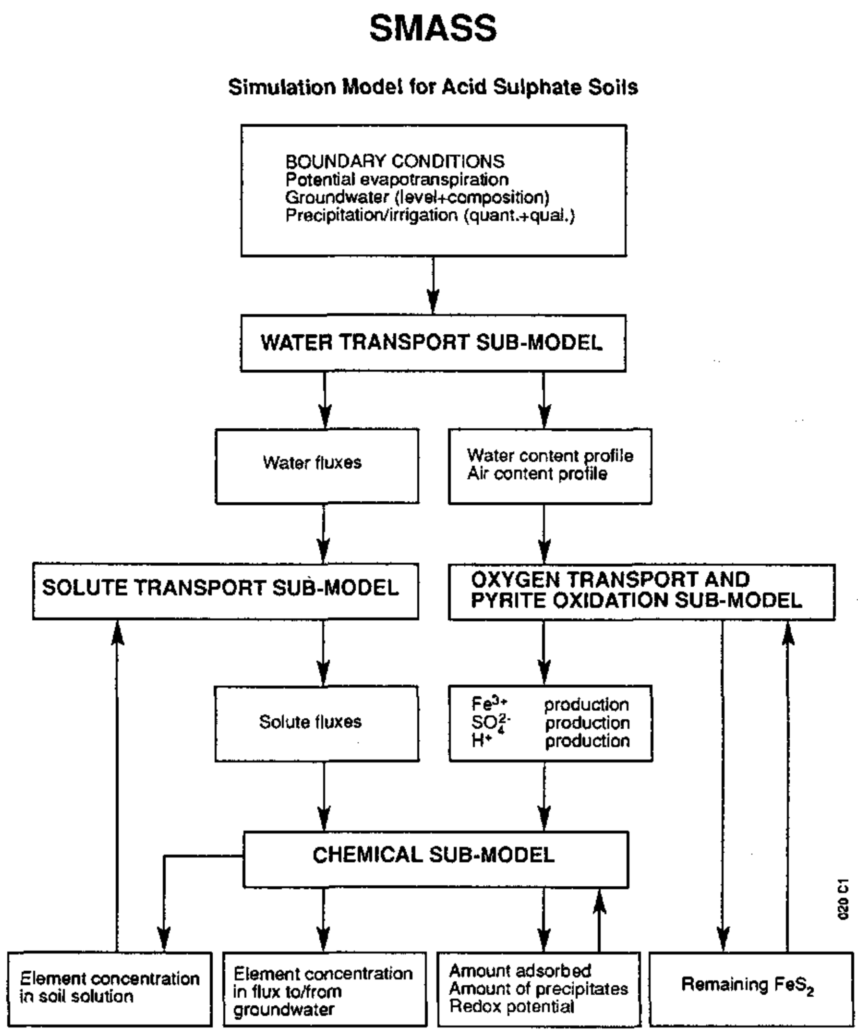

Figure 2.6: The structure of SMASS (Simulation Model for Acid Sulphate Soils), Bronswijk and Groenenberg 1993.

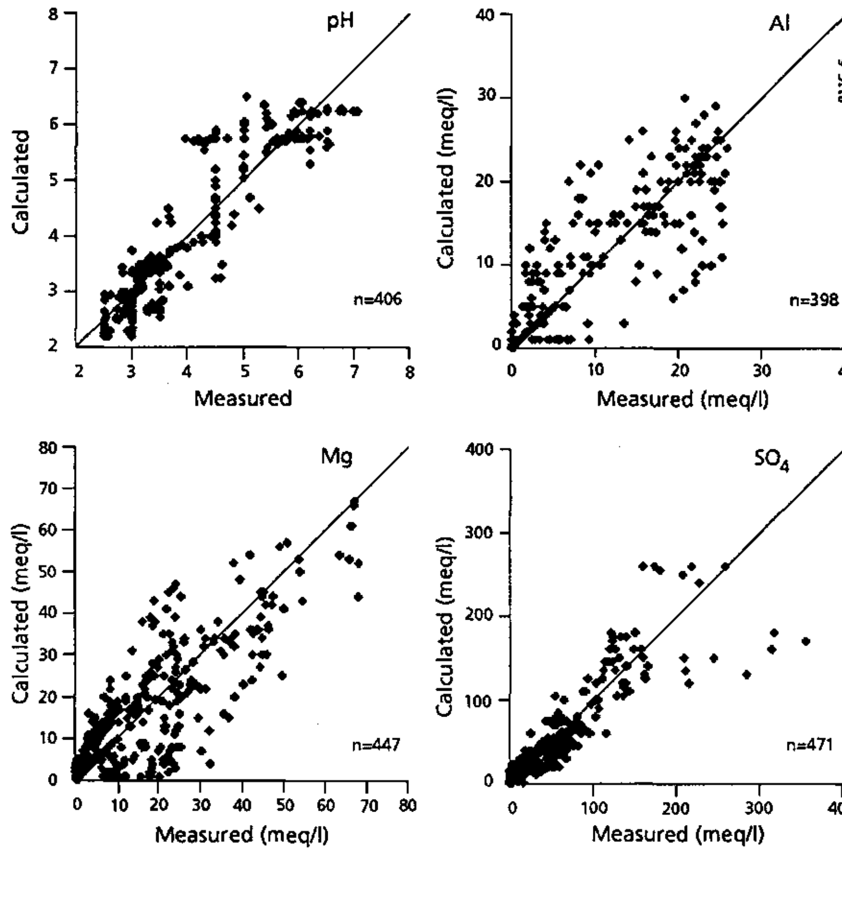

Figure 2.7: Comparison of model simulations of pH, Al^{3+}, Mg^{2+} and SO_4^{2-} concentrations with data measured in column experiments (van Wijk *et al.* 1993).

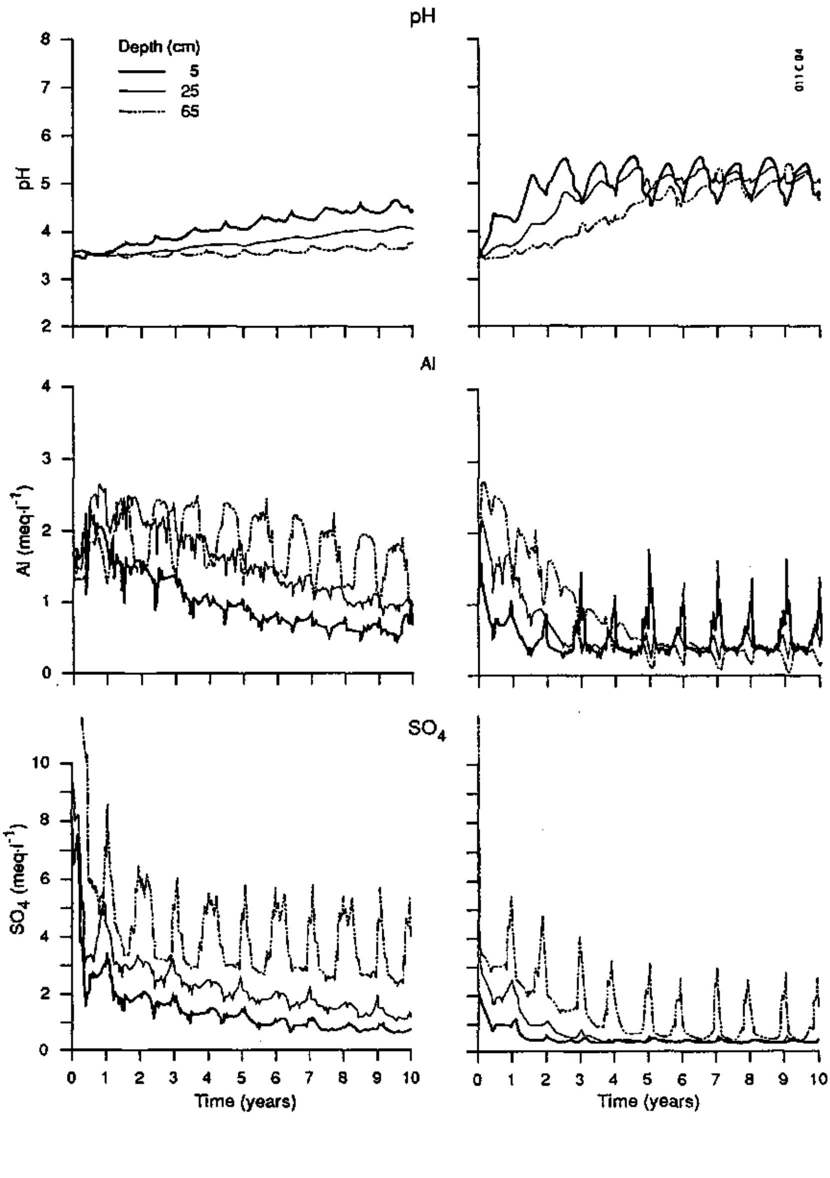

Figure 2.8: Model prediction of pH, Al^{3+} and SO_4^{2-} concentrations at depths 5, 25 and 65 cm in an actual acid sulphate soil in Barambai I, Pulau Petak, Kalimantan, Indonesia, for a period of 10 years. Left had side: present water management; right hand side: present water management extended with leaching with water of good quality during the wet season (van Wijk *et al.* 1993).

Model outputs are in terms of days. The model requires a large number of detailed input parameters for each of the sub-models. Hydraulic functions, climatic data, size and content of pyrite and many chemical parameters are needed. Validation of the model was reported by van Wijk *et al.* (1993), who imposed a number of water management strategies on the model and compared the outcome to measured data from soil columns subjected to the same strategies which were: drainage to study pyrite oxidation and subsequent acidification; submergence for the study of reduction processes; leaching with fresh and brackish water for removal of acidity.

Comparison of the predicted and the measured values for Al and Mg2+ show high dispersion, while pH and SO_4^{2-} show a reasonable and a good similarity, respectively (see Figure 2.7). The model is also used to predict the effects of water management strategies on soil chemical components over of 10 years. Figure 2.8 shows a prediction of pH, Al and pyrite profiles, comparing present water management to a situation with forced oxidation by drainage, combined with leaching by fresh water. The forced oxidation results, of course, in a strong acidification but it removes pyrite and Al faster from the system, and it results in a higher final pH compared to the present water management.

SMASS is certainly a breakthrough in the modelling of acid sulphate soils, encompassing a wide variety of processes. Some of its limitations have been indicated as well (Bouma *et al.* 1993): the model does not take physical swelling and shrinkage into account, which is acceptable over short time spans but difficult to accept over long periods. Unlike the Eriksson model, SMASS also does not entail bypass flow of water, a critical characteristic of ripening soils. It assumes water flow through a homogenous porous medium. The SMASS authors themselves (van Wijk *et al.* 1993) indicate that the actual implementation or a technical/economic evaluation of the proposed water management strategies has not been added.

All the models described deal with soil profiles, which are just points in the landscape. Simulation of the effects of management on whole landscapes demands reasonable spatial and temporal data for the key soil, the hydrological and the climatic characteristics.

VI. MANAGEMENT, LAND USE AND LAND USE PLANNING

In general, most management decisions have been taken, and are still being taken in ignorance of the unique characteristics of acid sulphate soils. If scientific assessment has been undertaken at all, it has usually been after the severe problems have become manifest. This is inevitable where development has taken place without previous experience of the problems and, especially, if the problems are downstream. The development of methods of assessment has also been one-eyed: concentrating on improvements in speeds and precision of specific determinations rather than dealing with soil heterogeneity and proper interpretation of data.

However, existing methods do enable reliable diagnosis of the problems, design of on-site reclamation and precautionary management of the water table to avoid, or at least minimise, acid generation. Methods of reclamation and management have been reviewed, most recently by Dent (1992) and Xuan (1993). In view of their obnoxious nature and the toxicities associated to them it is surprising to find such a wide range of land uses on acid sulphate soils. For generations farmers in coastal wetlands have, with great perseverance and skill and often at great cost, developed methods to live through the toxicities of acid sulphate soils. The widest range of land uses is reported from the Mekong delta of Viet Nam (Xuan *et al.* 1982, Xuan 1993, Tri 1996). Soil and water management is the key to solving the problems of acid sulphate soils (van Breemen 1976, Tuong 1993). Water table management, surface water management, leaching, narrow spacing of drains, maintaining a downward water flow in the surface soil, good levelling, timely ploughing and puddling are the most important measures to consider. Below, the most important land use systems on acid sulphate soils are briefly reviewed, including the types of management used.

A. Land use on potential acid sulphate soils

1. ***Mangrove forest exploitation.***

   Dramatic disappearance of mangrove forests on potential acid sulphate soils in favour of shrimp farming has been reported from the Mekong delta (Durang 1995), but is likely to have happened elsewhere as well. Rhizophora spp deliver first class charcoal. Besides cutting, mangrove forests are commonly overfished, resulting in disappearance of the spawning grounds for a large number of aquatic species. Assessment of the severity of the acid sulphate hazard of other kinds of land use may provide a powerful argument for retaining and protecting the natural ecosystem.

2. ***Fish or shrimp ponds.***

   Brinkman and Singh (1982) developed a method for reclamation of fishponds in potential acid sulphate soils in the Philippines. Using the tides and salt water they drained the ponds for forced oxidation of pyrite, ploughed the pond bottom for complete oxidation, let salt water enter the pond to dissolve the acid formed, drained the acid water at low tide, and repeated the oxidation. After 3-5 treatments, the pond bottom was free of acidity. Dikes were also washed with salt water. The system was extensively applied in Philippine coastal areas, and a comparative study of farmers in reclaimed and non-reclaimed fishponds and rice fields (Ligue and Singh 1988) showed that successful reclamation has enabled the farmers to establish financial independence, with average paddy rice yields rising from 0.5 to 2.6 ton ha^{-1} and an increase of 400 kg fish ha^{-1} yr^{-1} due to the reclamation only.

3. ***The rice and shrimp system***

   This system (Vo-tong Xuan *et al.* 1986) is applied on both potential (where it was developed) and actual acid sulphate soils in the Mekong delta. The monsoon climate with its contrasting dry and wet season results in coastal lands being characterised by a fresh and a salt water period. Farmers using the rice and shrimp system take advantage of this situation. They surround their land, which should be located next to a creek or a canal with strong tidal movement, with a deep ditch and make a surrounding dike of the excavated material. A the onset of the rainy season they manage the water in such a way that the salinity is drained quickly in order to have their rice seedbed ready early. Traditional or improved traditional varieties of rice are sown or transplanted in May and harvested at the end of the year with reported yields of 4 tons of paddy ha^{-1}. By that time the rainy season has stopped, and surface water becomes saline. The salt water is let into the ditches and onto the land, keeping it submerged or almost submerged throughout the dry season. In the original version of the system shrimp were caught from natural fry, resulting in yields up to 690 kg ha-1 yr-1. Fresh sediment was deposited on the field year by year from tidal water, raising the land and filling the ditch. This material is removed to heighten the surrounding dike, which thus ends up being made of good alluvial material without acidity. The system was killed by its success: too many people started applying the system, thereby voiding the natural waters of fry. In view of the economic attractiveness of shrimp farming, farmers have now abandoned the system, replacing it by shrimp cultivation using fry purchased from elsewhere in the country. Because these shrimp are raised in the early rainy season, the farmers also abandoned rice cultivation. Declining shrimp yields in 1994/1995 have brought poverty to many of them.

4. *Shallow drainage*

The aim of this technique (Vo-tong Xuan *et al.* 1982) is also to speed up removal of salinity during the early rainy season. Each field it provided with a surrounding deep ditch and dike, plus a number of parallel field drains and a gate. At the start of the rainy season farmers can drain salt quickly from their field at low tide, and close their gates at high tide. The system can enable farmers to have multiple crops such as double short duration rice or rice combined with a short duration upland crop such as watermelon or beans. Banjarese farmers in Southern Kalimantan apply a similar shallow drainage system called *handils* (Sarwani *et al.* 1993)

B. Land use on actual acid sulphate soils

1. *Extensive exploitation*

This activity comprises harvesting reeds for matting, and the exploitation of *Melaleuca leucodendron* for timber, firewood and oil extraction (Brinkman and Xuan 1991). *Melaleuca leucodendron* is also planted. There are few options on raw acid sulphate soils where severe acidity occurs at shallow depth.

2. *Rice*

is by far the most important crop cultivated on acid sulphate soils. In the Mekong delta, soils with a sulphuric horizon deeper than 50 cm have long since been used for traditional rice or deep water rice with low yields (around 1 ton/ha) while until recently, some 10 years ago, the inland fresh water Sulfaquepts were only scarcely used for cultivation. After the economic reform since 1986, settlers moved to the uncultivated lands. After studying satellite images Coolegem (1996) concluded that over the period 1987-1995 53% of a district with severely acid soils had changed in land use with an increase in irrigated rice during the dry season (28% of the district) at the cost of wasteland or *Melaleuca leucodendron* forest being most important. Hanhart and Ni (1993) developed a set of water management measures for rice on such land, recommending good levelling, narrow spacing of drains (30-60 m) to create a downward flow of water through the surface soil and brief drying of the surface soil at flowering to avoid deep reduction. Yields obtained were 3.6 - 3.8 t ha^{-1} with the economic break-even point at 2.15 ton. Drainage from the rice field brings an estimated 5 kmol per ha per crop of acid into the surface water, so the authors recommend separate irrigation and drainage. In areas with saline surface water in the dry season, traditional rice is cultivated. Moderate fertiliser levels of 100 kg N and 60 kg P are recommended, together with low lime application to improve Ca^{2+} availability (Ren *et al.* 1993). Plant nutrition research in rice on acid sulphate soils suffers from poor relationships between uptake of Ca^{2+}, Mg^{2+}, Fe^{2+} and the activity of these cations in the soil solution. Moore and Patrick Jr. (1993) recommend using E'-Ca^{2+}, E'-Mg^{2+} and E'-Fe^{2+}, the divalent charge fraction in the soil solution due to Ca^{2+}, Mg^{2+} and Fe^{2+}, instead, which shows much better relationships with plant uptake (see Figure 2.9).

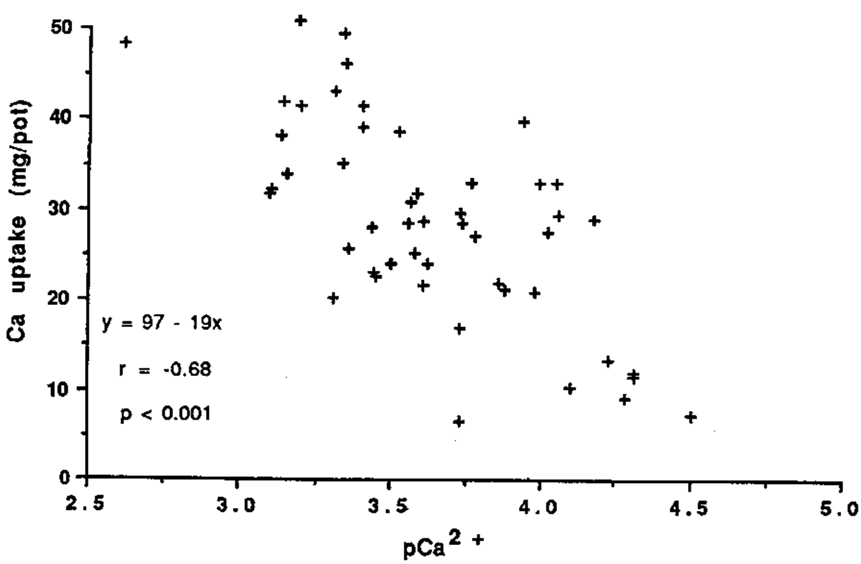

Figure 2.9: The relationship between Ca uptake by rice and Ca^{2+} activity in soil solutions in a growth chamber study (Moore and Patrick Jr. 1993)

3. *Balanta system*

In West Africa farmers apply the so-called ***Balanta*** system (van Gent and Ukkerman 1993). Land is ridged annually to a height in accordance with the expected fresh water flood of the rainy season.

4. *Annual upland crops*

Yam, sweet potato, cassava, and sugar cane, cultivated as an annual crop, are the most important. These crops precede rice cultivation in places where no proper water supply for rice in the dry season is present. Farmers make raised beds by piling up the surface soil before the start of the rainy season. Beds are leached strongly during the wet season. Crops are planted immediately after the recession of the flood. Moisture is supplied by residual water from the soil, water in the ditches between the beds and water from capillary rise. For yam, vegetative growth is luxuriant, but yields are modest, about 6 ton ha^{-1}, which is about 15 t ha^{-1} when recalculated on a basis of a fully used hectare without beds. The disappointing yields are attributed to excess moisture near harvest time (August) when the rainy season has started again (Durang 1995). After some 3-4 years, the land is levelled and, provided a source of irrigation water is available, rice is cultivated in a double crop system (Tri 1996).

5. *Perennial upland crops*

Sugar cane, pineapple, cashew nut. These perennial crops need to have dry feet in the flood season. Costly high raised beds, well over the level of the flood are needed. Pineapple and cashew are commonly cultivated by large scale cooperative farms, sugar cane is mostly a small holder crop. The large pineapple and cashew farms were established as state farms after the end of the Viet Nam war in 1975 but were reorganized to cooperative farms since 1987, with decisions now in the hands of the individual farmer. Sugar cane on acid sulphate soils suffers poor tillering, the canes are short and thin, and total yields average about 50 ton of raw cane ha^{-1} (Derevier 1991) while yields in non-acid soils of the Mekong delta can achieve 120 ton ha^{-1}. Al^{3+} toxicity was suspected to be the cause, but no correlation between Al^{3+} in the soil and nutrients in the plants could be established (Nga *et al.* 1993). For pineapple, 7 g P_2O_5 and 10 g K_2O fertilisation, mulching with grass and a sufficient height above the flood are recommended (Tri 1996, Sen 1987) leading to yields of 40-50 t ha^{-1}, even in areas with limited irrigation possibilities due to temporary salt surface water in the dry season.

C. Integrated soil, water and crop management

Tri (1996) discusses the land use systems in 4 study areas of the Mekong delta and also shows the historic development of land use. Figure 2.10 shows the example of Thanh Tan - Long An, Mekong delta and also indicates the soil-water management measures (raised bed construction, ploughing, puddling, leaching, construction of an irrigation and drainage system, field water management during the rice crop) that were taken along with changes being made in land use. The example makes clear how soil and water management are of primary importance for proper management of acid sulphate soils. The assessments were

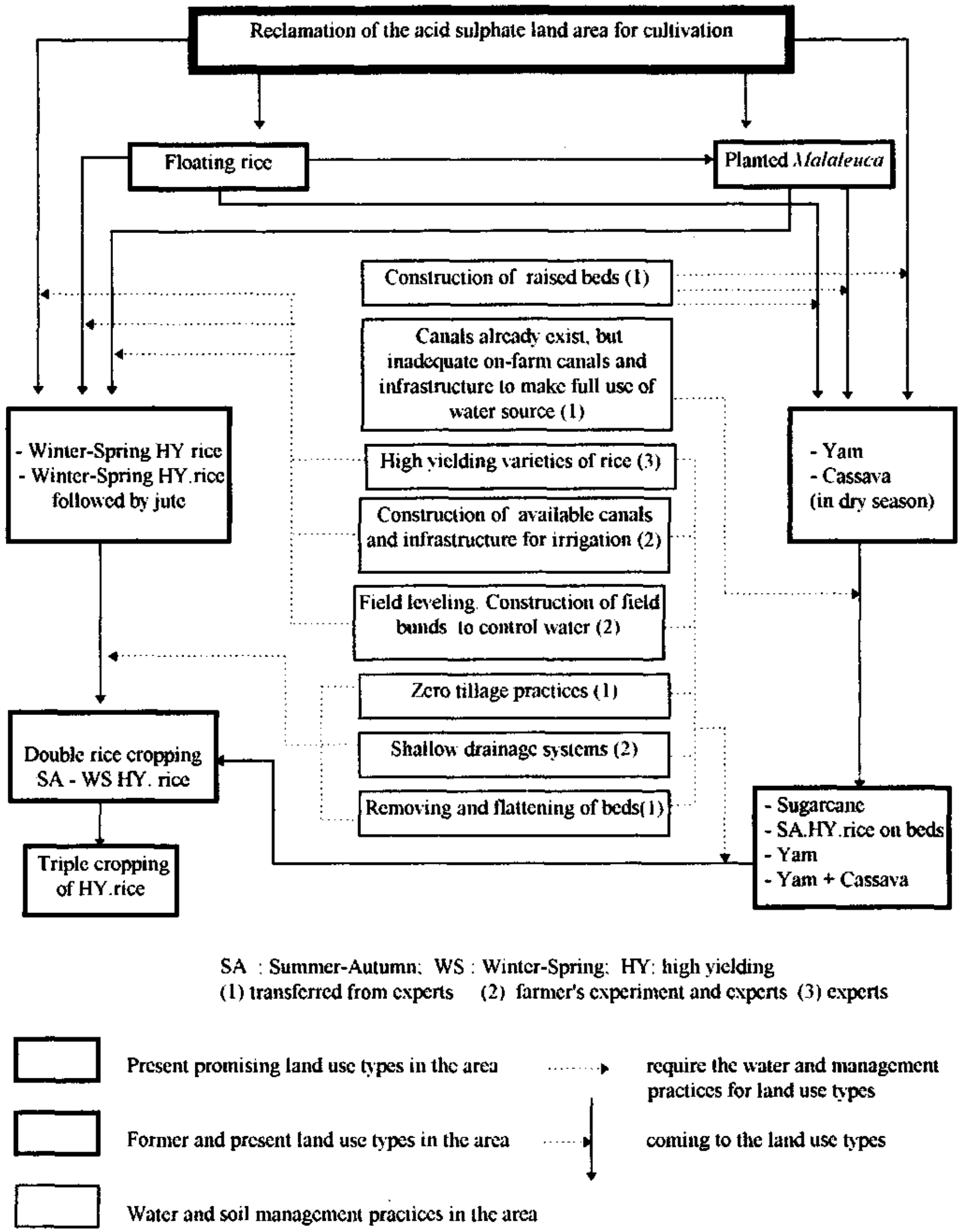

Figure 2.10: History of land use in Thanh Tan district, Long An province, Mekong delta, Vietnam (Tri 1996)

mainly made by the farmers themselves, and the integration of different soil and water management practices can only be made by the community of land users. Land use evolved through their learning process. Significantly, the problems perceived first were problems of drainage and water supply, and the response to later recognition of acidity problems has also been water table management.

D: Land Evaluation

Tuong *et al.* (1991) used hydrological factors as land qualities to determine the suitability of the land in the Mekong delta for rice cultivation (double or triple cultivation, modern or traditional rice). The hydrological land qualities selected are typical for coastal acid sulphate land: fresh water flood depth and flood duration during the wet season; rainfall amount and distribution emphasising the occurrence of dry spells in the early rainy season; tidal influence; periods during which salt surface water is present in the dry season and the adequacy of canals for irrigation were investigated and rated for their influence on rice cultivation. For instance, a flood depth of < 30 cm enables cultivation of modern, short duration rice; a flood of < 60 cm allows traditional varieties, while with a flood > 60 cm only deep water rice is possible. Tidal influence is judged for its potential in irrigation without pumping; a long period for salt surface water may make the time for double rice too short. The study results in suitability maps of the Mekong delta for the different double or triple rice cropping systems.

Van Mensvoort *et al.* (1993) carried out a land evaluation study of the acid sulphate soil part of the Mekong delta which, besides the hydrology, also included soil conditions and applied a wider range of land use types. The delta was divided into twelve zones (Figure 2.11) based on soil and hydrological conditions of acidity (sulphuric horizon < 50 cm deep, sulphuric horizon > 50 cm deep, no acidity), flooding depth (> 60 cm or < 60 cm), and surface water salinity in the dry season. Nine land utilisation types (4 rices, tolerant annual crops, sensitive annuals crops, pineapple, sugar cane and *Melaleuca leucodendron*) were described. Factor ratings of acidity, potential acidity, flood hazard, fresh water availability and salt intrusion tolerance were developed for each land utilisation type (LUT), based on farmers' experience in the delta. Key attributes used were the yields as Vietnamese farmers obtain them, provided they use good management techniques as described before in the land use section. A suitability judgement was made for each of the twelve zones, indicating present suitability, conditional suitability (i.e. the suitability when the most limiting constraint is lifted) and the most important remaining constraint (see Table 2.3). Rows showing possible improvements have been shaded. The study concludes that making fresh water available can improve the suitability for rice on all acid sulphate land and that well-constructed raised beds can make moderately acid soils (sulphuric horizon > 50 cm) highly suited for pineapple and sugar cane.

Tri *et al.* (1993) evaluated two Mekong delta districts using the same methodology, but in much greater detail. One district (Phung Hiep, PH) is only partly hampered by acid sulphate soil problems, the other district (Thanh Hoa, TH) is situated in the centre of the Plain of Reeds, an area dominated by acid sulphate soils. They distinguished 27 land units based on soil and hydrological criteria in PH and 23 in TH, and studied 28 and 29 land use

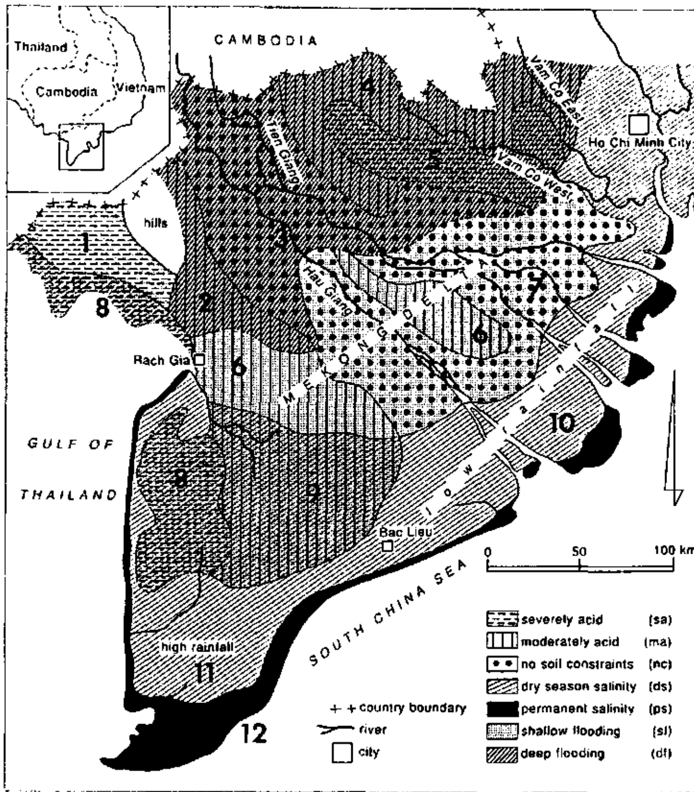

Figure 2.11: Map of land constraints to farming in the Mekong delta (van Mensvoort *et al.* 1993)

Table II.3: Evaluation of Zone 5, Central Plain of Reeds

Crop	present/conditional suitability	Conditional constraint	Remaining constraint
HT	N/N		soil acidity
DX	N/S3	fresh water availability	soil acidity
MUA	N/N		soil acidity
DWR	N/N		soil acidity
SUC	N/N		soil acidity
TUC	N/S3	fresh water availability	soil acidity
PIN	N/N		acidity, flood
SUG	N/N		acidity, flood
FOR	S2/S2		acidity, flood

systems for PH and TH, respectively. They included, for a more detailed judgement of the land use systems, not only yields obtained by farmers but also economic parameters such as capital intensity by initial investments and recurrent annual costs, gross income per year, and gross margin per year. They selected 11 LUT's for PH and 6 for TH as most promising, and used key attributes of yield and economic parameters for the evaluation, which showed what LUTs were highly-, moderately-, marginally- or un-suited for each of the land units, including identification of the most limiting factors.

On moderately acid land of PH, LUTs such as annual sugar cane in the dry season followed by rice in the wet season, cashew intercropped with pineapple, double rice cultivation and *Melaleuca* forestry can be recommended. In TH, with its poor soils and much more difficult hydrological conditions, single or double rice, or yam (Dioscorea alata) can be recommended.

The success or failure of the land use systems depends, however, on farmers skills. Present land use and farmer skills form, in fact, the basis for both land evaluation studies. In this study, and in Tri (1996) acid sulphate soils knowledge of various levels: from farmers, experts and specialists is brought together. All knowledge levels are valued equally, and it is claimed that the farmer-level knowledge has so far been underused. Farmer-level knowledge is built on generations of experience in using the land. The farmer knowledge not only generated interesting land use systems (rice/shrimp, yam, sweet potatoes, pineapples etc), but also explained how they were historically developed, under what conditions or in what sequence they can be applied, and what management measures need to be taken (e.g. leaching, mulching, zero-tillage application, methods of raised bed construction). The expert level knowledge can be regarded as collateral and reinforcing to the farmers' level knowledge: fertiliser recommendations based on field experiments *(inter alia* Ren *et al.* 1993), refinement of water management measures (Tuong 1993, Hanhart and Ni 1993), variety selection (Xuan 1993). Finally, true specialist knowledge of a more fundamental nature can also contribute to improved land use e.g. by better survey methods to improve land use planning (Bregt *et al.* 1993, Burrough *et al.* 1988); by getting a better grasp of the soil-plant relationships though improved methods of chemical characterisation (Moore and Patrick Jr 1993), or by modelling the processes in acid sulphate soils (Bronswijk and Groenenberg 1993). To date, the community of acid sulphate soils specialists has taken rather little account of the interests of the largest and most vulnerable group of land users, the farmers, and have yet to assemble detailed knowledge into coherent and accessible decision-support systems.

Chapter 3:

EXCHANGE OF KNOWLEDGE ON ACID SULPHATE SOILS BETWEEN SPECIALISTS, EXPERTS AND FARMERS

I. SUMMARY

The acid sulphate soils research community holds regular (once in 5-6 years) conferences for knowledge exchange. The proceedings of these conferences are a way to screen research developments over the years. This chapter reviews the contents of the proceedings to find out whether there has been a change in priorities in time, but also tries to screen whether the information is suited to meet the need for information of other groups of people involved with acid sulphate soils. The other groups involved in acid sulphate soils are: the farmers living on acid sulphate land, but also experts dealing with information transfer on this type of land such as district, provincial or regional land use planners and extension workers.

Conclusion from this exercise is that the specialists supply their information mainly to their fellow specialists, but also a substantial part of the knowledge can be used by the expert group. Specialists also generate knowledge suited for farmers, but the knowledge of farmers is rarely incorporated in the specialists work. During the most recent meeting (Ho Chi Minh City, 1993) farmers knowledge started to earn itself a place in the specialists' circles.

II. INTRODUCTION AND OBJECTIVES

For over two decades now (1973 to present), acid sulphate soils have been subject of research for a substantial group of scientists over the world. They have exchanged their newly acquired knowledge at regular intervals by means of conferences entirely dedicated to these soils at Wageningen (1972), Bangkok (1981), Dakar (1986) and Ho Chi Minh City (1992). The proceedings (Dost 1973, Dost and van Breemen 1982, Dost 1988, Dent and van Mensvoort 1993) form the core of the literature review given in chapter 2 of this thesis, and can be seen as an account of the progress in research on acid sulphate soils over the last 25 years. It should be realised that in two cases (Dakar and Ho Chi Minh City) the proceedings contain only a selection of the work presented at the conferences.

This chapter tries to find out whether there has been a change in research priorities over the years of the ASS community. It also reviews the proceedings of the conferences for practical applicability by farmers and experts. It is realised that this chapter is of a somewhat biased nature because applicability for farmers and experts was, to a large extent, not the objective of most of the specialists work. Applicability is, however, of importance for the goal of the work in Viet Nam carried out through the Wageningen - Can Tho Universities (WAU and CTU) co-operation: develop management packages for improved use of acid sulphate soils. The chapter therefore shows how useful the existing specialists literature is for the purpose of the WAU-CTU co-operation.

But there are other reasons showing the need for such a review as well. Brinkman (1982), probably inspired by his work on the construction of fishponds in acid sulphate areas under salt tides, a ready-made system for direct application by farmers, was the first to raise questions on the social and economic aspects of acid sulphate soils reclamation, indicating the lack of attention for the people who live on the land, the reasons why they go there, and also the implications of possible recommendations stemming from scientific work for the people concerned. One of the conclusions from the Bangkok symposium was that "researchers should move out from the laboratory into the farmers fields, both to back up basic research and to demonstrate the practical implication of new management practices".

One may wonder why scientists engaged in acid sulphate soil research should feel an obligation towards the people who use the land, and more so than other scientists investigating other types of land. The reason is, that "uniquely, acid sulphate soils and the problems they bring about are the products of land reclamation" (Dent and van Mensvoort, 1993). At this very moment migration programmes to acid sulphate areas are going on, some spontaneous (Viet Nam), others under government instigation (Indonesia). If such programmes, due to injudicious land reclamation, threaten the livelihood of hundreds of thousands of people, the scientists should take their responsibility. It is worth finding out whether they have done so.

III. METHODOLOGY

Information is grouped in subjects in a way somewhat similar to chapter 2 (identification, distribution and genesis; land use and farming systems; fertility and water management; land evaluation; modelling of processes; environmental problems) and presented as tables, one for each conference. For each publication is determined whether the information it contains is based on specialist knowledge, expert knowledge or farmer knowledge, and by which of these three groups the results obtained can be applied.

IV. RESULTS

A. People who deal with acid sulphate soils: Farmers, Experts and Specialists.

Dent (1986) grouped the people who deal with acid sulphate soils as follows: (1) farmers (2) agricultural and forestry staff in extension services (3) civil engineers (4) planning agencies (5) politicians, investors, international development agencies and (6) soil specialists. The last group can be enlarged with specialists in water management, mathematical modelling and environmental sciences. In this study, people dealing with acid sulphate soils are grouped according to Bouma (1993) in three categories: farmers and land users (group 1), experts (groups 2-5) and specialists (group 6). Farmers are those directly depending on the land for their livelihood. The experts are, according to Webster's dictionary, those who "have much training and knowledge in some special field". In this discussion, with the situation in the Mekong delta as reference, they are people who are engaged in transfer/application of knowledge on acid sulphate land. They particularly are the district, provincial and regional land use planners or extension workers. In most cases the experts are people using knowledge generated by specialists, which they try to apply to their own field of work, or try to extend to the farmers.

The specialists are those who carry out research on acid sulphate land. They used to be exclusively soil scientists. But, as will be shown later in this chapter, other specialists in fields such as water management, mathematical modelling, farming systems analysis and environmental science have also started to contribute to an extension of the knowledge on acid sulphate soils. Each category has its own experience in dealing with acid sulphate land. Ideally, there should be an exchange of knowledge and experience between the three categories to take full advantage of each others' findings.

B. Trends in research on acid sulphate soils

Tables 3.1, 3.2 and 3.3 review the papers of the Bangkok, Dakar and Ho Chi Minh city symposia, grouped in various subjects. The Wageningen (1973) proceedings were not included since this first acid sulphate soils meeting was purely meant for an exchange between scientists, and little in terms of practical applicability can be expected. The tables show where the knowledge was collected from (*i.e.* did the researcher continue along lines set out by colleagues, or use his/her own specialised knowledge to carry out his/her work, or was information used from experts or from farmers), whether the knowledge generated can be applied by specialists, experts or farmers, and whether the knowledge is applicable for farmers.

The way tables 3.1, 3.2 and 3.3 were compiled can best be demonstrated through some examples. When a specialists' investigation of the spatial variability of ASS properties in Kalimantan, Indonesia, concludes that a wide network of soil augerings will generate a similar quality soil map as a very narrow network of observations (Bregt *et al.* 1993), this conclusion is useful for both the specialist and the expert category, in this case soil surveyors. In the tables an S will be placed in the column "Knowledge generated by/collected from", and SE in the column "Knowledge meant for".

Ligue and Singh (1988) applied an enquiry to compare the social and economic status of farmers who adopted the fishpond reclamation technique of Brinkman and Singh (1982) to farmers who did not do so. They gathered their information from farmers (F) and generated information that can be applied by experts (extension workers, land use planners) and farmers (EF).

The integrated approach to land management of Kselik *et al.* (1993) uses specialists knowledge for experimental layout and expert knowledge for levels of fertiliser and cropping systems suitable for Kalimantan (SE). It generates knowledge particularly suited for expert and farmer application (EF).

In order to obtain a quantitative idea of the knowledge exchange between the three categories Table 3.4 was compiled. The columns "knowledge collected from" and "knowledge meant for" have been used. For each publication source(s) and destination(s) are linked. The publication of Kselik *et al.*, for instance, uses knowledge from SE, meant for EF, and thus generates knowledge exchange from S to E, from S to F, from E to E and from E to F. For each conference, the number of times a category of knowledge exchange is mentioned, is summed. Table 3.4 gives the totals for each symposium and for all three symposia, and expresses each kind of knowledge transfer in percentages. The table shows how during the symposia knowledge exchange from specialists to fellow specialists and to experts dominated. In Bangkok a high score (27%) was for knowledge from specialists to farmers. This is due to the large number of papers dedicated to fertility research, resulting in fertiliser recommendations useful for local experts and farmers.

Table 3.1: The Bangkok symposium (1982)

Author, Subject	Knowledge collected from	Knowledge meant for	Applicable for farmers yes/no/partly
Knowledge on identification, distribution and genesis of ASS land			
Pons & van Breemen, Formation of potential acidity	S	S	N
Thomas & Varley, Survey of sulphidic soils in tropics	S	S/E	N
Dent & Raiswell, Quantitative models for prediction of acidity	S	S/E	N
Paramanathan & Gophinatan, Classification problems in ass	S	S/E	N
Marius, ASS distribution & properties in Senegal & Gambia	S	S	N
Knowledge generated by experimental work on fertility and water management			
Attanandana *et al.*, fertility of ass Thailand (pot & field)	S	E/F	P
Charoenchamratcheep *et al.*, Lime & fertiliser, Thailand (field)	S	E/F	Y
Maneewon *et al.*, Use of marl for rice, Thailand (field)	S	E/F	Y
Le Van Can, Rock phosphate application, Viet Nam field)	S	E/F	Y
Arulandoo & Pheng, Straw, lime & fertilisers, Malaysia (field)	S	E/F	Y
Ponnamperuma & Solivas, Manganese & Lime (pots)	S	E/F	N
Touré, Lime, ash, green manure, pre-flooding, Senegal (pots)	S	E/F	P
Khouma & Touré, Lime & P fertilisers in rice, Senegal (field)	S	E/F	P
Yin & Chin, Water management in oil palms Malaysia	S/E/F	E/F	Y
van den Eelaart, Management problems, Indonesia	S/E/F	E/F	Y
Ponnaperuma & Solivas, Variety screening for iron toxicity	S/E	E/F	Y
Wada *et al.*, Chemistry monitoring in rice, Thailand	S	S	N
Alva & Larsen, Application of tracers to study P in rice	S	S	N
Sen, Sampling of soil cores	S	S	N
Knowledge on land use and farming systems			
Xuan *et al.*, Rice cultivation methods, Viet Nam	F	E/F	Y
Brinkman & Singh, Reclamation of fishponds, Philippines	S/E	F	Y
Singh, Pond acidification after inundation, consequences	S	E/F	Y
Singh, Management of fishponds, Philippines	S/E	E/F	Y

Table 3.2: The Dakar Symposium (Dost 1988)

Author, Subject	Knowledge collected from	Knowledge meant for	Applicable for farmers yes/no/partly
Knowledge on identification, distribution and genesis of ass land			
van Mensvoort & Tri, Ass without jarosite	S	S	N
Loyer *et al.*, Effects of recent Sahelian drought on ass land	S	S/E	N
Wada & Bongkot, Pyrite formation in mangroves	S	S	N
Fanning *et al.*, S and metals in ass in dredged harbour material	S	S/E	N
Prokopovich, Engineering problems of ass in California	S	S/E	N
Pulford *et al.*, Inhibition of pyrite oxidation in mine waste	S	S/E	N
Burrough *et al.*, Spatial variability in ass for survey	S	S/E	N
Pons, Classification in inceptisols or entisols?	S	S	N
Konsten, Field method for potential & actual acidity	S	S/E	N
Knowledge generated by experimental work on fertility and water management			
Sen, Evaporation & acidification	S	S	N
Agyen-Sampong *et al.*, Rice improvement by variety selection, fertility & water management	S/E	S/E/F	Y
Prade *et al.*, Iron uptake in rice	S	S/E/F	Y
Knowledge on modelling			
Bouma, Morphology for simulating water movement	S	S	N
Knowledge on environmental problems of acid sulphate soils			
Doyen, Multiple uses of mangroves	S/E/F	S/E	N
Le Reste, Aquatic & fisheries consequences of dam building	S/E	S/E	N
Knowledge on land use and farming systems			
Singh et al., Fishpond reclamation: Philippine experience	S/E/F	E/F	Y
Knowledge on social and economic aspects			
van der Klei, Ass a technical or a socio-economic problem?	S/F	S/E	N
Ligue & Singh, Socio-ec. status on recl. and non-recl. ASS	F	E/F	Y

Table 3.3: The Ho Chi Minh City Symposium (1993)

Author, Subject	Knowledge collected from	Knowledge meant for	Applicable for farmers yes/no/partly
Knowledge on identification, distribution and genesis of ASS-land			
Andriesse, Methods of surveying ass	S	S/E	N
Bowman, Removing pyrite by hydraulic separation	S	S/E	N/P
Bregt *et al.*, Survey strategy based on variability	S	S	N
Diemont *et al.*, Standard sedimentation profiles	S	S	N
Fanning & Witty, Revisions of soil classification	S	S/E	N
Fitzpatrick *et al.*, Origin of inland & tidal ass in Australia	S	S	N
Giani, Potential acidity in marine & moor peats	S	S	N
Sadio & van Mensvoort, Saline acid sulphate soils in Senegal	S	S	N
Knowledge on land use and farming systems			
Chaang *et al.*, Land use in former mangroves	F	S/E	Y
van Gent & Ukkerman, Balanta rice farming system	E/F	S/E/F	Y
Sarwani *et al.*, Farmers land use in Kalimantan	F	S/E/F	Y
Nga *et al.*, Sugarcane in ass	E/F	E/F	Y
Xuan, Integrated land uses	E/F	E/F	Y
Knowledge generated by experimental work on fertility and water management			
Deturck *et al.*, Rice on ass in Sri Lanka	S/E	E	P
Ren *et al.*, N,P,K and lime for rice on ass	S/E	E	P
Hamming & vd Eelaart, Water flow in ass, Kalimantan	S	S/E	N
Hanhart & Ni, Water management of rice fields	S/E/F	E/F	Y
Kselik *et al.*, Integrated water management, fertility & cropping systems in Kalimantan	S/E	E/F	Y
Montori *et al.*, Rehabilitation of rice fields in Senegal	S/F	S/E/F	P
Moore & Patrick, Metal availability & uptake in rice	S	S	N
Oborn, Liming and P on cereals in Sweden	S/E	E/F	P
Phung & Lieu, Microbes in ass	S	S	N
Sterk, Leaching of acid from raised beds	S	S/E	N
Sylla *et al.*, Variability of soil constraints for rice	S/E	S/E	P
Hai & van Parijs, Effect of fluoride on Al toxicity	S	S	N
Tuong, Water management in ass	S/E	S/E	P
Tuong *et al.*, Land preparation and leaching effectivity	S	S/E/F	N
Knowledge on land evaluation			
Dent, land evaluation and land use planning	S	S/E	N
Tri *et al.*, Land evaluation based on present land use	S/E/F	S/E/F	Y
van Mensvoort *et al.*, Land evaluation by farmers experience	S/E/F	S/E/F	Y
Knowledge on modelling			
Bouma *et al.*, Way & means of modelling ass	S	S	N
Bronswijk, Groenenberg, Model prediction of processes	S	S	N
van Wijk *et al.*, Validation of ass simulation model	S	S	N
Eriksson, Modelling water flow & solutes	S	S	N
Danh & Tuong, Solution chemistry in soil columns	S	S	N
Knowledge on environmental problems of acid sulphate soils			
van Breemen, Environmental problems of ass	S	S	N
Callinan *et al.*, Fish kills in ass water	S/E	S/E	N
Palko & Yli-Halla, Acidity released upon drainage	S/E	S/E	N
Willett *et al.*, Acid drain water from pass	S/E	S/E	N

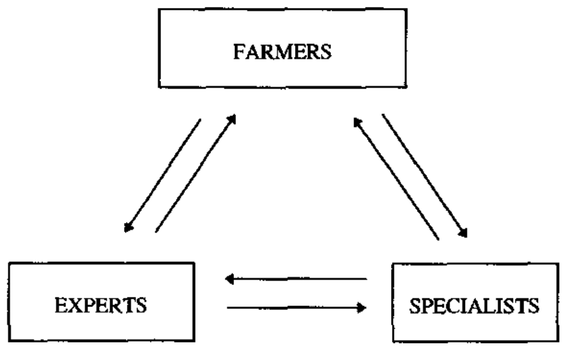

Figure 3.1: Balanced exchange of knowledge between the main groups of people involved in acid sulphate soils: farmers, experts and specialists

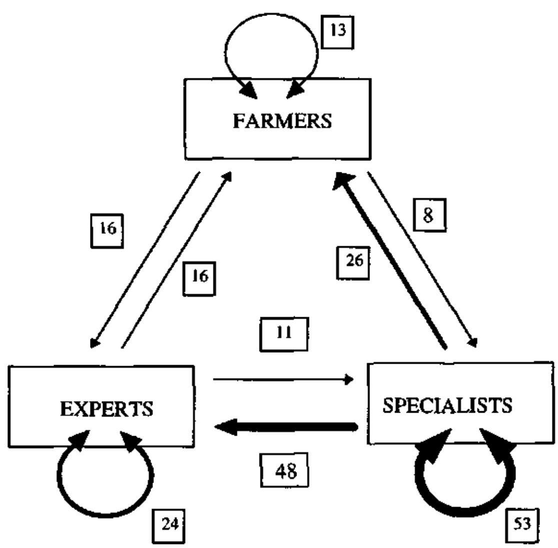

Figure 3.2: Exchange of knowledge between farmers, experts and specialists involved with acid sulphate soils, derived from the proceedings of the Bangkok, Dakar and Ho Chi Minh City Conferences

Table 3.4: Specialists (S), experts (E) and farmers (F) knowledge exchange over three ASS conferences in numbers and percentages

Explanation in the text. Between brackets: numbers expressed as percentages

From → To	Bangkok	Dakar	Ho Chi Minh City	Total
S → S	8 (15)	16 (33)	29 (25)	53 (25)
S → E	16 (29)	12 (25)	20 (18)	48 (22)
S → F	15 (27)	3 (6)	8 (7)	26 (12)
E → S	0 (0)	3 (6)	9 (8)	12 (6)
E → E	4 (7)	4 (8)	16 (14)	24 (11)
E → F	5 (9)	2 (4)	9 (8)	16 (7)
F → S	0 (0)	2 (4)	6 (5)	8 (4)
F → E	3 (6)	4 (8)	9 (8)	16 (7)
F → F	3 (6)	2 (4)	8 (7)	13 (6)
Total	54 (100)	48 (100)	114 (100)	216 (100)

Figure 3.1 shows a balanced exchange of knowledge between farmers, experts and specialists. In Figure 3.2 the information of Table 3.4 has been visualised, showing the total number of times a knowledge exchange between two categories has been identified over the three conferences. The arrows indicate the direction of the knowledge transfer, *i.e.* from S to E means that in a publication specialist knowledge has been applied, but that the results and recommendations are applicable for experts.

Initially the main accent of the acid sulphate soils research was on explaining the genesis and the chemical processes, and on the methodologies for survey or soil classification (Dost 1973). This work served the goals of the soil scientists: exchange knowledge on the formation, the identification, the physiography and mapping, the properties of acid sulphate soils, and the effects of fertiliser applications. There was also a contribution on alarming acidification after empoldering, and one on the corrosive action to steel by acid. Later, in the Bangkok conference, (Dost and van Breemen 1982) other aspects, in particular improvement of the soil fertility and some initial work on land and water management received attention. The Dakar Symposium (Dost 1988) added work on acid sulphate problems in mine spoils but the genetic, survey and classification work prevailed. It was only in Ho Chi Minh City that work on land and water management, traditional farming systems, land evaluation, modelling and environmental problems received attention in ASS research, involving many other disciplines aside from soil science.

C. Review per research category for practical applicability

1. Knowledge on identification, distribution and genesis of ASS land

This work forms the basis of acid sulphate soils research, and has long dominated the literature. Even in Dost (1988) half the papers is on this subject, but this may be attributable to the editor who made a selection of the work presented. In Dost and van Breemen (1982) and Dent and van Mensvoort (1993) about 20% of the papers was on this subject. The knowledge generated under this heading is almost exclusively meant for fellow specialists and for some experts, notably for soil surveyors or mine engineers. One may state that this type of information is only accessible to fellow specialists but Dent (1993) gives examples of how information of this category might be used at all levels of decision making, from single fields to country wide planning. Dent (1993) shows the need for "Knowledge-based decision-support systems" enabling decision makers (*i.e.* farmers, experts and specialists) to gather and make proper use of land information they need to make wise decisions about land use.

2. Knowledge on land use and farming systems

Vietnamese farmers in the Mekong delta have been particularly inventive in adjusting to the adverse conditions of acid sulphate land. To some extent they may have been comparatively lucky because of the great diversity in soil and hydrological conditions (Tuong *et al.* 1991). Xuan *et al.* (1982) are the first to describe two cultivation techniques developed by farmers on acid sulphate land, the shallow drainage system which speeds up the removal of soluble toxins in the early rainy season and the "acid avoidance technique", a system whereby rice is planted at the end of the flood season during recession of the flood when soil conditions are optimal. Xuan *et al.* (1991) favour the "zero-tillage technique" which saves time (and investments) between dry season crops, thus enabling two or three rice crops per year on ripe acid sulphate soils. Brinkman and Xuan (1991) report the use of *Melaleuca leucodendron* for forestry; Nga *et al.* (1991 and 1993) describe the way farmer grow pineapples and sugar cane. Tri (1989) and Xuan (1993) review farmer activities in general, and give additional information on systems of combined rice and shrimp or rice and moulting crab cultivation, and on upland crops such as cassava, yam, sweet potato, jute, kenaf and water melon.

Compared to Viet Nam, other parts of the world are less represented in this category. Brinkman and Singh (1982) and Singh (1988) show the methodology and the positive results of acid sulphate land reclamation for fishponds in the Philippines. Land drainage for large scale, commercial oil palm plantations in Malaysia is described by Yin and Chin (1982). These land use systems, however, require much heavier investments compared to the Vietnamese systems. In Ho Chi Minh City, Chaang *et al.* (1993) described the increase in rice land on acid sulphate soils in the Merbok scheme, Malaysia through improved water management and fertiliser application. Two papers describe low investment systems comparable to the Vietnamese examples: Van Gent and Ukkerman (1993) on the Balanta system of rice cultivation in West Africa, in which land is ridged in dependence of the expected wet season flood, and Sarwani *et al.* (1993) on reclamation techniques of the Banjarese farmers who start by reclaiming the land for rice cultivation and later combine this for a better profit with tree crops such as coconut, oranges, cloves and coffee on mounds or ridges.

3. Knowledge on fertility and water management

The literature shows a large number of fertility oriented experiments on irrigated rice, amending the soil mainly with lime and with various phosphorus fertilisers but also with more eccentric materials as wood ash, marl, manganese dioxide, rock phosphate or green manure. Studies were carried out in nutrient solutions, pot trials and field trials. Modest applications (30 - 60 kg P_2O_5 per hectare) of P-fertilisers are generally recognised as having significant positive effects on rice yields. Contrasting results were obtained regarding the application of lime. While some researchers claim strong effects, especially when experiments are carried out in well controlled conditions as is the case in pot trials (e.g. Attanandana 1982) which also omit the potential detrimental effects stemming from the subsoils. In field experiments Charoenchamratcheep *et. al.* (1982) and Maneewon *et. al.* (1982) find only effects of lime when combined with P-fertilisers. Main reason for these contradictory results might well be a lack of proper characterisation in advance of the conditions under which the plants grow in the field experiments. Water management is rarely taken into account in the field experiments on fertility and is the reason for the contrasting results obtained. An attempt to bring more structure is given by Osborne, as quoted in Dent (1992) and by Ren *et al.* (1993). In both cases soils are first grouped according to the severity of the acidity, with Osborne distinguishing five classes (Thailand), and Ren *et al.* two classes (Viet Nam). Contrasting effects are especially seen in raw acid sulphate soils and Ren *et al.* recognise, that this is caused by effects of water management. Low doses of a few hundred kilos of lime can already be beneficial, provided good water management is provided. In the case of Ren *et al.* this means repeated pre-leaching and flushing of the surface soil to remove soluble toxins.

Water management is often called the key factor to improvement of acid sulphate soils (van Breemen 1976). Optimisation of farmer field water management to enable double rice cultivation in the Mekong delta is described by Hanhart and Ni (1993). They include (1) proper timing of the crops immediately after the flood recession instead of waiting for natural rains in the early wet season (2) very accurate land levelling and (3) brief periods of drying of the surface soil to prevent deep reduction and its associated toxicity problems.

An example of a true integrated approach to research of the possibilities for land use is given by Kselik *et al.* (1993) who showed positive effects of a combination of intercepting acid drain water from adjacent forest land, good levelling, puddling and liming.

The research on fertility has moved from classical pot trials and field trials to more integrated fertility approaches recognising the importance of other management aspects of the land, in particularly water management, on the fertility status of the soil. This has lead to recommendations which recognise proper water management as a precondition for sound effects of fertiliser applications. Application of these techniques by farmers have been reported from Malaysia (Chaang *et al.* 1993) and Viet Nam (Tri 1996).

4. Evaluation of acid sulphate land

The first two examples of studies evaluating acid sulphate land were published by van Mensvoort *et al.* (1993) and Tri *et al.* (1993). Both studies were of a qualitative nature and used specialists' knowledge on the land to divide the entire Mekong delta, and two Mekong delta districts, respectively, into zones based on more or less severe soil and hydrological constraints. Various land use types (LUTs), as applied by Mekong delta farmers, are described. The key attributes of the land use systems are the crops cultivated and the land/water management techniques developed by Vietnamese farmers. Tri *et al.* (1993)

make an economic evaluation in terms of capital intensity and recurrent annual costs. Both studies express the land requirements in terms of tolerance to soil acidity and hydrological requirements. For each soil zone the present suitability for the selected LUTs is determined, in Tri *et al.* (1993) in economic sense, in van Mensvoort *et al.* (1993) as relative production levels within the Mekong delta. The latter study also adds the suitability after the most important constraint has been removed.

These two studies can assist experts in designing land use plans. Tri *et al.* (1993) used economic data at one time in two districts, but did not include market studies for recommended produce, while van Mensvoort *et al.* (1993) do not include economic considerations. The two studies are, however, examples of integrating farmers, experts and specialists knowledge and supply information that is useful for all three categories.

5. Mathematical simulation models in acid sulphate soils research

Mathematical modelling has first been applied by Dent and Raiswell (1982) who built a model to predict the rate and severity of acid sulphate soil development (Dent & Raiswell, 1982); Bouma (1988) proposed the use of morphological data for simulation of water flow in clay soils. Both the Bangkok and Dakar symposia recommended more attention to the application and development of mathematical simulation models for acid sulphate soils. This plea was answered in Ho Chi Minh City, where modelling activities became a substantial part of the research presented there. Bronswijk and Groenenberg (1993) presented the basic principles of SMASS, a computer simulation model for the chemical and physical processes in acid sulphate soils. The model calculates the chemical and physical consequences of various water management options through four sub-models (see chapter II).

Van Wijk *et al.* (1993) apply the SMASS model for a number of water management strategies in South Kalimantan, Indonesia. They predict the chemical and physical consequences of, for instance, maintaining the present water management, forced drainage to a certain depth and the flushing of the surface soil with fresh water, and compare them with results obtained from column experiments in which such strategies were applied.

Eriksson (1993) limited his work to the modelling of water and solute flow in acid sulphate soils in Viet Nam. This seems appropriate in the Vietnamese case since in the Mekong delta most acid sulphate soils have already undergone pyrite oxidation to a great depth, which makes further pyrite oxidation unlikely. Danh and Tuong (1993) studied the soil solution chemistry in acid sulphate soil columns subjected to different leaching treatments. The research supplied validation data for the Eriksson model. Their columns were: (1) not subjected to leaching and permanently submerged; (2) leached and permanently submerged, and (3) leached, periodically left to fall dry to a depth of 40 cm, and submerged again. They concluded that only ferrous-iron concentrations responded strongly to the oxidation-reduction status of the soil, but that leaching is slow, and removal of toxins equally slow.

All modelling activities described above were geared towards predictions of the chemical composition of the soil and the soil water. This in itself is an extremely complicated affair in view of the many processes going on. The SMASS model, although a fine example of scientific work, is not capable of prescribing implications when applied in practice in the field and a disclaimer of this sense is mentioned by van Wijk *et al.* (1993). It should also be realised that SMASS is a very large model, demanding a very large quantity of basic data to run and so complicated that it can only be used by specialists. So far, models have not been capable of incorporating the spatial variability, inherent in acid sulphate soils. This variability, as indicated by Burrough *et al.* (1988) and Bregt *et al.* (1993) is of a short range, with commonly used parameters as EC showing extremely high short range variability. SMASS predicts one-dimensional conditions in a soil profile, and extension to field scale is problematic.

From the above can be seen that mathematical simulation models have earned their place in explaining and quantifying processes in acid sulphate soils. Their application is especially useful for knowledge transfer at specialist level and for teaching purposes. The expert and farmers levels cannot yet be advised by them. For land evaluation and land use planning, for instance, they cannot yet be applied. Existing quantitative yield predicting models used in land evaluation (WOFOST, QLE), when applied to the conditions of the Mekong delta, will predict very high potential production levels in view of the favourable climatic conditions in the delta. This top-down approach shows an immense gap between potential and actual production levels on acid sulphate soils. Explanation and quantification of the difference is impossible due to a lack of knowledge on the relationship between the complicated and strongly variable acid sulphate soil conditions and plant performance.

An illustration of this problem is given by Hoa and Guiking (1989) when they compared yield predictions made by the model QUEFTS (Janssen *et al.* 1989) to yields from N-P-K fertiliser trials on non-acid soils in the Mekong delta, after adjustment of the model to be suited to rice. Actual yields (on non-fertilised plots) varied between 30-140% of the estimated yield. For the fertilised plots similar problems occurred. The model predicted effects of phosphorus at all levels of application, but the actual field experiments only showed no more effect at applications over 30 kg P_2O_5. It was concluded that another limitation had taken over.

Mathematical modelling has received some extra attention in this text because the expectations of this type of research are very high, while the answers it can give are still relatively few. It might be advisable to tune down the high expectations and to let the mathematical modelling play a role in answering certain, well selected key processes of which already now is known, through other research, that they hold a promise (Bouma *et al.* 1993). An example might be the optimisation and mathematical modelling of leaching with fresh water of the surface soil prior to cultivation, which is repeatedly mentioned as an effective way to improve raw acid sulphate soils (van Breemen, 1993; Tuong 1993). Such research should be connected to periods of high surface water run-off, so that the acidity in surface waters is diluted. A second example is the study and mathematical modelling of moisture availability to some of the recently introduced dry land crops such as yam and sweet potato. Such types of work may come up with clear recommendations to experts and farmers and can be more useful than an all-encompassing model.

6. Knowledge on environmental problems of acid sulphate soils

The detrimental effects of injudicious land reclamation were frequently reported and warnings were often given (e.g. Gora Beye 1973, Brinkman 1982). Those reports, however, limited their message to the difficulties of reclamation, the limited land use possibilities and poor crop performance, not so much the environmental effects it might have. Dent (1986) listed the detrimental environmental effects of ASS reclamation: loss of wetland habitat, loss of amenities, changes in sedimentation or erosion patterns, unfavourable changes in water chemistry and diseases.

Environmental problems received attention for the first time during the Ho Chi Minh City symposium. Callinan *et al.* (1993) and Willet *et al.* (1993) reported seasonally recurrent fish mortality and disease in Australian estuaries which were associated with drainage of sugar cane fields in acid sulphate soils. Palko and Yli-Halla (1993) presented a straightforward model, successfully linking the surface percentage acid sulphate soils to the total acidity of the drain water in rivers. Environmental problems are still a specialists' subject although some of the work presented can be applied by experts.

D. Other aspects of knowledge applicability

Most scientists use specialised knowledge and methodologies to generate new knowledge meant for other specialists. When reviewing the Dakar and Ho Chi Minh City symposia (see Table 3.2 and 3.3) it seems that most scientists continued along the same lines as during the Bangkok symposium. Dakar (Dost 1988) showed two (out of 18) papers covering social and economic aspects of acid sulphate soil reclamation. These papers collected information from farmers to bring across a message to specialists. Van der Klei (1988) uses information collected from Diola farmers in Casamance, to convince the specialists and experts that the problems of acid sulphate soils reclamation are not only technical, but are largely due to economic and political reasons: the farmers prefer to grow cash crops instead of mangrove swamp rice, and the young generation disappears to the city and does not take over the duties from their parents. Contrary to this there is political pressure from the central government to make a large reclamation project succeed, while the local Diola population is not interested. Doyen (1988) explains the multiple values of the mangrove ecosystem for fellow scientists and experts, partly based on the activities of local farmers' and fishermen.

Some specialists try to generate knowledge in such a way that it can be directly applied by farmers. An outstanding example is the reclamation method for fishponds in tidal lands in the Philippines developed by Brinkman & Singh (1982), further elaborated by Singh (1982a, 1982b), which was applied extensively by farmers and followed up for its performance (Singh *et al.* 1988, Ligue & Singh 1988). Other examples are the work of Hanhart and Ni (1993) giving directly applicable recommendations for rice cultivation on severely acid soils, and the integrated research of Kselik *et al.* (1993) which presents readily applicable recommendations for experts and farmers.

E. The VH 10 Can Tho/Wageningen model for exchange of knowledge on acid sulphate soils between specialists, farmers and experts.

Out of the 7 papers presented at Ho Chi Minh City incorporating farmers knowledge, five were from Viet Nam. These reports were generated through the project VH 10 (Viet Nam - Holland 10), a project of co-operation between WAU and CTU. The researchers involved gave the incorporation of farmers knowledge a high priority. They recognised a great need for straightforward, farmer applicable recommendations, and gave research resulting in such recommendations a high priority. A the same time they realised that for several generations, farmers have tried, by trial and error, to overcome the problems of their land. Many failed, but many also succeeded in finding their own solution for their own conditions. Studies of existing farmers' techniques for the improvement of these soils have been high on the priority list of project activities and have been extensively reported (see land use and farming systems).

The CTU University itself has intensive links with the provincial authorities and their extension services (leading staff of the extension services usually studied at CTU University), with farmers co-operatives, state farms and individual farmers. This network was initiated by the CTU Faculty of Agriculture since 1976, *i.e.* soon after the end of the Viet Nam war in order to assess the problems of the local population (Xuan 1986, 1989).

Dutch staff has tried to contribute to this network in the acid sulphate soils areas, by visiting the provincial and district authorities, numerous state farms, co-operatives and individual farmers. Staff members of CTU frequently carry out work like soil surveys, hydrological surveys, deep well studies, design of irrigation schemes etc. for local (district) and provincial authorities. Delegations from all provinces frequently visit the University, asking for advice. The majority of the students at CTU are from the rural areas of the delta.

The wide network of contacts is a good basis to assess the needs of the rural population, to determine the priorities in research and the proper locations for it to be carried out, and also for dissemination of research results back to the rural population. The working model used thus consisted of (1) a research nucleus at CTU with all necessary laboratory facilities; (2) a field research station at which, under more or less controlled conditions, research was carried out; (3) a number of field stations where research findings, first tested at field scale in the research station, were tried out under farmers' conditions in co-operation with local/district/provincial extension services and advanced farmers interested in applying the newly developed techniques and finally (4) farmers' fields. The people engaged in this working model are the specialists at CTU University, the various experts such as agricultural and forestry staff in extension services, or local engineers in district and provincial planning offices and the farmers.

It is difficult to quantify the effects of this "farmer-expert-specialist model". In the early and mid eighties most contacts were with the large scale state farms which were established on acid sulphate land after the end of the Viet Nam war. At that time it was difficult to pass on the research findings because they often prescribed measures on a scale of one hectare or less, which was necessary in view of the immense short range variability of the soil/hydrological conditions. These findings were not appreciated at large scale state farms, thousands hectares in size. Since the economic liberalisation and privatisation of agriculture, which started in 1988, the findings are applied by individual farmers. Most spectacular is the application on thousands of hectares of the double-rice system as described by Hanhart and Ni (1993). Their method was filmed, translated for farmer application and shown on local TV. The VH 10 Can Tho - Wageningen farmer-expert-specialist model is described in detail in the following chapter of this thesis.

V. CONCLUDING REMARKS

The acid sulphate soil research community is widening its research scope and has started to incorporate other sciences besides soil science. The danger exists, however, that the newly acquired knowledge will only reach fellow scientists if this research is not followed up by systematic translation towards farmers conditions and a supportive system of extension to bring the knowledge to the farmer. Particularly in acid sulphate soil research the scientists have an obligation towards the poor farmers since "uniquely the problems of acid sulphate soils have been brought about by land reclamation" (Dent and van Mensvoort, 1993). The VH 10 Can Tho / Wageningen model, as handled in the Mekong delta may stand out as an example of this integrated specialists-experts-farmers approach.

Soil specialists should try to generate their knowledge in such a way, that it can be applied at expert and farmer levels. There is a need for knowledge-based decision-support systems enabling decision makers (*i.e.* farmers, experts and specialists) to gather and make proper use of land information they need to make wise decisions about land use.

Chapter 4:

THE VH 10 MODEL FOR CO-OPERATION WITH THIRD WORLD UNIVERSITIES

I. INTRODUCTION

Universities in third world countries are often assigned heavy responsibilities with regard to their role in society. The World Bank (1988 expects these universities to (1) prepare people for high-level scientific, professional, technical and managerial jobs; (2) generate knowledge and innovation for development through research done by the universities themselves but also by acquisition and dissemination of knowledge from elsewhere, and (3) provide services needed for development through outreach activities and consultancies.

Unfortunately, many universities in third world countries appear as fountain-heads with a tendency to concentrate on fundamental research (i.e. research that creates knowledge for understanding) and show less interest in applied research *i.e.* research that translates fundamental knowledge into knowledge for action (van den Bor & Fuller 1984). Besides, universities simply lack staff, funds and mandates to face such massive tasks.

Universities in third world countries might well have relatively easy access to development assistance funds. Universities are institutions with a relatively well trained staff of academic (often western) education, mastering of foreign languages is no problem and access is easy for potential donors. This relatively easy access to funds makes University co-operation an important form of development co-operation.

Selvaratnam (1988) describes pros and cons of university co-operation between developing and developed countries. He mentions the following merits:

1. the building up of institutional and organisational capability;
2. the establishment of new teaching and research institutions;
3. integration of higher education in national, regional and local culture;
4. relief of manpower shortage and the emergence of an intellectual, skilled and technocratic community trained in developed countries;
5. reduction of dependency on foreign expertise and staff;
6. greater access to international journals and other literature and the growing use of English as an international scientific language.

The co-operation, however, has, according to Selvaratnam, an equally long list of setbacks.

1. the co-operation could be an instrument in the hands of developed countries to control and manipulate the institutions in developing countries;
2. curricula might develop that bear little or no practical relevance for the community outside the university;
3. one-sided establishment of centres of excellence in the developed countries;
4. the creation of an academic establishment with views alien to the needs of the developing countries: "carriers of cultural and scientific imperialism";
5. research conducted for acquiring individual knowledge and not in line with research needs of the local community in the country of origin.

The subsequent text describes the situation of the University of Can Tho, a relatively small university in the agrarian society of the Mekong delta, Viet Nam. Over the last 20 years it faced tremendous constraints in terms of funds, trained staff and access to foreign assistance. This University, and particularly its Faculty of Agriculture, has decided to place emphasis on its role in local rural society, the third merit mentioned above.

Government sponsored programmes of co-operation between Universities in the Netherlands and their counterpart institutions in third world countries have been carried out through NUFFIC (the Netherlands University Foundation for International Co-operation) since 1968 (NUFFIC 1978). A programme of co-operation between Dutch and Vietnamese Universities was started in 1980. Seventeen projects were proposed out of which 12 were actually started in 1980. One of these projects, encoded VH 10 (Viet Nam-Holland project number 10), was entitled "Research for the management of acid sulphate soils in the Mekong delta" and was a joint activity of the Universities of Can Tho and the Wageningen Agricultural University. The project continued from 1980 till the middle of 1992.

This project is described in detail in this text with emphasis (1) on the rather unusual way it was organised and (2) on the way it supported the CTU in its responsibilities towards the rural population of the Mekong delta. Most University co-operation projects focus their goals towards strengthening university departments by curriculum development and provision of equipment for teaching. VH 10 included such activities, but placed a much stronger accent on applied research, outreach activities in the field involving interaction with individual farmers, farming communities, local and provincial authorities. Research results were disseminated through workshops which were attended by these user groups and which were shown on local TV.

Through decades of training many capable, well trained specialists are present in third world countries, particularly in universities. Still, in development co-operation in general, responsibilities for projects have generally been assigned to project managers from the "first world". University co-operation projects seem particularly suitable to shift much more of the responsibilities to the third world Universities. In age and professional experience the third world experts are often superior to "first world" experts. The VH 10 project has, throughout the 12 year of project duration, left a large share of the responsibilities in Viet Nam.

It may now seem as if this sharing of responsibilities has been a deliberate policy from the start of the project. That is incorrect. In the original project proposals a full time project co-ordinator was foreseen, but this was rejected from the Vietnamese side. The main reason is simple: in 1980 Viet Nam did not allow foreigners to stay longer than 6 months of a year in Can Tho. This automatically implied that for at least half the time the project had to be executed by the Vietnamese counterparts themselves.

II. CTU, ITS MANDATE AND ROLE IN DEVELOPMENT OF THE MEKONG DELTA

Can Tho University (CTU) was established in 1966 and is the only institution of higher education in the Mekong delta. Originally it had 5 faculties: Sciences, Social Science and Law, Pedagogy, Letters and Agriculture. In those early war-struck years most students were in Law and Letters, one of the simple reasons being that these sciences require little or no expensive teaching equipment. Besides, the unbalanced education also existed because during the war being a student was not so much to acquire knowledge for serving society, but to avoid military service (Xuan and van Mensvoort, 1989).

After the war, from 1975 onwards, the University was reorganised several times, resulting in a structure with three divisions: Agriculture, Teacher Training and Medicine, with respectively seven, five and one Faculty, and a separate faculty of Marxist-Leninist Philosophy, in charge of basic training during the first two years. The VH 10 project co-operated with the Faculties of Agriculture, particularly the Soil Science Department, and with the Faculty of Water Management and Land Improvement, particularly the rural engineering and agrohydrology departments.

At the moment of writing of this thesis (1996) the University is undergoing an intensive reorganisation again. The main objective of this reorganisation is "to meet better the demands from society" (Duong, 1995). The reorganisation is inspired by the fast changes in society which have taken place in Viet Nam since the introduction of "doi moi", the economically more liberal policy, in 1986. Universities are no longer completely sponsored by governmental funds, with scholarships for every student and without tuition fees. CTU trains students to a BSc level in a four years curriculum with the exception of medicine, which takes 6 years.

The University of Can Tho as a whole, and the Faculty of Agriculture in particular, has strong links with the rural society in the Mekong delta. These links were initiated soon after the end of the Viet Nam war. The Faculty took it as its duty to assess the problems of the rural society and seek for ways to assist. The discussions with farmers and local leaders were a "give and take" process (Xuan 1986), an approach similar to Participatory Rural Appraisals and was helpful for both the university and the farming community. It helped in identifying research priorities.

The links of CTU are at various levels. They are with provincial and district authorities and their agricultural extension services (virtually all staff of the extension services are graduates from CTU), but also by means of a co-operative programme with key farmers throughout the delta. These farmers co-operate with the University by testing of new planting materials or farm management techniques. The strong imbedding in the rural society is also shown by the fact that virtually all students are farmers children and that the students of the CTU Faculty of Agriculture have a one year compulsory practical period, in which they carry out a thesis research subject, often at their fathers' farm or the farm of a relative.

III. SUPPORTING THE ROLE OF CTU IN THE RURAL SOCIETY OF THE MEKONG DELTA THROUGH THE VH 10 PROJECT

The goal of the VH 10 project was to develop practical methods for improving the use of acid sulphate land. This goal implies a heavy emphasis on applied research and a relatively limited role of specialised fundamental research. Van Breemen (1976) had written the theory on the chemical processes and the solute chemistry in acid sulphate soils, and supplied a brief "agronomists view" on how the land could be used better. The VH 10 project tried to translate the fundamental knowledge into applied research. In the early part of the project research was carried out by means of a science-driven, top-down approach, concentrating on the survey, inventory and processes of formation of the Vietnamese acid sulphate soils and on experimentation in a field station, designed and constructed with facilities for complete soil and water management and suited for field experiments. The station was thought to become the central focus of all field research, bringing solutions that could be extended to areas of the delta with hydrological regimes similar to the ones experimented upon in the station.

There are, however, cases in which the theory with which Dutch experts were familiar when going to Viet Nam, could not be applied. Also there are striking examples of the unexpected knowledge present with Vietnamese farmers. Some examples are given below.

The most striking example of missing fundamental knowledge is probably the fact that in large parts of the Mekong delta the most conspicuous morphological feature of acid sulphate soils, the pale yellow mottling of jarosite, is absent. This has lead to situations in which soils were thought to be non-acid, but turned out to be chemically similar and just as difficult to cultivate as "normal" acid sulphate soils with yellow mottles (van Mensvoort and Tri, 1988).

In its first phase, 1980-1983, the project foresaw the construction of a field research station, specially designed and constructed for applied acid sulphate soils research (Stamhuis, 1982). This station was constructed at Hoa An, about 35 km south-west of Can Tho City. The project had high expectations of this station. The station was constructed in such a way, that a wide variety of hydrological regimes, as they occur in the delta, could be simulated and tested. The layout of the station showed three main compartments: a deep flooded, a shallow flooded and a deep drained part. Full control of all water management aspects such as irrigation/drainage of the entire station and irrigation/drainage per field, evaporation, controlled water levels in the fields, oxidation/reduction status of the soil were incorporated in the design. The station was designed with a surrounding dike for complete water control and with high lift pumping stations. With financial support of various provinces in the delta and labour inputs by staff and students of CTU the station was realised.

It turned out impossible, however, to convince the Vietnamese counterparts of the need to perform complete water management of the entire station. To them it was an insurmountable problem to pump water over a high dike surrounding the station and pump it out again at the drainage side, while the station was surrounded by surface water having tidal movements, which could be used for irrigation. The surrounding dike was never closed, and tidal water was used for irrigation and drainage in order to save petrol for the pumps. This resulted in experiments which might just as well have been carried out in a station without a surrounding dike.

The station at Hoa An has been used intensively for a large number of experiments for about ten years, and mainly yielded results on fertiliser application and variety trials (Ren *et al.* 1993). However, it never met the high expectations raised in the beginning of the project. Over the years more and more experiments were carried out in farmers fields, since the station could only offer the hydrological and soil conditions of Hoa An, not of other places in the delta. The nearness of Can Tho, however, made it remain a suitable place for experimentation, but not as all-encompassing as expected.

There was, however, a much more important reason to move away from the Hoa An station. Half the Mekong delta is hampered with the problems of acid sulphate soils and the need for simple field methods for improvement of these soils is great. Contrary to what was expected before the start of the project, from old times, farmers have tried, by trial and error to overcome these problems. Many failed, but many also succeeded in finding their own solution for their own conditions. Vietnamese farmers turned out to use their land for a much wider variety of crops and land/water management practices than presumed possible. These farmer solutions to solving the management problems of their land became apparent during the soil survey activities in the early years of the project. This local knowledge was new to the Dutch specialists. It was decided to include field research based on the farmers' techniques for the management of these soils. Gathering the farmers' knowledge, widening it by experimentation in farmer fields based on this knowledge, and extrapolating/disseminating the newly acquired knowledge to other parts of the delta became the key research activities of the project.

Although having to cope with low yields, difficult land and a poor income, farmers succeeded in growing crops such as yams, sweet potatoes, cassava, pineapples, bananas, sugar cane and cashew nuts on some of the worst soils of the delta (Vo Tong Xuan 1993). Double cropping systems of rice in the wet season and shrimps in the dry season are found (Xuan *et al.* 1986), or irrigated yams in the dry season and rice in the wet season (Durang 1994, Tri 1996). Land management techniques such as raised bed building, zero-tillage (Xuan 1994, Henstra, 1995) and the shallow drainage system to speed up de-salinisation in the early rainy season (Xuan *et al.* 1982) were unknown to Dutch experts. With all these practices present at farmer fields, it was much more rewarding to move there instead of concentrating the experiments in a single research station.

Finding the information on local techniques of land and crop management in acid sulphate soils was only possible thanks to the intricate network of contacts of CTU throughout the delta. The provincial and district authorities, and especially their agricultural extension services, actively participated in knowledge generation and transfer. They provided funding and staffing of field experiments, they sent their staff to Can Tho for training, were often the source of farmer knowledge to the VH 10 staff, and organised meetings with farmers to transfer the VH 10 knowledge to the farmers.

The VH 10 project thus profited from the VH 10 network, but at the same time it reinforced it. Dutch specialists could bring their fundamental knowledge on acid sulphate soils to Viet Nam, passed the knowledge on to the local experts and farmers, and discussed practical problems of land use with these user groups.

IV. SPECIAL CHARACTERISTICS OF THE PROJECT ITSELF

In this section a number of elements are described which were important to the VH 10 project, but which may not be found in many other projects.

1. Project Continuity

The project continued for twelve and a half years. Although this may not be necessary for all projects, it is a great asset when long-term activities such as staff training or building of faculties or departments at Universities are involved.

- Both from the Dutch and the Vietnamese side, the same people remained responsible for the entire duration of the project. Long-term contacts with the same people enhance the mutual feelings of responsibility, dedication to the cause of the project and mutual trust. The fact that no Dutch staff was permanently stationed in Can Tho may well have contributed to the long term involvement of most Dutch staff. One may wonder whether expatriate staff, residing in Can Tho, would have remained attached to the project for such a long period.
- Almost all counterpart staff remained involved throughout the project period and continued their activities in the same field thereafter. Counterparts all (but one) went back to Can Tho after completing their studies abroad. The VH 10 project sponsored ten MSc studies in fields related to project research. The fellows remained in close contact with their home country by letting all of them go back to Viet Nam to carry out the field research for their MSc theses.
- One of the attractions of staying at CTU was the participation in local consultancies carried out by Can Tho staff after their graduation abroad. Staff of the soil science department and water management faculty have, over the last 10-12 years, taken part in numerous consultancies, both for local provinces, districts or co-operative farms, and as consultants to international agencies such as Non Governmental Organisations, the Mekong Committee or the World Bank. This not only provided them with the necessary extra income on top of their monthly salary, but also made them realise that CTU is the only place in the delta where local knowledge is sought by these agencies when they are in need of local consultants.

2. Mutual interest

The project was not called "Curriculum development and supply of facilities to CTU, but "Research for the management of acid sulphate soils". The subject is of interest to both the donor and the receiving partner. The problems addressed in the project is also recognised by the local populace, which makes it possible to get support from local authorities in the receiving country. Clearly pointed questions to specialists in the donor country are much more challenging than general requests for lecture courses, general curriculum development or staff training requests.

3. Limited multidisciplinarity

At the start of the project, the fundamental knowledge on the project's subject was present at one department of AUW, the department of Soil Science and Geology. The applicable knowledge that needed to be generated, was of a much wider nature, needing inputs from other departments as well. Multidisciplinarity, therefore, was only present in a sense that one department, where clearly the most knowledge was present, was leading, but that additional inputs from other departments were also necessary. This particularly applies to the water management aspects of the acid sulphate soils problemacy. From the start, it was realised that water management is the key to improved land use on acid sulphate soils (van Breemen, 1976), but expertise was not present. Water management experts needed to acquire the complicated chemical knowledge on the soils, which was offered to them by the soil scientists, before they could devise appropriate measures.

4. No experts permanently stationed in the recipient country

Throughout the project the maximum presence of Dutch project staff was about 6 months of a year, while in most years this was only 3 - 4 months. Such a staffing situation has one major advantage: most of the time the work needs to be carried out by local project staff and decisions have to be taken within local infrastructures and hierarchies. Permanently stationed foreign experts may easily have the tendency to create their own hierarchy which often stands perpendicular to existing local hierarchies, but is accepted because the foreign expert "is the project". For the duration of the project such deviating hierarchies may be accepted, but will easily be discontinued the moment a project terminates. The VH 10 project indicates that it might be well worth giving preference to projects in which experts from donor countries are guiding and directing projects, but not actually execute them. The sense of responsibility and involvement of the receiving partner's project staff is strongly stimulated.

5. The principle of learning from each other:

There has been an initial period of two, three years in which the main activities concerned transferring knowledge from the Dutch to the Vietnamese. At that time, acid sulphate soils were a specialism of Dutch soil scientists, who had a world wide reputation in this field of work. Later, however, the core work of the project was to carry out applied research in order to solve problems faced by farmers and other users of this difficult land. Problem identification in the field, gathering of indigenous knowledge from farmers and translation into field experiments became more and more important. This work used mutual equality as a principle, meaning that there was as much to learn from Vietnamese farmers and scientists for the Dutch as there was for the Vietnamese to learn from the Dutch.

6. CTU's intricate network of local contacts

CTU's deliberate policy to create, maintain and use an intricate network of contacts with the rural population at various levels (provinces, districts, state farms, co-operative farms and individual farmers) cannot be left unmentioned when discussing special aspects of the project. For the project this network was, indeed, a lucky strike. It provided local knowledge, locations for execution of experiments, local financial and labour support, a way to disseminate knowledge, and places to stay for staff and students.

7. Special research set-up: farmer and expert side by side.

VH 10 objectives called for applied research, carried out in such a way that transfer of the acquired information to farmers is possible. The research was carried out at various levels.

- Level I: Laboratory and greenhouse experiments under relatively well controlled conditions at CTU. Such experiments are, for instance, tests on the performance of crops in the greenhouse using acid sulphate surface soils from the delta (Ren *et al.* 1993), experiments testing the speed of reduction/oxidation of various types of acid sulphate soils, and test on improving soils with salt and brackish water (van Mensvoort *et al.* 1991).
- Level II: Field experiments carried out at the field in Hoa An station, a field research station, designed for applied acid sulphate soils research (Stamhuis, 1982). As explained earlier, the project had high expectations of this station, but it turned out to be unmanageable at least in

the way it was originally intended and experiments were tuned down to set-ups which might just as well be realised outside the station. Still, with the infrastructures present, experiments on land management for rice could be done at the station. Examples are: tests on frequency of irrigation and drainage, optimum surface water levels and drain spacing (Hanhart and Ni, 1993), fertilizer trials (Ren *et al.* 1993), and variety trials.

- Level III: Experiments in farmer fields and state farms were carried out to apply techniques (based on farmer knowledge and specialists knowledge) under practical field conditions. Examples of such research are trials on the optimal methods of constructing raised beds for upland crops (Sterk 1993, Nga 1993, Tri 1996, Minh 1996) and the work done on optimisation of the water management for rice cultivation on acid sulphate soils (Hanhart and Ni 1993).

This research set-up makes it possible to translate findings from the laboratory or the research station to farm level trials and vice-versa.

V. PROJECT ACTIVITIES: MANAGEMENT, INFRASTRUCTURAL PROVISIONS, TEACHING, RESEARCH.

1. Research policy

The inventory of existing farmer's techniques for the improvement of the acid sulphate soils has been high on the priority list of project activities. The intensive links of the CTU, as described before, with the provincial authorities and their extension services, with farmers co-operatives, with large scale state farms and with individual farmers could be utilised intensively. VH 10 staff have tried to contribute to an extension of this network in the acid sulphate soils areas, by visiting the provincial and district authorities, numerous state farms and co-operatives. Staff members of CTU frequently carried out work such as soil surveys, hydrological surveys, deep well studies or the design of irrigation schemes for local (district) and provincial authorities. Delegations from all provinces frequently visit the University, asking for advice. Dutch VH 10 staff sometimes contribute to these activities. The majority of the students at CTU are from the rural areas of the delta.

The wide network of contacts is a good basis to assess the needs of the rural population, to determine the priorities in research and the proper locations for it to be carried out, and also for dissemination of research results back to the rural population.

2 Research protocol

Creating facilities (in manpower and equipment) for research, and giving a start to a research programme was the prime activity during the first phase (1980-1982) of the project. The training aspects of the project during that phase (training of laboratory staff, introductory courses given by Dutch scientists in Viet Nam) were meant to create a group of scientists capable of carrying out research activities. Once the necessary infrastructure was provided, the research activities were started in the course of 1982. It was then thought necessary to agree with the Vietnamese counterparts on a research protocol, with procedures for research planning and decision making.

The contents of the protocol were as follows. The protocol limits the activities strictly to research areas of importance for the project, describes those research areas in detail (soil characterisation and identification, soil and water management, fertilisers and other chemical amendments, variety selection, cropping systems research and soil physics) and sets a number of priority subjects.

An annual time schedule is proposed to decide which research experiments will be carried out during a particular year. The protocol also gives the criteria for a priority sequence, based on scientific significance, practical relevance and feasibility of research proposals. The protocol also takes into account the financial possibilities at CTU, states how the co-ordination and the execution of the research work should be carried out, and gives some rules for the use of the experiment station. Formats are given for research proposals, and for research reports.

3. The nature of the research

The objectives of the project indicate a strong accent on applied, problem solving research. This is imperative. The Vietnamese society faces numerous difficulties, the unstable food supply being one of the most crucial problems. The University of Can Tho, the only institution for research and higher education based in the Mekong delta, regards it as its duty to carry out research that is based on the needs of the rural population. This, of course, is a beautiful sentence, and reflects a respectable philosophy. But this does and cannot imply, that during the years of research every experiment carried out within the VH 10 project should absolutely reflect this philosophy. Scientists often feel safer within the limits of fundamental research. Problem solving research often is "black box"-research: a problem is faced, a possible explanation for the problem is discussed, an experiment on the basis of the theoretical hypothesis is designed and executed. The subject of the VH 10 research, however, is very complex. Many factors of a chemical, physical, biological, or hydrological nature play a role, and it is usually impossible to keep all these factors under control. The results of any experiment, regardless whether they are positive or negative, run the danger of being attributed to the wrong factor. This danger may be biggest when positive results are obtained: the theoretical explanation used as a basis for the experiment will immediately be embraced as the right one. One of the main duties of the research management in the VH 10 project was therefore to try to safeguard the independent and scientific problem-solving approach to the research.

VH 10 is essentially a technical research project, trying to find technical solutions to agricultural problems. The research work in the project covers a number of technical sciences. The nature of the research is such, that simple, low-cost solutions should be found which can be applied on farm scale. It was not strictly one of the goals of the project to take care of the dissemination and large scale application of results obtained. However, the way in which research was embedded in the local network of contacts guaranteed dissemination.

4. Some special aspects and bottlenecks of the VH 10 research

Problems encountered in carrying out research in Viet Nam are in no way different from many other places: few technical means; no possibility for importation of equipment outside the context of foreign projects because of lack of funds and economic isolation; shortage of staff with the present staff regularly "invited" to carry out urgent jobs for others; heavy bureaucracy; emphasis on "parrot teaching" partly because of lack of materials.

A large portion of the experiments in the VH 10 project are carried out by both Dutch and Vietnamese undergraduate students. A major advantage of this system is that workers are strongly motivated. But the system clearly has also disadvantages. The students lack experience, and should be supervised very strictly. When the experiment is done in the laboratory at CTU, this strict supervision can be given, but if the student carries out a field experiment in a remote place, or even in the VH 10 experiment station, some 40 km from the CTU campus, this supervision is often not strict enough. This has lead to situations in which the students had to take decisions without consulting their supervisor (when to irrigate, when to apply crop protection) or that decisions were taken by the station manager which were not in line with the experimental set-up with the student powerless to go against these decisions. After long debate it was finally agreed upon that Dutch AUW students could spend their practical period at CTU. Early 1986 the first two students went to Viet Nam.

Language was a serious problem in the VH 10 project. Most senior Vietnamese staff speak sufficient English or French. But the junior staff members trained since 1975 have had rather poor language training and no chance for practice whatsoever. It is a major stumbling block for entry into courses abroad. All courses given by Dutch lecturers and lecture notes have to be translated sentence by sentence. The language problem also makes the Vietnamese hesitant to write research proposals and reports in English. CTU students produce their thesis in Vietnamese. The staff member in charge of guidance is expected to make an English summary, giving the goals, methods and results of the experiment, but these summaries usually were strongly delayed or did not materialise at all.

VI. THE SHIFT FROM COLLECTIVE AGRICULTURE TO A FREE MARKET ECONOMY AND ITS CONSEQUENCES FOR THE PROJECT.

After the reunification in 1975 the Vietnamese government decided upon a plan for collectivisation of agriculture in Southern Viet Nam. One of the foundations for this collectivisation was an inventarisation of the land. It was the Southern Branch of the Institute of Planning which was charged with this task. The inventarisation resulted in soil maps, and also gave the Institute a picture of land use. Large tracts of land were not used at all or only very extensively and seemed ideal for the establishment of large scale state farms. At the same time these unused lands, however, suffered from acid sulphate and salinity problems. The government had no intentions to completely collectivise the intensively used land near the Mekong river branches. Reasons for this were: (1) land reform programs had already been carried out by the former South-Vietnamese government. Redistribution of land with numerous small holdings of often less than a hectare was the result. To some extent, these programmes had already given land to the landless. (2) Collectivisation might have caused big problems for the government as it had already experienced in northern Viet Nam where, after the end of the colonial war against the French, the collectivisation of the Red River delta had lead to hunger and starvation for millions of people (Tezenas du Montcel 1957). Some form of collectivisation was, however, practised in most villages, making them strongly resemble the "kolchoze" type of collective farm. Farmers were expected to perform all work in groups. This, however, has been an age old custom in the delta. More important was the strict system of yield control and interference by provincial and district authorities as to what the farmers should grow on the land. Farmers were pushed into growing rice, the only produce under tight market control by the government. Faced with fixed, low prices and heavy taxes in the form of a share of the yield, farmers were discouraged and production became very low.

The empty lands seemed ideal for the purpose of establishing state farms. There were virtually no people living there. Here were large tracts of flat land, with plenty of water in the rainy season. Furthermore, these lands had been hideouts for the Vietnamese resistance forces during the war and thus deserved help from the central government. After the war there was a mood that (as stated by a proud state farm manager in 1980) after beating the Americans, it would be very easy to beat the acidity and salinity of the land. Others were inspired by one of Uncle Ho Chi Minh's most famous aphorisms: "every square meter of the land should be used to the full for the benefit of the people".

Various governmental institutions were responsible for the farms. Soon after 1975 the national army came to help in establishing and running some of the state farms and assisted in canal excavation for other farms as well. Other farms were under the direct responsibility of the Ministry of Agriculture. In every province farms were established under the responsibility of the agricultural service of the provincial government lead by the provincial people's committees.

Some 60 large scale state farms, varying in size from 3,000 to 10,000 hectares were established. All of them were of the "Sovchoze" type, i.e. state farms with complete control of all activities by the leadership of the farm. Sometimes romantic farm-names referred to the peaceful and quiet character of the place (Quyet Thang, Do Hoa) but they were more often prosaically numbered (Ha Tien 13) or named after the numbering system of the canals (85B). The total area of all state farms together was about 300,000 hectares. It is relatively easy to draw large scale state farms on maps in an office, but it is much more difficult to staff and equip them, and even more difficult to turn them into profitable enterprises. In the years immediately following the reunification of the land (1976-1979) many citizens from Ho Chi Minh City were forced to work on these state farms, digging canals and making raised beds. The farms became known as the "new economic zones". Most labourers returned to Ho Chi Minh City at the end of 1978 when an extremely high flood in the rainy season chased them from the land.

State farm managers almost exclusively came from northern Viet Nam. Most of them were from the military ranks and had been given special training in the USSR but did not know what to expect in the Mekong delta. Many of them were quickly disillusioned when faced with the remoteness of the farms, the difficult access to their land, the lack of staff, the lack of knowledge on the land, the poor land and poor crops and, simply, because they were no farmers.

The central government supported the farms with equipment. A contract with an Austrian firm resulted in the purchase of 600 expensive tractors (200 HP) and a maintenance factory in Can Tho. Big machinery such as ploughs and other soil tillage equipment matching these tractors was also purchased, and distributed over the farms. In most cases the equipment was permanently kept outdoors, badly used, poorly maintained, resulting within a few years in rusty heaps of steel.

Staffing was a problem. Most farms were grossly understaffed. There were plans in the early eighties to move a million people from overcrowded provinces in the Red River delta to the Mekong delta to staff the state farms. These plans were never realised, but radio campaigns, encouraging parents in the North to send their young adult children to "the poor, underdeveloped South" met with some success. A few thousand poor, ignorant youths were trapped for years in remote state farms with military discipline, hard work, and extremely low salaries.

Running the farms was a different story altogether. Most farms, even late into the eighties, used only a small portion of their land for cultivation simply because they lacked staff to do more or had learned the hard way that large parts of the land were unusable: crops failed completely. There are many stories of failures and few stories of successes. One farm decided to use an aeroplane for sowing deep water rice at the onset of the rainy season. There was no staff to harvest it. Some farms needed to be completely rebuilt every dry season because the thatched housing was washed away every year by the flood. In most cases tractor drivers were paid per hectare ploughed land, resulting in quick, rough work with a very uneven surface. This is a guarantee for a poor rice crop.

With the introduction of the "doi moi" policy in 1986 of economic liberalisation, the state farms also slowly started to change. The strict "sovchoze" system was increasingly abandoned and was replaced by "kolchoze" types of collective farms with much more responsibilities and freedom to decide for the farm workers themselves. In most farms the central management changed into an administrative unit, offering central mechanised facilities for ploughing, harrowing or harvesting, which could be hired by the farm workers. In many cases the farm administration also made contracts for purchase of the produce, which the farmers could take or leave at their wish. It depends strongly on what kind of crops are produced whether farmers take this possibility or not. For highly industrialised crops such as pineapples (produce is mainly used for canning and juice for export), most farmers choose to sell to the "kolchoze" administration. For produce which can more easily be sold to local markets (rice, wood, sugar cane) most farmers sell individually to middle men.

Since 1990, another aspect was added. Free settlement of individuals into the unused acid sulphate land became possible. This brought about a large number of new settlers, particularly in the northern part of the Mekong delta, in the Plain of Reeds. This area is situated relatively close to the densely populated part of the delta, with cities as My Tho and Long An, and even near to Ho Chi Minh City.

Between 1980 and 1987 the VH 10 project was convicted to Co-operation with the state farms for the field experimentation. The farms were the only places where foreign staff was allowed to stay, but in many cases they were the only place around and the only place where labour was available. Research results were often unacceptable for "sovchoze" type farms because virtually all solutions were small scale solutions. This is best illustrated by the results of Hanhart and Ni (1993), who describe the intricacies of rice cultivation on acid sulphate soils. They prescribe meticulous control over the water as a precondition for successful rice cultivation, with distances of about 15-30 m between ditches. This sort of solutions, of course, are impossible to carry out on a large scale state farm of 5000 hectares with few staff.

In the years between 1987 and 1990, when the economic liberalisation took place, the activities of VH 10 were geared from the state farms towards the private farmers. Not only did they supply a treasure of knowledge to the project, it also became possible to disseminate new knowledge directly to farmers. It is in this period that the knowledge exchange model between farmers, experts and specialists, which was the true strength of the programme, was developed and applied. An example of what happened in some of the acid sulphate soils areas since 1987 is given by Coolegem (1996) who compared changes in land use in the Thanh Tan district, in the centre of the Plain of Reeds, through satellite image interpretation. 53% of the land surface of the district underwent a change in land use, of which half was a change from wasteland or Melaleuca forestry to irrigated rice by small farmers in the dry season. These farmers apply the techniques as prescribed by Hanhart and Ni (1993), further elaborated by Husson *et al.* (1994, 1995), and fertiliser applications by Ren *et al.* (1993).

VII. CONCLUSIONS

The VH 10 project has profited from the strong embedding of the CU Faculties of Agriculture and of Water Management and Rural Engineering in the rural society of the Mekong delta. The network of contacts with provincial and district authorities, particularly the agricultural services has contributed heavily to the project outcome.

The research set-up of the project shifted from a technology-driven top-down approach in the early eighties to a system with a balanced knowledge exchange between farmers, local experts and soil/water specialists. This approach much more successfully generated practical recommendations suited for application by farmers.

The special, unusual organisational aspects of the project: (1) no permanent foreign staff present in Viet Nam; (2) large share of the responsibility for the execution of the project left with the Vietnamese counterparts; (3) long term continuity of the project with the same staff (twelve-and-a-half years); (4) mutual interest in the project objectives for both partners; (5) applying the principle of learning from each other; might be worth considering for application in other projects and have worked positively in the case of VH 10.

The project profited from the political change of economic liberalisation in Viet Nam in the second half of the eighties since the recommendations for improved use of the acid sulphate soils, which turned out almost exclusively small scale recommendations, could much better applied by small farmers than by large scale state farms.

Chapter 5:

TWO CASE STUDIES OF INTEGRATING FARMER, EXPERT AND SPECIALIST KNOWLEDGE ON ACID SULPHATE SOILS

A: Coarse land evaluation of the acid sulphate soil areas in the Mekong delta based on farmers' experience

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B: Present Land Use As Basis For Land Evaluation In Two Mekong Delta Districts

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A. COARSE LAND EVALUATION OF THE ACID SULPHATE SOIL AREAS IN THE MEKONG DELTA BASED ON FARMERS' EXPERIENCE

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I. ABSTRACT

Using the FAO Framework for land evaluation, a coarse land evaluation exercise is carried out for acid sulphate soil zones of the Mekong Delta. The Delta is divided into twelve physical zones based on soil constraints: severe, moderate/slight, or absent acid sulphate conditions; and hydrological constraints: deep or shallow flooding, surface water salinity in the dry season; and the availability of a fresh water source for irrigation.

Nine Land Use Types (LUTs) are described, four based on rice, four on upland crops, and one on forestry. The land requirements of these LUTs are expressed in terms of their tolerance to soil acidity and their hydrological requirements. The relative production in the Mekong Delta and the management practices of the farmers are used as key attributes of the LUTs.

For each soil zone, the present suitability for the nine LUTs is determined, and also the conditional suitability after the most important constraint has been removed (if possible).

The land evaluation exercise indicates, that:

1. Fresh water availability is a crucial factor;
2. Making fresh water available in moderately and slightly acid sulphate soils improves unsuitable land to moderately suitable for irrigated rice and tolerant upland crops;
3. Severely acid land will only become marginally suitable for irrigated rice, but moderately suitable for tolerant upland crops when fresh water is supplied for irrigation;
4. Well-constructed raised beds not only overcome the flood but also improve the soil. Moderately acid soils in areas with low floods become highly suitable for pineapples and sugarcane, provided the period of saline surface water is short or absent.

II. INTRODUCTION

So far, there have been few systematic land evaluation studies of acid sulphate land (Le Quang Tri 1989; Tuong et al. 1991). One of the main reasons is, probably, the complexity and our insufficient knowledge of the most typical land quality, the toxicity hazard. Certainly, the toxic properties of acid sulphate soils and the processes causing them have been studied extensively, but not as qualitative, let alone quantitative, ratings of land qualities. In this study, therefore, the land quality 'toxicity' will be characterized simply by the depth to the sulphuric horizon.

Water management is the key to the improvement of acid sulphate soils (Dent 1986), particularly in areas where lime cannot be applied on large scale. In the Mekong Delta, there are complicated, strongly contrasting but, also, well studied hydrological regimes which determine the possibilities for land improvement. Flood hazard, salt water intrusion and the availability of irrigation water are the most important land qualities used in the study.

When there is not enough reliable experimental data on crop performance, the best source of information is the farmers. The crops they now cultivate have been selected after trial and error. Each of the land use types dealt with here is practised by farmers on acid sulphate soils in the Mekong Delta.

III. THE PHYSICAL ZONES OF THE MEKONG DELTA

For land evaluation, we must delineate a limited number of mapping units that: (i) differ from one another in important constraints for agricultural development; and (ii) are reasonably homogeneous in themselves. Soil and hydrological studies (Vê et al. 1989; Ton That Chieu et al. 1990; Tuong et al. 1991; Tran An Phuong 1990) have been used to distinguish 12 physical zones.

Soil constraints

The two dominating soil constraints are soil acidity and soil salinity. The salinity occurs in two ways. Soil salinity, i.e. a saline saturation extract of the soil, only occurs in a very narrow zone along the coast, and only in the dry season. More important is salinity in the surface water. In a broad zone, especially along the South China Sea, salt water intrudes. In this zone, even soils which are not saline cannot be used for agriculture in the dry season, because there is no fresh water for irrigation. In this study, the salinity of the surface water is used, not the soil salinity. In the Mekong Delta, acidity and salinity may occur to such a degree that the land is unsuitable for crops. In other areas, the soil problems restrict agricultural use to some extent, but do not make it impossible.

The depth to the sulphuric horizon (pH below 3.5 with, or without, jarosite mottles) is used to characterise the land quality toxicity (see Figure 5.1). When it appears within the upper 50 cm soils are dubbed 'severely acid'; between 50 and 80 cm the soils are moderately acid; between 80 and 120 cm slightly acid; below 120 cm no acidity problems need be anticipated. When the groundwater is below 50-60 cm, even severely acid soils will no longer have capillary rise of toxic substances to the soil surface (Tuong et al. 1991), so moderately acid soils will not acidify by capillary rise in the dry season.

Hydrological constraints

A depth of flooding of more or less than 60 cm is thought to be an important boundary in view of agricultural possibilities. A flood over 60 cm strongly reduces the choice of rice varieties (too deep, even for most traditional rices) it also makes it impractical to construct raised beds for upland crops such as pineapples or sugarcane. The beds will need to be very high, a lot of land is lost to ditches and the risk of digging in potentially acid subsoil material is high.

Irrigation water is saline when the Electrical Conductivity is over 4 mS cm^{-3}. A distinction is made between non-saline, dry season saline (up to nine months of the year) and permanently saline (> 9 months) areas.

The availability of fresh water (not meant as a contrast to saline water, but as the physical presence of a canal for irrigation in the dry season) determines the agricultural possibilities during that period. In many parts of the Mekong Delta an intricate canal system is present, leading fresh water to all fields. This is particularly the case near the rivers. In more remote areas or areas with unfavourable soil conditions, the system is less intensive. Often, only narrow strips of land along canals can be regarded as having fresh water available. It is impossible to draw this constraint on a map of the scale used in Figure 5.1, but it is taken into account in the evaluation.

The map

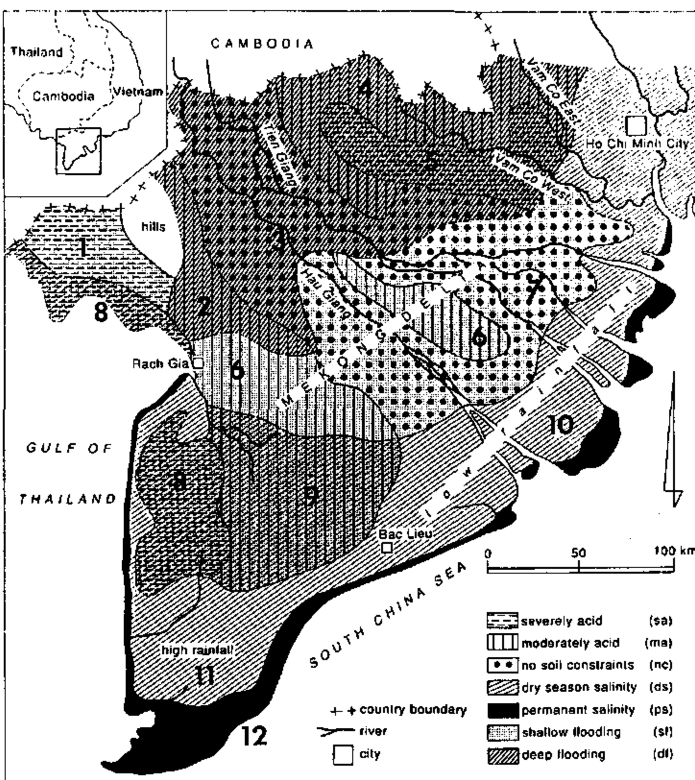

Figure 5.1: Map of land constraints to farming in the Mekong delta

Figure 5.1 shows twelve physical zones, based on present soil and hydrological constraints. The constraints for each zone are indicated in the legend. In the south-western tip of the Delta, mean rainfall is more than 2000 mm year^{-1}, near Ho Chi Minh City only 1500 mm year^{-1}, which falls in a comparatively short period. High and low rainfall separate zones 10 and 11 but these are zones without acid sulphate soils. In this paper, only zones having acid sulphate soils (1,2,4,5,6,8 and 9) are taken into account.

IV. LAND USE TYPES (LUTs)

The land evaluation exercise is carried out for the most important LUTs of the acid sulphate land in the Delta.

Rice LUTs

Naturally, rice LUTs are prominent, and the four most important rice cropping patterns in the Delta are taken into account: *Dong Xuan rice* (DX) - irrigated, dry season, high yielding variety rice, cultivated from about mid December to mid March; *He Thu rice* (HT) - mostly rainfed, high yielding rice, often with supplementary irrigation during dry periods, usually cultivated from May to August; *Mua rice* (MUA) - rainfed, commonly transplanted traditional rice cultivated from May to December; *Deep Water rice* (DWR) - rainfed traditional rice cultivated in areas with a rainy season flood deeper than 60 cm over the soil surface, growth period from May to December.

Other LUTs

Sensitive Upland Crops (SUC) of which soybean, mungbean and maize are the most important. They are mainly cultivated as irrigated crops in the dry season. Recently, these crops, especially the beans, have been promoted by local governments because they are potential export products and can contribute to crop diversification, so they have been incorporated in the present study.

Tolerant Upland Crops (TUC) such as cassava, yam and sweet potatoes are generally planted after the recession of the flood (December) and harvested just before the flood (August). They need irrigation in the dry season. Only low raised beds are needed to increase the thickness of the good soil above the sulphuric horizon and to avoid waterlogging during heavy rains in the early rainy season.

Pineapple (PIN) and sugarcane (SUG) are tolerant of acidity, especially pineapples. They need high raised beds to overcome the flood period and, if well constructed, the beds can increase the depth to the sulphuric horizon. Irrigation is often not practised because of the high beds. Both crops are grown by individual farmers and, also, by large state farms, whereas the above mentioned crops are exclusively cultivated by individual farmers. Sugarcane cultivation discussed here is with ratoons. Some few farmers cultivate sugarcane as an annual crop.

Melaleuca leucodendron (FOR) is planted for constructional timber and firewood. The tree is native and very resistant to soil acidity.

V. KEY ATTRIBUTES OF THE LUTs AND THEIR LAND REQUIREMENTS

Table 5.1 shows the key attributes used in this study. Only the crop production is used and management practices of the farmers. It is realised that others are very important too: economic profitability, environmental impact, water requirements, but these are beyond the scope of this paper.

Table 5.1 Key attributes

1. Relative production in the Mekong Delta		
All crops (% of best yields)	DX rice in t ha^{-1}	Suitability
80 - 100	4 - 5	high = S1
60 - 80	3 - 4	moderate = S2
40 - 60	2 - 3	marginal = S3
< 40	< 2	not = N
2. Optimal Management Practices of farmers		

Table 5.2 indicates the relevance of five land use requirements for the nine LUTs discussed here. Soil acidity is important for all LUTs. Potential acidity is irrelevant for the rice LUTs because wetland rice keeps the potential acidity where it is. It is relevant for the upland crops because raised beds need to be made which might lead to acidification of potentially acid material. The flood is not relevant for DX rice because it is cultivated in the dry season and for DWR because it needs deep flood. It is relevant for all others; even *Melaleuca* suffers impeded growth during a long, deep flood. Fresh water supply is important for all LUTs except rainy season traditional rice (MUA and DWR) and *Melaleuca*. Salt water intrusion is relevant for all except DWR, which is only cultivated in deep fresh water floods.

Table 5.2 Relevant land use requirements of 9 LUTs on acid sulphate soils

	LUTs								
	DX	HT	MUA	DWR	SUC	TUC	PIN	SUG	FOR
1 Soil acidity	+	+	+	+	+	+	+	+	-
2 Potential acidity	-	-	-	-	+	+	+	+	-
3 Flood hazard	-	+	+	-	+	+	+	+	+
4 Fresh water supply	+	+	-	-	+	+	+	+	-
5 Salt water intrusion	+	+	+	-	+	+	+	+	+

+ = relevant
- = irrelevant

Tables 5.3 and 5.4 indicate the extent to which the land meets these requirements in the form of factor ratings for DX rice and sugar cane, respectively. These two crops were chosen as examples because DX rice is getting more widespread in the Delta with high investments for irrigation, fertilisers and crop protection. Sugarcane is chosen as an important tolerant upland crop needing high investment because of raised beds.

For DX rice, only toxicity (as reflected by the depth of the sulphuric horizon), fresh water availability (the crop is cultivated in the dry season) and salt water intrusion influence the yield. Potential acidity plays no role because DX rice does not disturb it. Flooding is not important because the crop is cultivated in the dry season.

Table 5.3 Factor ratings for Dong Xuan Irrigated rice

Land quality	diagnostic factor	S1	S2	S3	N
toxicity	depth sulphuric horizon	>100 cm	50-100 cm	<50 cm	-
fresh water availability	fresh water available in dry season	yes			No
salt intrusion	months saline surface water with EC>4 mS/cm	0	<3	3-4	>4

Table 5.4 Factor rating for sugarcane

Land quality	Diagnostic factor	S1	S2	S3	N
Toxicity	depth sulphuric horizon after construction of raised beds	not present	>100 cm	50-100 cm	<50 cm
Potential acidity	depth sulphidic material before construction of raised beds	>100 cm	50-100 cm	<50 cm	-
Flood hazard	flood depth before construction of raised beds	<30 cm	30-60 cm	60-100 cm	>100 cm
Fresh water availability	fresh water available in dry season	perma-nently	tempo-rarily	no	-
Salt intrusion	months saline surface water with EC>4 mS/cm	<3		3-4	>4

In the case of sugarcane, all land qualities need to be taken into account. With its deep roots, it will easily suffer from soil acidity. Potential acidity will be disturbed during construction of raised beds. Beds need to be over the flood to avoid water logging. A deep flood makes bedding impossible because of loss of land and costs of construction. Fresh water availability in the dry season for irrigation is important, without irrigation sugarcane will only perform marginally. Many farmers in the Delta, in fact, have no irrigation water for the sugarcane. When salt intrudes for a very short period (up to 3 months) it will not harm the crop, but when longer it strongly reduces crop growth, and with more than 4 months, sugarcane is not suited. Similar factor ratings can be made for the other LUTs.

VI. LAND SUITABILITY

Tables 5.5 through 5.8 indicate the suitability of four acid sulphate soil zones in the Delta for the nine LUTs discussed. P/C suitability indicates the present and the conditional suitability, i.e. the suitability under the present conditions and the suitability when the most limiting constraint has been removed. This conditional constraint is indicated in the third column, while the last column indicates the limiting constraint that remains. In case the land becomes more suitable for a certain crop after removal of the conditional constraint, the row is shaded. Full tables are presented for West An Giang (zone 2), Central Plain of Reeds (zone 5), Central Trans-Bassac and North Cuu Long (zone 6) and Central Ca Mau Peninsula (zone 9).

Table 5.5 Zone 2, West An Giang

Crop	**p/c suitability**	**Conditional constraint**	**Remaining constraint**
HT	N/S2	fresh water	acidity
DX	N/S1	fresh water	none
MUA	N/N		deep flood
DWR	S2/S2		acidity
SUC	N/S2	fresh water	acidity
TUB	N/S2	fresh water	acidity
PIN	N/N		deep flood
SUG	N/N		deep flood
FOR	S1/S1		*none*

For zone 4, West and North Plain of Reeds, suitability is similar as zone 2. The difference between the two zones is mainly in the extent to which fresh water is, at present, available in the dry season. This is more developed in zone 2 than in zone 4. The suitability for DX rice is, with continued and skilful land and water management, increased to the S1 level.

Table 5.6 Zone 5, Central Plain of Reeds

Crop	p/c suitability	Conditional constraint	Remaining constraint
HT	N/N		soil acidity
DX	N/S3	fresh water	soil acidity
MUA	N/N		soil acidity
DWR	N/N		soil acidity
SUC	N/N		soil acidity
TUB	N/S3	fresh water	soil acidity
PIN	N/N		acidity, flood
SUG	N/N		acidity, flood
FOR	S2/S2		acidity, flood

Most of the suitabilities for zone 5 (see Table 5.6) are also applicable to zone 1, The Ha Tien Plain. The difference is the flood depth, which makes construction of raised beds possible in Ha Tien. The suitability for pineapples and tolerant upland crops, being the only crops tolerant to the extreme acidity, is only marginal. Another big problem of zone 1 is the difficulty of bringing fresh water there. Clearly zones 1 and 5 are the most difficult, and have few prospects. Zone 6 consists of two areas which are, already, quite intensively used for agriculture. Water conveyance to most farms already exists, which explains why no clear change in suitability can be obtained for the rice crops. In those places where fresh water is not available, construction of secondary and tertiary canals can improve the suitability from N to S2 and, after some years of skilful use, probably to S1. Construction of raised beds is relatively easy and without much risk, because the layer of soil needed to construct the bed is not severely acid. Besides, construction of beds increases the thickness of the non-acid layer. Land becomes highly suitable for pineapples and sugarcane.

Table 5.7 Zone 6, Central Trans-Bassac, North Cuu Long

Crop	p/c suitability	Conditional constraint	Remaining constraint
HT	S2/S2		acidity
DX	S1/S1		none
MUA	S2/S2		acidity
DWR	N/N		shallow flood
SUC	S3/S3		acidity
TUC	S2/S2		acidity
PIN	N/S[illegible]	flood, raised beds needed	none
SUC	N/S1	flood, raised beds needed	none
FOR	S1/S1		none

Table 5.8 Zone 9, Central Ca Mau Peninsula

Crop	p/c suitability	Conditional constraint	Remaining constraint
HT	S2/S2		acidity, salinity
DX	N/N		salinity, acidity
MUA	S2/S2		acidity
DWR	N/N		low flood
SUC	N/N		salinity, acidity, flood
TUC	N/N		salinity, acidity, flood
PIN	N/S2	flood, raised beds needed	acidity, salinity
SUC	N/S2	flood, raised beds needed	acidity, salinity
FOR	S2/S2		acidity

Table 5.8 shows suitabilities for the nine LUTs in the Central Ca Mau Peninsula. This is particularly heterogeneous area in view of all land qualities. Potential and actual acidity are very severe in a number of places, especially in the south-western part. Flooding is not deep. Salinity varies strongly in number of months and concentration. Land suitability is as varied as land conditions and, in general, the zone is a particularly difficult one. Conveyance of fresh water to the zone by large canals, and possibly, pumping stations is under study but needs careful consideration because of the intricate hydrological situation and the ecological vulnerability.

In West Ca Mau Peninsula (zone 8), the area of the U Minh forest and surroundings is very heterogeneous. In the centre is the U Minh peat dome, which is fast getting smaller. Immediately surrounding the peat dome is an area with severe, recently-developed acid sulphate soils, due to drainage and burning of the peat dome. Severe acidity, long periods of salt water intrusion and peat soils make agricultural use virtually impossible. The outer part of the zone consists of moderately acid soils having similar conditions as zone 9. This part is moderately suitable for HT and MUA rice (long rainy season) and moderately suitable for pineapple.

VII. SOME GENERAL REMARKS

There is a limit to the quantity of fresh water which can be made available in the dry season because of low flow in that period. Excessive irrigation upstream may lead to increased salt water intrusion near the coast.

Environmental aspects of the LUTs were not taken into account in this study. Only the possibilities of agricultural crop production are reviewed. Lack of data on the effects of the proposed LUTs is the reason for this. It is realised that the provision of fresh water in acid sulphate areas may lead to acidification of surface water from the dikes of the canals. The same applies to the unwise construction of raised beds. In severely acid areas, even rice fields release acid-related substances, such as soluble aluminium and iron into the surface water.

Conditions in the zones are often very variable. Locally, the suitability at farm level may be very different from what is predicted for the zone as a whole.

VIII. CONCLUSIONS

1. Making fresh water available in moderately and slightly acid sulphate areas improves unsuitable land to moderately suitable for irrigated rice and tolerant upland crops. Such areas can be given highest priority in development for agricultural use;
2. Severely acid land will only become marginally suitable for irrigated rice, but moderately suitable for tolerant upland crops when fresh water is supplied for irrigation. Severely acid areas such as the Central Plain of Reeds and Ha Tien Plain should not have priority in development for agricultural use;
3. Well constructed raised beds not only overcome the flood but also improve the soil. Moderately acid soils in areas with low floods become highly suitable for pineapples and sugarcane, provided the period of saline surface water is short or absent.

B. PRESENT LAND USE AS BASIS FOR LAND EVALUATION IN TWO MEKONG DELTA DISTRICTS

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I. ABSTRACT

Land use systems are described and land use types are selected for land evaluation in two districts of the Mekong delta, Vietnam: Phung Hiep and Thanh Hoa. Phung Hiep has a wide variety of soils, ranging from fertile soils recently deposited by the Mekong river to severely acid sulphate soils. Thanh Hoa is strongly dominated by acid sulphate conditions.

Based on soil and hydrological characteristics, 27 land units are distinguished in Phung Hiep and 23 in Thanh Hoa. Eighteen and thirteen present land use types are identified in Phung Hiep and Thanh Hoa, respectively. The most important land and water management practices are the construction of raised beds for upland crops, and an optimal use of tidal movement for irrigation and drainage in both districts. In Phung Hiep ditches are excavated for combined rice and shrimp cultivation.

Costs of inputs of present land use, gross incomes and recurrent costs are generally higher in non-acid and slightly acid areas than on acid land. There are exceptions: the promising land use type of cashew combined with pineapple, and sugar cane followed by rice have a high gross margin per year. Upland crops such as cabbage, ginger, sugar cane or yams require very high investments but give greater gross margins than rice, except when rice is combined with shrimp. Eleven land use types in Phung Hiep and six in Thanh Hoa are selected for a suitability classification.

The results of land suitability indicate that in Phung Hiep the non-acid areas are highly suitable for vegetables followed by rice, but that this type of land use is not recommended for the acid areas. Land use types of sugar cane followed by rice, cashew inter-cropped with pineapple, double rice and Melaleuca are suitable for both the non-acid and the acid soil areas. In Thanh Hoa double rice and upland crops such as yams and sugar cane are moderately suited for the acid areas and highly suited for the non-acid and slightly acid parts.

II. INTRODUCTION

The objective of land evaluation is to select the optimum land use for each defined land unit, taking into account both physical and socio-economic considerations and the conservation of environmental resources for future use (FAO, 1983). The first formal land evaluation studies in Vietnam, carried out in the framework of a resource inventory of the Mekong delta (Tuong et al. 1991) concentrated on the physical conditions of the land. Little attention was paid to selection and description of land use types relevant to the physical and socio-economic conditions. In this study, present land use is taken as basis for land evaluation in Phung Hiep and Thanh Hoa districts. Phung Hiep has partly very fertile, partly acid sulphate soils. Thanh Hoa was chosen as an area representative for the severe acid sulphate soils of the delta.

III. METHODS AND MATERIALS

The study follows the FAO Framework for Land Evaluation (FAO 1976). It involves a study of the land, resulting in land units based on soil and hydrological differences, and a description of the land use types. Land use systems, i.e. land use types applied under certain soil and hydrological conditions, are next distinguished. Following the 'filtering system' described in FAO (1983) the most promising land use types are selected, based on (i) the benefits to the farmer, (ii) the development targets of the local government, (iii) the recurrent agricultural conditions in the area, and (iv) the increase in production potential of the farms in terms of employment, crop intensification and diversification, and production per hectare. The land use requirements of these promising land use types are established and finally a matching exercise determines to what extent a land unit meets those requirements.

Present land use types are used as basis for the land evaluation exercise because they have been developed by trial and error, are adapted to the local conditions and have proved to be feasible and acceptable to the local farmers. It was felt too risky to propose completely new forms of land use, especially in hostile acid sulphate soil areas.

For both study areas general and detailed soil and hydrological survey maps were available at scales varying from 1/250 000 to 1/25 000. All land use data were collected by farmer interviews, February/March 1990 for Phung Hiep, May/June 1991 for Thanh Hoa.

IV. THE STUDY AREAS

Phung Hiep is a district of Hau Giang province, located west of the Bassac river, about 35 km Southwest of Can Tho town (Figure 5.2). Area is about 24 000 ha. Roughly 40% consists of non-acid river clays, situated in the northern part of the area; the southern part has acid sulphate soils of various degrees of severity. Except for the most acid part the entire area has access to irrigation and drainage canals. Strong tidal movement is present throughout the district, and water is fresh throughout the year. Floods in the wet season occur all over the district with a maximum depth of about 80 cm. All land is used for agriculture with a wide variety of products. Phung Hiep is a densely populated district, especially the northern part and around the town of Phung Hiep.

Thanh Hoa district, covering 37 000 ha, is situated in the Plain of Reeds, about 30 km north of Long An town in An Giang province (Figure 5.2). Acid sulphate soils, floods in the rainy season and lack of fresh water in the dry season are severe constraints for land use. Only a quarter of the area is cultivated for rice and upland crops. Most of the cultivated areas are along the West Vam Co river and the main canals where there are favourable conditions for irrigation and drainage. Wetland covered with *Eleocharis spp* and *Cyperus spp* occupies about half the area, about 25 per cent consists of natural *Melaleuca spp* forest. The population of Thanh Hoa is about 31,000, resulting in a population density of 66/km^2, low for the Mekong delta. Most people are poor farmers with a low education level, only 5% of the farmers own farming implements as tractors, buffaloes or pumps. Apart from oil extraction from *Melaleuca* leaves there are virtually no off farm activities.

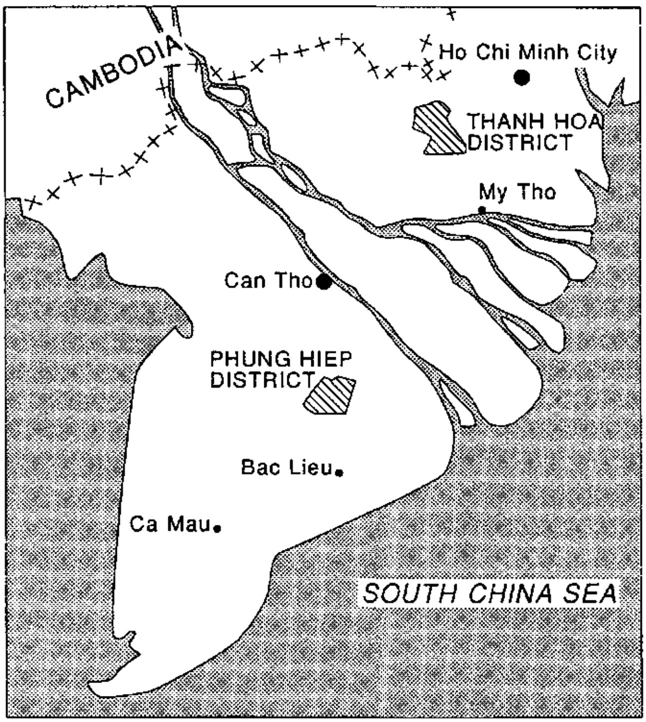


Figure 5.2: Location of Phung Hiep and Thanh Hoa districts

V. LAND UNITS

Land units are distinguished according to soil conditions and hydrological regimes which determine, to a large extent, the land use possibilities in the Mekong delta. Twenty-seven units are identified in Phung Hiep. A description is given in Table 5.9. Phung Hiep has 40% non-acid, 38% slightly acid, 20% moderately acid and 2% very acid soils. Most extensive land units are nrs. 1, 14, 16, 25.

Twenty-three units are identified in Thanh Hoa. The detailed description is given in Table 5.10. Thanh Hoa has 17% non-acid, 43% moderately acid and 40% very acid soils. Most extensive land units are nrs. 9, 10, 15, 22.

VI. PRESENT LAND USE

Present land use has been taken as a basis for land evaluation because land use types are already practised in the various physical conditions and provide basic information needed to describe socio-economic, technical and management attributes. They are probably acceptable to the local population, and have often only been accepted after long trial and error.

Phung Hiep

Figure 5.3 shows the cropping calendar of 15 major land use types practised in Phung Hiep. The way in which farmers apply these land use types varies strongly with differences in soil and hydrological conditions. It is therefore important to distinguish land use systems, i.e. a land use type practised under specified soil and hydrological conditions. Table 5.11 shows the 28 land use systems present in Phung Hiep, grouped according to soils. In the non-acid part seven land use systems are distinguished of which two can only be practised with pump irrigation or drainage. In the slightly acid part eleven land use systems are practised, seven without irrigation and drainage, two are based on gravity irrigation and drainage, one has irrigation by gravity and drainage by pumping and one uses irrigation and drainage by pumps. In the acid part one system uses irrigation by gravity and drainage by pumps.

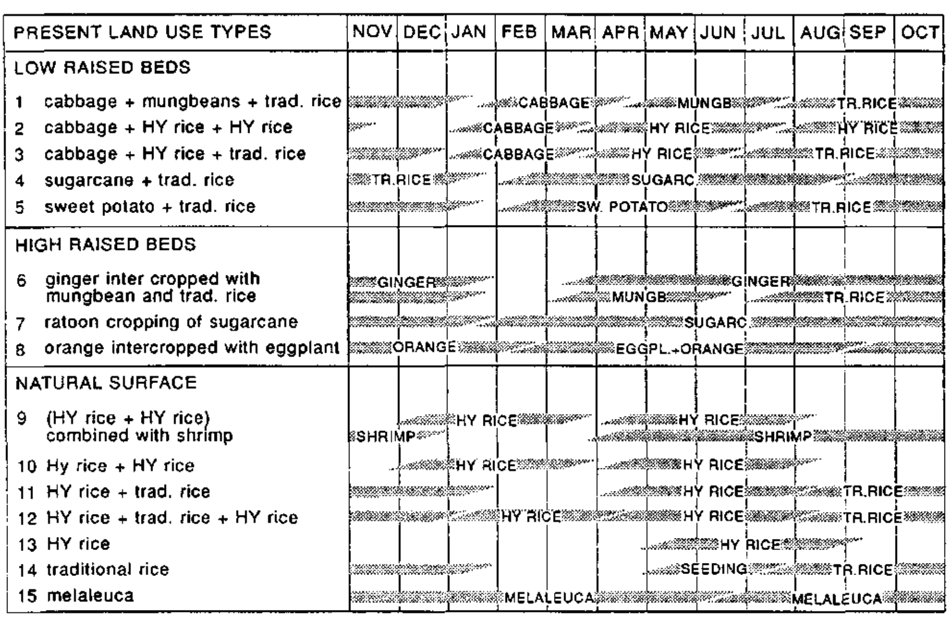


Figure 5.3: Cropping calendar of present land use types in Phung Hiep

Table 5.9 Land units and their characteristics in Phung Hiep district

Land Unit	Soil Types		Soil Characteristics		Hydrological Characteristics		
					Tide level relative to land surface		
	Land Unit Code	SoilTaxonomy subgroups	depth to Sulfuric horizon (cm)	depth to Sulfidic material (cm)	Avg.Flood depth (cm)	High tide March/April	Low tide Nov/Dec
1	NA1 F1 H+/↓ L+	Typic Humaquept fluvic	-	> 150	< 40	at/below	at
2	NA1 F1 H↑L+	Typic Humaquept fluvic	-	> 150	< 40	above	at
3	NA1 F2 H↑ L+	Typic Humaquept fluvic	-	> 150	40-60	above	at
4	NA1 F2 H↑L↓	Typic Humaquept fluvic	-	> 150	40-60	above	below
5	NA1 F3 H↑ L+	Typic Humaquept fluvic	-	> 150	60-80	above	at
6	NA2 F3 H↑ L+	Typic Humaquept	-	> 150	60-80	above	at
7	SA1 F3 H↑ L+	Typic Humaquept fluvic	-	100-150	60-80	above	at
8	SA1 F3 H↑L↓	Typic Humaquept fluvic	-	100-150	60-80	above	below
9	SA2 F2 H↑ L+	Typic Humaquept fluvic	100-150	> 150	40-60	above	at
10	SA2 F2 H↑L↓	Typic Humaquept fluvic	100-150	> 150	40-60	above	below
11	SA3 F1 H↑L+	Typic Humaquept	-	100-150	< 40	above	at
12	SA3 F2 H↑L↓	Typic Humaquept	-	100-150	40-60	above	below
13	SA3 F2 H↑L+	Typic Humaquept	-	100-150	40-60	above	at
14	SA3 F3 H+/↓ L+	Typic Humaquept	-	100-150	60-80	at/below	at
15	SA4 F1 H+/↓ L+	Sulfic Humaquept	100-150	> 150	< 40	at/below	at
16	SA4 F2 H↑L+	Sulfic Humaquept	100-150	> 150	40-60	above	at
17	SA4 F2 H↑L↑	Sulfic Humaquept	100-150	> 150	40-60	above	above
18	SA4 F3 H+/↓ L+	Sulfic Humaquept	100-150	> 150	60-80	at/below	at
19	SA4 F3 H↑L+	Sulfic Humaquept	100-150	> 150	60-80	above	at
20	SA4 F3 H↑L↑	Sulfic Humaquept	100-150	> 150	60-80	above	above
21	MA F1 H+/↓ L+	Sulfic Humaquept	50-100	> 100	< 40	at/below	at
22	MA F1 H↑L+	Sulfic Humaquept	50-100	> 100	< 40	above	at
23	MA F2 H↑L↑	Sulfic Humaquept	50-100	> 100	40-60	above	above
24	MA F3 H+/↓ L+	Sulfic Humaquept	50-100	> 100	60-80	at/below	at
25	MA F3 H↑L+	Sulfic Humaquept	50-100	> 100	60-80	above	at
26	MA F3 H↑L↑	Sulfic Humaquept	< 50	> 100	60-80	above	above
27	VA F3 H+/↓ L+	Typic Sulfaquept		> 50	60-80	at/below	at

Explanation of the codes:

NA = not acid; SA = slightly acid; MA = moderately acid; VA = very acid

F1,2,3 = maximum flood depth

H = high tide level in the dry season compared to soil surface

L = low tide level at the end of the flood season compared to soil surface

↑= above soil surface ↓= below soil surface +/↓ = at or below soil surface + = at soil surface

Table 5.10 Land Units and their characteristics in Thanh Hoa district

Unit	Land Unit Code	Soil type	Soil characteristics		hydrological characteristics				
		Vietnamese Classification	Sulfuric horizon depth cm	Sulfidic material depth cm	flood depth cm	flood time (from/to)	Salt intr. months	Possibility of gravity drainage	Fresh water in dry season
1	NA Fd3 Ft1 Su4 Wd1 Wf2	Alluvial	-	> 100	< 30	15Sep/15Dec	< 3	Good	Temporary
2	NA Fd1 Ft1 Su4 Wd1 Wf2	Soils	-	> 100	50-100	15Sep/15Dec	< 3	Good	Temporary
3	NA Fd1 Ft2 Su4 Wd3 Wf3	with	-	> 100	50-100	15Sep/30Dec	< 3	Very poor	No
4	NA Fd1 Ft1 Su5 Wd2 Wf1	deep	-	> 100	50-100	15Sep/15Dec	0	Poor	Permanent
5	NA Fd1 Ft1 Su5 Wd2 Wf2	sulfidic	-	> 100	50-100	15Sep/15Dec	0	Poor	Temporary
6	NA Fd1 Ft2 Su5 Wd3 Wf3	material	-	> 100	50-100	15Sep/30Dec	0	Very poor	No
7	MA1 Fd1 Ft2 Su4 Wd3 Wf3	Potential	-	50-100	50-100	15Sep/30Dec	< 3	Very poor	No
8	MA1 Fd1 Ft1 Su4 Wd1 Wf2	moderately	-	50-100	50-100	15Sep/15Dec	< 3	Good	Temporary
9	MA1 Fd1 Ft2 Su5 Wd3 Wf3	acid	-	50-100	50-100	15Sep/30Dec	0	Very poor	No
10	MA1 Fd1 Ft1 Su5 Wd2 Wf1	sulphate	-	50-100	50-100	15Sep/15Dec	0	Poor	Permanent
11	MA1 Fd1 Ft2 Su5 Wd3 Wf1	soil	-	50-100	50-100	15Sep/30Dec	0	Very poor	Permanent
12	MA2 Fd3 Ft1 Su4 Wd1 Wf2	Actual	50-100	> 100	< 30	15Sep/15Dec	< 3	Good	Temporary
13	MA2 Fd1 Ft2 Su4 Wd3 Wf3	moderately	50-100	> 100	50-100	15Sep/30Dec	< 3	Very poor	No
14	MA2 Fd1 Ft1 Su5 Wd2 Wf1	acid sul-	50-100	> 100	50-100	15Sep/15Dec	0	Poor	Permanent
15	MA2 Fd1 Ft2 Su5 Wd3 Wf3	phate soil	50-100	> 100	50-100	15Sep/30Dec	0	Very poor	No
16	VA1 Fd1 Ft1 Su4 Wd1 Wf2	Potential	-	0-50	50-100	15Sep/15Dec	< 3	Good	Temporary
17	VA1 Fd1 Ft1 Su4 Wd3 Wf3	severely acid	-	0-50	50-100	15Sep/30Dec	< 3	Very poor	No
18	VA1 Fd1 Ft1 Su5 Wd2 Wf1	sulphate	-	0-50	50-100	15Sep/15Dec	0	Poor	Permanent
19	VA1 Fd1 Ft2 Su5 Wd3 Wf3	soil	-	0-50	50-100	15Sep/30Dec	0	Very poor	No
20	VA2 Fd1 Ft2 Su4 Wd3 Wf3	Actual	0-50	> 50	50-100	15Sep/30Dec	< 3	Very poor	No
21	VA2 Fd1 Ft1 Su5 Wd2 Wf1	severely	0-50	> 50	50-100	15Sep/15Dec	0	Poor	Permanent
22	VA2 Fd1 Ft2 Su5 Wd3 Wf3	acid sulphate	0-50	> 50	50-100	15Sep/30Dec	0	Very poor	No
23	VA2 Fd1 Ft2 Su4 Wd3 Wf3	soil	0-50	> 50	50-100	15Sep/30Dec	< 3	Very poor	No

Explanation of the codes:
NA = not acid; MA = moderately acid; VA = very acid
Fd = flood depth
Ft = Flooded time
Su = Salt intrusion duration
Wd = Possibility for drainage by gravity
Wf = Fresh water availability in the dry season

Table 5.11 Present land use systems in Phung Hiep; Capital Intensity (i.e. initial investment (II) and recurrent annual costs (RAC), Gross Income per year (GI), Gross Margin/ha/year (GM) and Gross Margin/ha/manday

PRESENT LAND USE SYSTEMS	CAPITAL INTENSITY		GI	GM/Ha/Year	GM/Ha/Manday
	IIx1000VND	RACx1000VND	x1000VND	x1000VND	x1000VND
A. Non-acid Soil Zone:					
1. Cabbage + mungbean + traditional rice	410	3,035	12,320	9,284	18
2. Cabbage + irrigated HY rice + HY rice	410	3,468	12,050	8,581	19
3. Cabbage + irrigated HY rice + traditional rice	410	3,258	11,900	8,641	21
4. Orange inter-cropped with eggplant	5,080	758*	26,800	26,042	**
5. Irrigated HY rice + pump drained HY rice	660	1,509	3,450	1,940	8
6. Irrigated HY rice + traditional rice	410	1,015	2,700	1,684	8
7. Irrigated HY rice + trad. rice + pump drained HY rice	660	1,873	4,650	2,776	9
B. Slightly Acid Soil Zone					
8. Sugarcane + traditional rice	2,100	3,223	7,610	4,386	12
9. Sweet potato + traditional rice	200	1,510	3,000	1,489	7
10. Sugarcane (3 years)	3,780	1,610	8,000	6,389	21
11. Ginger inter-cropped with mungbean and trad. rice	3,980	3,112	19,074	15,961	40
12. Gravity irr. HY rice + gravity drained HY rice / shrimp	1,010	1,563	5,820	4,257	13
13. Gravity irrigated HY rice + traditional rice / shrimp	1.010	1,512	7,050	5,537	19
14. Gravity irrigated HY rice + gravity drained HY rice	660	1,219	3,150	1,930	8
15. Gravity irrigated HY rice + pump drained HY rice	660	1,261	3,000	1,739	7
16. Gravity irrigated HY rice + traditional rice	410	883	2,550	1,667	8
17. Irrigated HY rice + traditional rice	410	923	2,550	1,627	8
18. Irrigated HY rice + traditional rice + pump drained rice	660	1,561	4,050	2,488	8
C. Acid soil zone:					
19. Sugarcane + traditional rice	2,100	3,182	7,060	3,878	10
20. Eucalyptus	2,100	198	4,000	3,801	**
21. Cashew inter-cropped with pineapple	5,040	316	6,653	6,337	31
22. Sugarcane (3 years)	5,040	1,610	8,000	6,389	21
23. Gravity irrigated HY rice + pump drained HY rice	660	1,181	2,280	1,099	5
24. Gravity irrigated HY rice + traditional rice	410	769	1,830	1,060	5
25. Irrigated HY rice + traditional rice	410	827	1,830	1,002	5
26. Irrigated HY rice	410	432	1,200	767	6
27. Traditional rice	0	120	720	600	7
28. Melaleuca	760	61	5,500	5,448	**

US$ 1 = VN Dong 4,000 (02/1990)

(*) : no data available on hired labour

(**) : no data

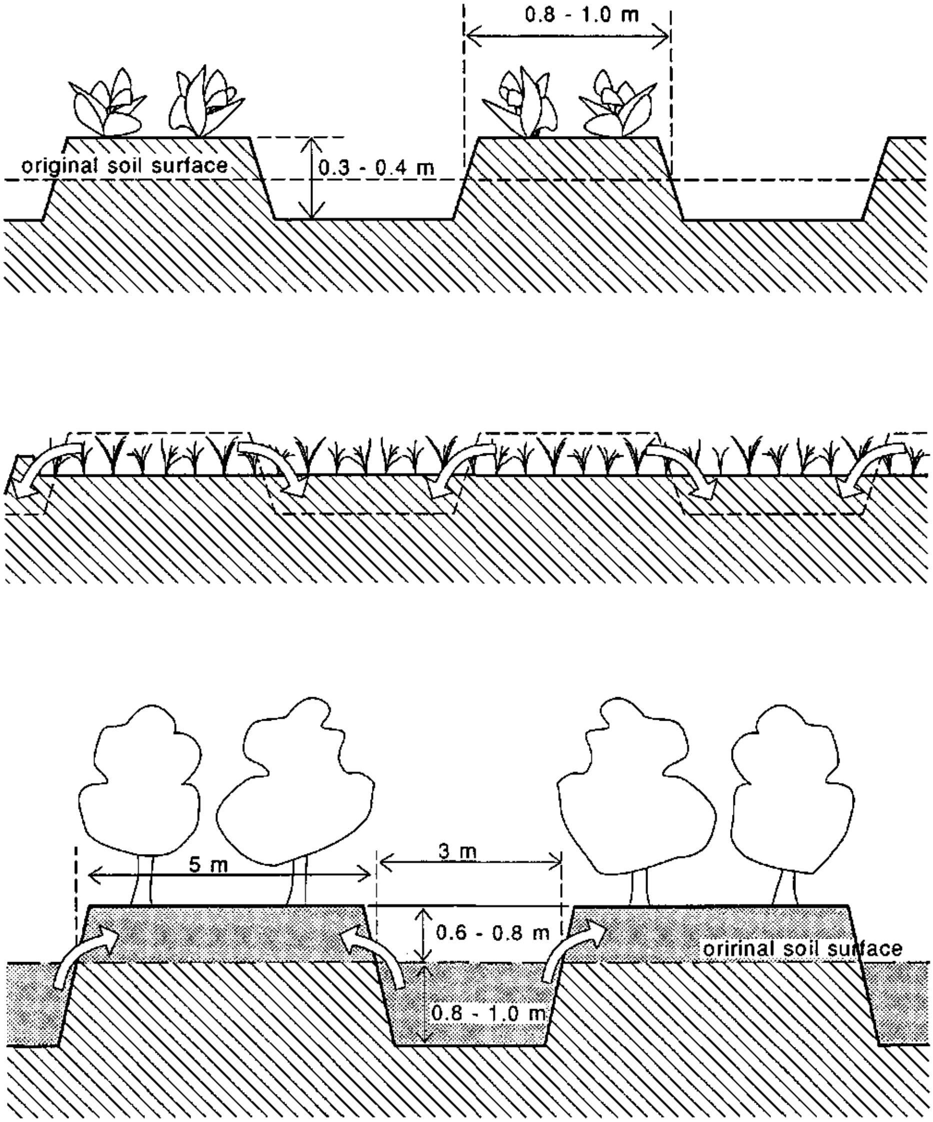


Figure 5.4: Types of raised beds in non-acid and slightly acid soils, Phung Hiep

Land and water management, cultivation practices

Construction of raised beds is the most important land management practice. Low and high beds are constructed to avoid flooding in the rainy season and to improve the poor internal drainage of the heavy textured natural soil. Vegetables and other upland crops are grown on the beds. Rice is grown on the natural soil surface, as is the case with *Melaleuca*. The way in which beds are constructed depends on soils and crops. In non-acid and slightly acid soils temporary low raised beds are constructed for upland crops during the dry season and high raised beds for crops which grow all year round (Figure 5.4). In the moderately and very acid soils precautions are needed to avoid bringing the acid part of the soil profile to the top of the bed (Figure 5.5).

Another land and water management practice is needed when applying the combination of rice on the fields and shrimps in the ditches surrounding the field. This system was recently introduced in Phung Hiep and requires (i) tidal water movement throughout the year, (ii) flood protection by means of high dikes surrounding the fields and (iii) gravity tidal irrigation and drainage facilities during the flood period. Rice/shrimp land use types are only found in the slightly acid area where tidal irrigation and drainage is possible throughout the year. A schematic design is given in Figure 5.6.

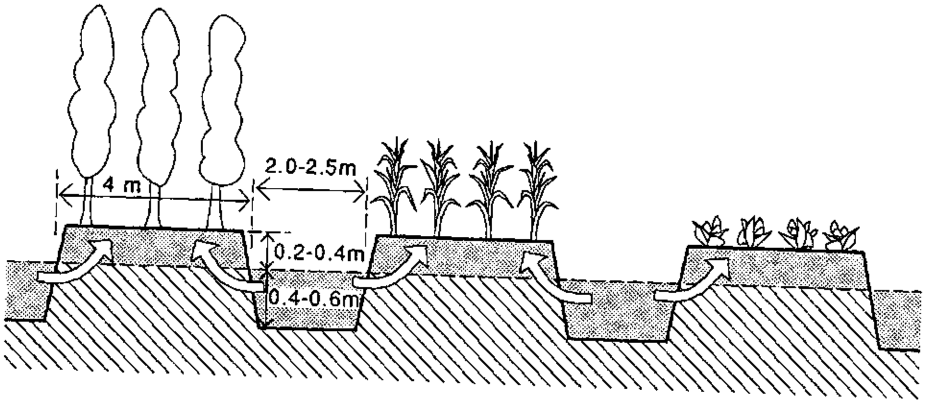
Ploughing on non-acid land is mainly done by tractors, on slightly and moderately acid land by buffalo. Land preparation for vegetables and upland crops is done by hand, as well as sowing, (trans)planting and fertilisation. The use of fertilisers and pesticides is high in the non-acid and slightly acid areas, but low on acid soils. The quantity of seed used for high yielding rice is 200-300 kg/ha. This high quantity of seed is needed to control weeds and to give a high number of main panicles, a major factor to increase yields.

Family labour is the most important labour source. In the double or triple rice land use systems of the slightly and non-acid areas farmers use hired labour for land preparation, (trans)planting of rice, irrigation of upland crops and the harvest. In the acid areas family and exchange labour is mainly used. Only in peak labour periods of some crops such as sugar cane or pineapple hired labour is indispensable. Yields are generally higher in the slightly and non-acid areas, and double or triple crops are cultivated much more extensively compared to the acid part.

Financial analysis

Table 5.11 shows that the recurrent costs and gross income in the slightly and non-acid areas are generally higher than in the acid part. Recently introduced systems (numbers 1-4, 8, 11-13, 19, 23, 21 and 28) gave much higher gross incomes in the slightly and non-acid part compared to the acid zone. Gross incomes from double rice differ little between soils.

Capital intensity refers to the levels of capital investment and the recurrent costs of a land use system. Gross margin/ha/year and gross margin/man-day can be used to analyse the profitability of a land use system for a farmer. Results are also shown in Table 5.11. Orange inter-cropped with eggplant, ginger inter-cropped with mung bean and traditional rice, ratoon sugar cane and cashew inter-cropped with pineapple require high capital investment, mainly due to the need to construct raised beds. At the same time these systems have the highest gross income. Other systems require low capital investment.



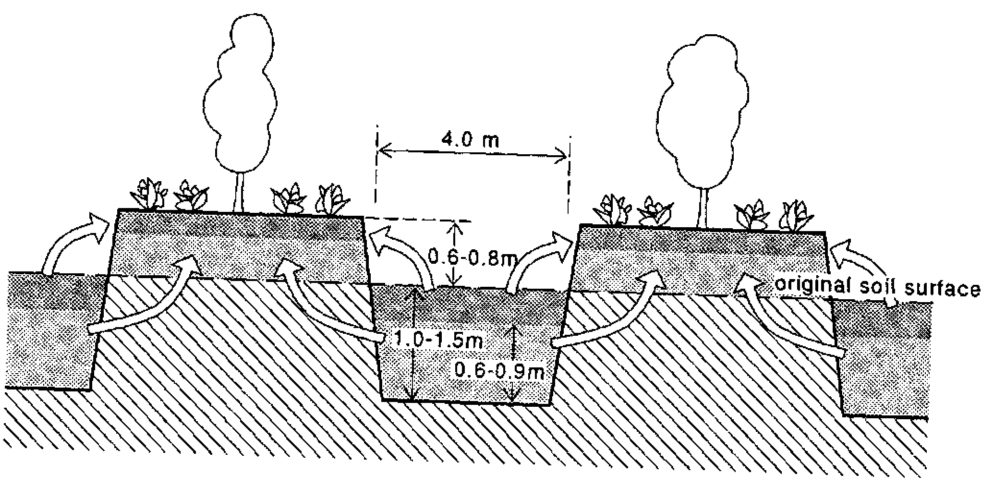


Figure 5.5: Types of raised beds in acid soils

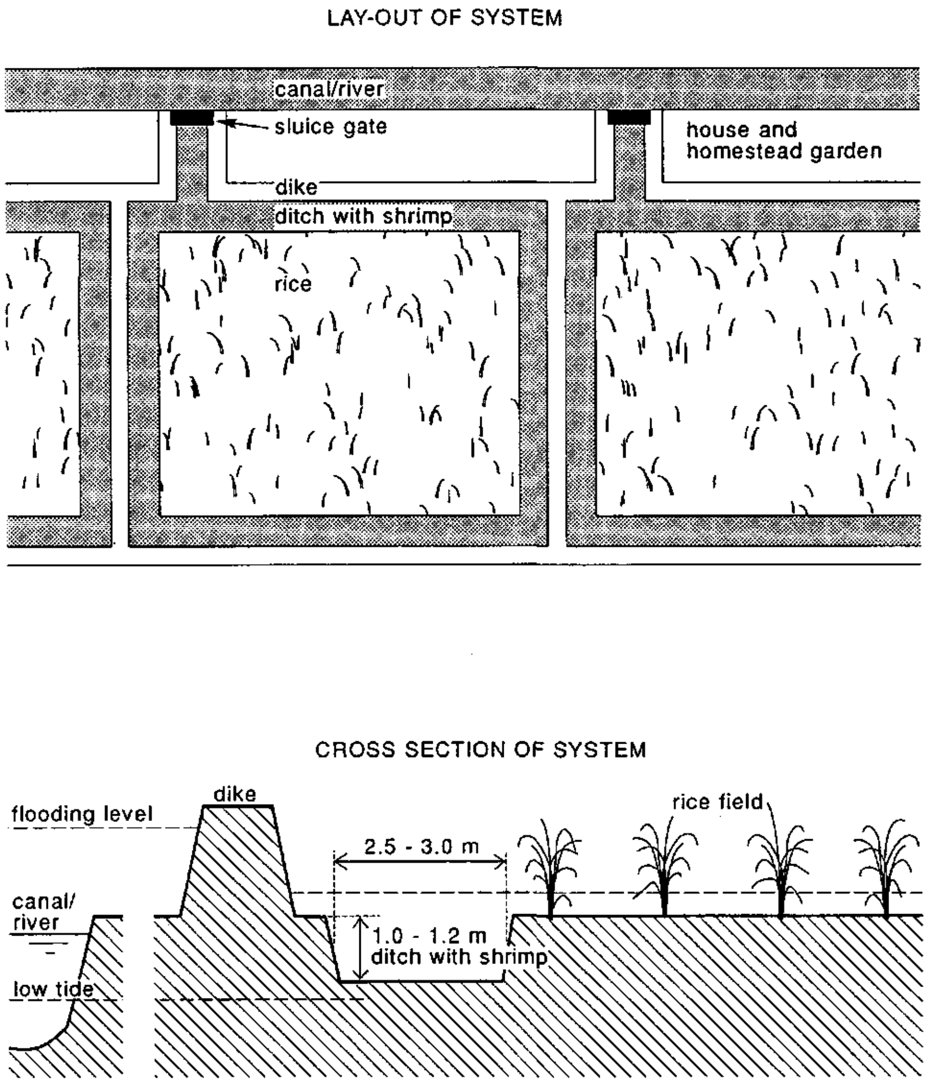


Figure 5.6: Ditch system for combined rice-shrimp cultivation in Phung Hiep

Recurrent costs are generally higher in the slightly and non-acid areas compared to the acid areas. Gross margin/ha/year varies within and between soil zones. Most systems have a low gross margin/ha/year in the acid area but this does not apply to some promising systems such as cashew inter-cropped with pineapple, sugarcane followed by rice and Melaleuca. The latter do, however, have high recurrent costs. Gross margin/manday is high in systems with cashcrops (cabbage, ginger, sugar cane, cashew) but low in all rice systems, independent of the soil quality. The only exception is the system where rice is combined with shrimp cultivation.

Thanh Hoa

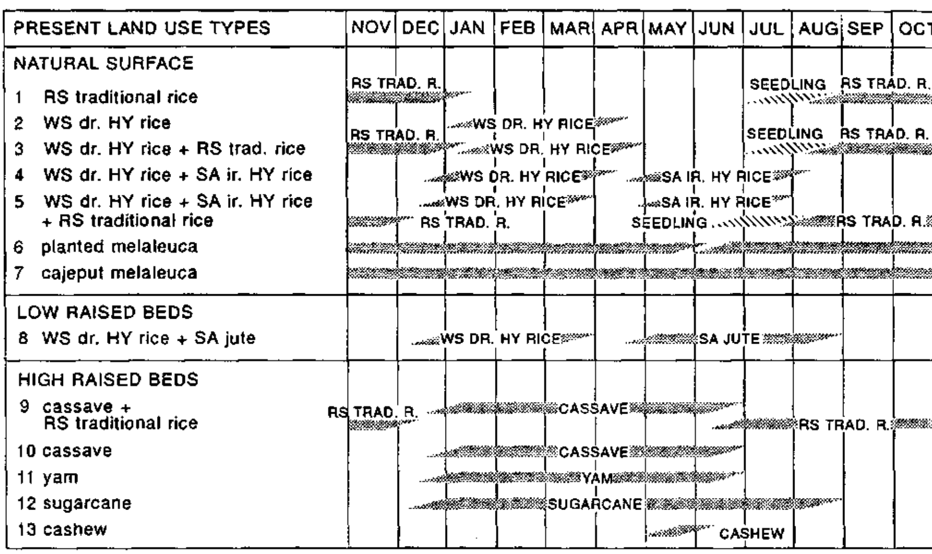


Figure 5.7: Cropping calendar of Present Land Use Types in Thanh Hoa

Present land use types and land use systems

Thirteen land use types were identified in Thanh Hoa, a surprisingly wide variety for what is mainly recently cleared acid sulphate land. The cropping calendar of the land use types is shown in Figure 5.7. Single, double and triple rice are most widespread. Upland crops (yams, sugar cane, cassava, cashew) are cultivated on small scale only.

In Thanh Hoa 29 land use systems can be distinguished. They are shown in Table 5.12, and have been grouped according to soil conditions. Double rice systems and yams are cultivated in all soil conditions, even on a limited scale in the very acid soils. Triple rice is only found in a thin fringe along the Vam Co river which crosses the district. Cassava and sugar cane are not found in very acid conditions, Melaleuca is only cultivated (or exploited) on moderately and very acid soils.

Land/water management and cultural practices

In order to cultivate HY rice farmers must surround their fields with small dikes to enable the pumping out of flood water in December, at the end of the rainy season. In this way they can start the rice crop early and use floodwater surrounding the field for gravity irrigation. They also construct a shallow drainage system (Vo Tong Xuan, 1982) to remove soluble acidity from the topsoils in the early part of the rainy season.

High raised beds are needed to cultivate permanent upland crops (cassava, sugar cane, cashew) and low raised beds for mixed systems of rice and jute. Other new cultivation techniques which are not specific for the area are crop multiplication, zero-tillage between two rice crops to gain time, irrigation and drainage and finally fertiliser application.

Financial analysis

The financial analysis of the 29 land use systems, as shown in Table 5.12, indicates that double and triple rice, yams and sugar cane give the highest gross incomes. At the same time, these crops require the highest investments. Double or triple rice gives a high gross margin per ha per year in non-acid areas. In the acid area, yams gives the highest gross margins, even higher than the double or triple rice systems on good soils. Although economically attractive, it must be realised that yams are not a staple food in Vietnam and therefore has limited marketing and exportation possibilities.

The major part of the investments goes into the special soil and water management measures necessary to overcome the land constraints, i.e. the preparation of the land. Double, triple rice and upland crops have high labour requirements (150 - 300 mandays/ha/year) with peaks at land preparation and harvesting. Ploughing, irrigation, rice threshing with hired machinery strongly raise the inputs for double and triple rice crops.

Wide price fluctuations can have a strong effect on the calculations made here. This applies especially to sugar cane and jute, which showed a strong price decrease in 1992.

Comparing Land Use Types in Phung Hiep and Thanh Hoa

Phung Hiep data were gathered one year earlier than Thanh Hoa. Price increase has occurred due to inflation. Initial investments for double rice crops, for instance, varies between 400 and 600,000 VN Dong in Phung Hiep, and between 500 and 900,000 in Thanh Hoa. The recurrent costs, however, are far higher in Thanh Hoa. Main reason is the tidal irrigation during the dry season, which can be done in Phung Hiep, but not in Thanh Hoa. This means high pumping costs in Thanh Hoa.

In both districts capital intensity usually increases with decreasing soil quality. When cultivating sugar cane, for instance, farmers need to construct higher raised beds because the acid soils are in low places, implying higher initial investments in labour and recurrent costs for maintenance. Striking is also the decrease in income by Melaleuca forestry when comparing Phung Hiep to Thanh Hoa. The market in Thanh Hoa is saturated, resulting in low prices. Remarkably the economically most interesting systems of one district are not found in the other. Phung Hiep has horticultural systems because the district has easy access to markets (Phung Hiep town, Can Tho, Ho Chi Minh City). Thanh Hoa is isolated. On the other hand, yams are not cultivated in Phung Hiep.

Table 5.12 Present land use systems in Thanh Hoa; Capital Intensity (i.e. initial investment (II) and recurrent annual costs (RAC), Gross Income per year (GI), Gross margin/ha/year (GM) and Gross margin/ha/manday.

PRESENT LAND USE SYSTEMS	CAPITAL INTENSITY		GI	GM/Ha/ Yr	GM/Ha/ Manday
	IIx1000VND	RACx1000VND	x1000VND	x1000VND	x1000VND
A. Non-acid Soil Zone:					
1. Traditional rice	220	1,383	2,000	595	5
2. Drained HY rice + irrigated HY rice	500	4,410	7,356	2,896	14
3. Drained HY rice + irrigated HY rice + trad. Rice	800	4,582	10,000	5,338	18
4. Drained HY rice + jute	700	3,048	3,750	632	2
5. Cassava + traditional rice	450	1,649	5,330	3,607	36
6. Cassava	450	881	2,498	1,542	32
7. Yam	1200	2,549	4,875	2,127	14
8. Sugar cane	640	2,489	6,150	3,554	24
B. Moderately Acid Soil Zone					
9. Drained HY rice + irrigated HY rice	630	4,304	7,327	2,959	14
10. Drained HY rice + irrigated HY rice + trad. rice	900	4,044	9,900	5,766	25
11. Drained HY rice	600	854	3,200	2,287	24
12. Cassava	520	1,648	2,664	929	8
13. Yam	1,500	3,589	6,825	2,986	16
14. Sugar cane	750	2,730	5,250	2,395	12
15. Cassava + traditional rice	840	1,790	5,172	3,242	17
16. Melaleuca forestry for timer	2,214	739	1,050	291	2
17. Melaleuca for cajiputi oil	350	50	1,270	1,142	9
C. Potentially Severely Acid Zone:					
18. drained HY rice + traditional rice	900	3,360	4,500	1,051	6
19. drained HY rice + irrigated HY rice	950	4,331	6,262	1,836	9
20. Drained HY rice + irrigated HY rice + trad. rice	1,130	4,044	9,400	5,243	21
21. Cassava	920	1,056	2,581	1,372	12
22. Yam	1,840	4,289	11,895	7,300	39
23. Sugar cane	1,840	2,816	8,875	5,753	37
D. Severely acid soil zone					
24. Drained HY rice + irrigated HY rice	1,100	4,220	7,375	3,045	15
25. Drained HY rice + jute	1,550	3,100	4,000	745	3
26. Yam	2,400	4,523	12,350	7,427	39
27. Cashew	2,200	319	1,112	3,066	59
28. Melaleuca forestry for timber	2,214	739	1,050	291	2
29. Melaleuca for cajiputi oil	350	50	1,270	1,142	9

US$ 1 = VN Dong 7,500 (05/1991)

VII. SELECTED LAND USE TYPES AND THEIR KEY ATTRIBUTES

Following the "filtering" system of FAO (1983), and taking into account the development objectives of the local government, the agricultural conditions of the area, the present land use types, and the social and financial analysis, 11 land use types were selected for the land evaluation exercise. They are shown in Tables V.13 and V.14 with the key attributes: potential production, cultural practices, capital intensity (i.e. capital investment and recurrent costs), labour requirements, maximal gross margin/ha/year. The tables also show the market orientation of the produce.

Table 5.13 Selected Land Use Types (LUTs) of Phung Hiep District and their key attributes

Selected LUTs	Maximum[1] Production	Capital intensity		Labour requirements	Gross Margin[2] per year	Market orientation
	ton/crop/ha	Initial investment	Recurrent costs	Manday/ha/yr	x1000 VND/yr.	
LUT 1: Vegetable + vegetable + rice	Cabbage: 23 HY rice: 4.5 trad.rice: 4	Low	High	560	14,500	Cabbage: local cash crop Rice: subsistence
LUT 2: Vegetable + irrigated HY rice + rice	Cabbage: 23 HY rice: 5 trad.rice: 4	Low	High	485	8,500	cabbage: local cash crop rice: subsistence and export
LUT 3: Irrigated HY rice + rice/shrimp	HY rice: 5-6 trad.rice:4.5 shrimp: 0.2	Medium	Medium	330	5,500	rice: subsistence and export shrimp: export
LUT 4: Irrigated HY rice + drained HY rice	Irr.rice: 5 Dr.rice : 6	Low	Medium	210	2,000	subsistence and export
LUT 5: Irrigated HY rice + traditional rice	HY rice: 5 trad.rice: 4	Low	Low	250	1,600	subsistence and export
LUT 6: Sugarcane + traditional rice	Raw Cane: 85 Trad.rice:2.5	Medium	High	420	4,000	rice: subsistence cane: local cash crop
LUT 7: Ratoon Sugarcane	Raw Cane: 100	High	High	335	6,000	local cash crop
LUT 8: Fruit trees/ eggplant	Orange:270,000[3] Eggplant: 20	High	Medium	[5]	26,000	local cash crop
LUT 9: Ginger/mungbean/ traditional rice	Ginger: 15 Mungbean: 0.3 Trad.rice: 2.3	High	High	430	15,500	ginger: export mung and rice: local cash crop
LUT 10: Cashew/pineapple	Cashew: 3 Pineapple: 10	High	Low	200	6,500	cashew: local cash crop pineapple: export
LUT 11: Melaleuca (timber)	35000 stem/ 6 years	Low[4]	Low	90	5,200	local cash crop

[1] yields and gross margins of highly suitable land are mentioned
[2] capital intensity and recurrent costs classes are:
High: 3,000,000 - 6,000,000 VN Dong
Medium: 1,000,000 - 3,000,000 VN Dong
Low: below 1,000,000 VN Dong
[3] number of fruits per ha per year
[4] costs of planting not included
[5] no data

For Phung Hiep, the selected LUTs 1, 2, 3, 8 and 9 can help to increase the cash income of the farmer, will provide goods suited for export, create more employment and provide more subsistence food. The selected LUTs 4 and 5 will provide more subsistence and exportable rice. LUTs 6 and 7 will produce more raw material for the local sugar factories and provide employment. LUTs 10 and 11 will increase the productivity of the acid areas by raising the income of farmers, provide timber for local consumption and possibly for export.

For Thanh Hoa, the LUTs 1, 2, 3, 5 and 6 are attractive because they increase the cash income of the farmer, provide goods suited for export, create more employment and provide more subsistence food. Melaleuca has been chosen because it seems the only possible option for the severely acid areas, even though the economic outlook is not very promising.

When comparing similar selected LUTs in the two districts it appears, that the recurrent costs for double and triple rice (LUT 1-2-3 in Thanh Hoa, LUT 4-5 in Phung Hiep) are higher in Thanh Hoa than in Phung Hiep. This is because tidal irrigation can be practised at least part of the time in Phung Hiep, while in Thanh Hoa irrigation is needed throughout the dry season, raising the costs. Additionally, inflation has taken place (Thanh Hoa was surveyed one year after Phung Hiep). The higher price for rice in 1991 has also improved that gross margins in Thanh Hoa. The price of Melaleuca timber dropped dramatically. Gross margin was 5.2 million VN Dong during the Phung Hiep survey, a year later it had dropped to 0.3 million Dong in Thanh Hoa. The ratoon sugar cane of Phung Hiep is expected to give higher production and also a higher gross margin (LUT 7 Phung Hiep, LUT 6, Thanh Hoa).

Table 5.14 Selected Land Use Types (LUTs) of Thanh Hoa District and their key attributes

Selected LUTs	Maximum[1] Production	Capital Intensity		Labour requirements	Gross margin[2] per year	Market orientation
	ton/crop/ha	Initial investment	Recurrent costs	Manday/ha/yr	x1000VND/yr	
LUT 1: drained HY rice + traditional rice	HY rice: 3 trad.rice: 2.1	Low	Medium	175	2,262	subsistence and export
LUT 2: drained HY rice + irrigated HY rice	dr HY rice:4.3 irr HY rice:3.3	Low	High	211	3,305	subsistence and export
LUT 3: drained HY rice + irr. HY rice + trad.rice	dr HY rice: 5 irr HY rice:4.4 trad.rice: 2.5	Low	High	235	5,766	subsistence and export
LUT 4: Melaleuca	Timber: 140 m^2 Honey: 15 kg Fish: 90 kg	High	Low	120	291	subsistence and cash crop
LUT 5: Yam	Tubers: 19	High	High	191	7,427	cash crop
LUT 6: Sugarcane	Raw cane: 59	High	Medium	157	5,743	cash crop

[1] yields and gross margins of highly suitable land are mentioned

[2] Capital intensity and recurrent costs classes are:

High : over 3,000,000 VN Dong Medium : 1,000,000 - 3,000,000 VN Dong

Low : below 1,000,000 VN Dong

VIII. SUITABILITY CLASSIFICATION

Tables V.15 and V.16 show the land use requirements that are relevant for the LUTs selected. Soil acidity, for instance, is important for all LUTs with the exception of Melaleuca forestry since Melaleuca does not seem to be affected by acidity. Potential soil acidity is relevant as soon as a LUT requires disturbance of the soil by construction of raised beds for dryland crops or ditches for shrimp. Floods are relevant for virtually all LUTs except when traditional rice is cultivated. Double rice may easily suffer problems in years of early or very fast rising flood. Deep floods also affect dryland crops and Melaleuca. The presence of fresh water in the dry season is imperative for all agricultural activities in that time of the year. In Phung Hiep fresh water is available everywhere, but possible tidal irrigation and drainage adds an extra dimension. Salt water intrusion may be relevant in Thanh Hoa when rice is cultivated in the dry season.

Table 5.15 Relevant land use requirements for selected LUTs in Phung Hiep

Land Use Requirements	Land Use Type										
	LUT1	LUT2	LUT3	LUT4	LUT5	LUT6	LUT7	LUT8	LUT9	LUT10	LUT11
1 Soil Acidity	+	+	+	+	+	+	+	+	+	+	+
2 Potential Soil Acidity	-	-	+	-	-	+	+	+	+	+	-
3 Flood hazard	+	+	+	-	+	+	+	+	+	+	-
4 Potential tidal irrigation	-	+	+	+	+	-	-	-	-	-	-
5 Potential tidal drainage	-	-	+	+	-	-	-	-	-	-	-

\+ Relevant land use requirement
\- Irrelevant land use requirement

Table 5.16 Relevant land use requirements for selected LUTs in Thanh Hoa

Land Use Requirements	Land Use Type					
	LUT1	LUT2	LUT3	LUT4	LUT5	LUT6
1 Soil acidity		+	+	-	+	+
2 Potential Soil Acidity	-	-	-	-	+	+
3 Flood hazard	-	+	+	+	+	+
4 Potential fresh water supply in dry season		+	+	-	+	+
5 Potential tidal drainage	-	+	+	-	-	-
6 Salt water intrusion	-	+	+	-	-	-

\+ Relevant land use requirement
\- Irrelevant land use requirement

The requirements of each selected LUT should next be expressed in terms of factor ratings. Table 5.17 and 18 show two examples, one for selected LUT 3 (double crop rice and shrimps) in Phung Hiep, and one for selected LUT 6 (sugar cane) in Thanh Hoa. Similar ratings can be made for the other LUT's.

For soil acidity, the depth to the sulfuric horizon is used. A sulfuric horizon within 50 cm depth makes the land unsuited for rice and shrimp (Table 5.17) and for sugar cane (Table 5.18). The depth to potentially acid sulfidic material is important since in both the rice/shrimp and sugar cane excavations are inevitable for construction of canals (shrimp) and raised beds (sugar cane). Sulfidic material within 50 cm makes the rice and shrimp system unsuitable, but sugar cane is still marginally suited. Inevitably sulfidic material will be exposed when constructing the beds, especially in areas with deep floods. Deep sulfidic material (over 100 cm) will not be touched.

Floods and tides are of great importance in Phung Hiep. Floods less than 60 cm do not negatively influence a traditional rice crop but, whenever 60 cm or deeper, rice will have lower yields. Above 80 cm flood, traditional rice is not possible. A high tide above the soil surface combined with low tides below the surface offer the farmers optimal conditions for water management of both rice and shrimp. Yields will be reduced when tides are different.

Table 5.17 Factor Ratings for selected LUT 3 (Irrigated High Yielding rice + a second rice crop, combined with shrimps) in Phung Hiep

Land Use Requirements		Factor ratings			
Land Quality	Diagnostic factor	S1	S2	S3	N
Soil acidity (both rice and shrimp)	depth sulfuric horizon (cm)	> 100	> 100	50-100	< 50
Potential soil acidity (both rice and shrimp)	depth sulfidic material (cm)	> 100	> 100	50-100	< 50
Flood hazard (rice)	maximum flood depth (cm)	< 60	60	60-80	> 80
Possibility of tidal irrigation (rice)	high tide level compared to soil surface	above	at/below	below	-
Possibility of tidal drainage (rice)	low tide level compared to soil surface	below	at	above	above
Possibility of tidal irrigation (shrimp)	high tide level compared to soil surface	above	above/at	at	below
Possibility of tidal drainage (shrimp)	low tide level compared to soil surface	below	below	at	above

Suitability ratings: S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N = not suitable

Table 5.18 Factor ratings for selected LUT 6 (sugar cane) in Thanh Hoa

Land use requirements		Factor ratings			
Land quality	Diagnostic factor	S1	S2	S3	N
soil acidity	depth sulfuric horizon (cm)	absent	> 100	50-100	< 50
potential soil acidity	depth sulfidic material (cm)	> 100	50-100	< 50	-
flood hazard	maximum flood depth (cm)	< 30	30-50	50-100	> 100
possibility of fresh water supply	fresh water availability in dry season	permanent	temporary	no	-

Suitability ratings: S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N = not suitable

Floods are also important in Thanh Hoa, but not so tides. Tidal movement is limited in the dry season, tidal irrigation is not possible. In the rainy season tides are absent. Floods over 100 cm make sugar can impossible; floods between 50 and 100 cm will strongly reduce crop yields. A permanent supply of fresh water in the dry season guarantees a good crop.

Where fresh water is only temporary because of salt intrusion during the dry season, yields are reduced.

Tables 5.19 and 5.20 show the land units of both districts, their suitability for the selected land use types and the limiting factors.

Table 5.19 Land suitability classification for Phung Hiep District

Unit		Suitability classes			
	Land Unit Code*	S1	S2	S3	N
1	Na1 F1 H+/- L+	LUT 1,7,8,9,10,11	LUT 2,4,5 di	LUT 3,6 dfi	-
2	NA1 F1 H- L+	LUT 1,2,5,7,8,9,10,11	LUT 4 d	LUT 3,6 df	-
3	NA1 F2 H- L+	LUT 1,2,5,6,7,9,10,11	LUT 4,8 df	LUT 3 d	-
4	NA1 F2 H- L-	LUT 1,2,3,4,5,6,7,9,10,11	LUT 8 f	-	-
5	NA1 F3 H- L+	LUT 6,11	LUT 4 d	LUT 1,2,3,5,7,8,9,10 df	-
6	NA2 F3 H- L+	LUT 6,11	LUT 4 d	LUT 1,2,3,5,7,8,9,10 df	-
7	SA1 F3 H- L+	LUT 6,11	LUT 4 d	LUT 1,2,3,5,7,8,9,10 dfp	-
8	SA1 F3 H- L-	LUT 4,6,11	-	LUT 1,2,3,5,7,8,9,10 fp	-
9	SA2 F2 H- L+	LUT 5,6,7,9,10,11	LUT 1,2,4,8 dfs	LUT 3 d	-
10	SA2 F2 H- L-	LUT 3,4,5,6,7,9,10,11	LUT 1,2,8 fs	-	-
11	SA3 F1 H- L+	LUT 1,2,5,7,9,10,11	LUT 4,8 dp	LUT 3,6 df	-
12	SA3 F2 H- L-	LUT 1,2,3,4,5,6,7,9,10,11	LUT 8 fp	-	-
13	SA3 F2 H- L+	LUT 1,2,5,6,7,9,10,11	LUT 4,8 dfp	LUT 3 d	-
14	SA3 F3 H+/- L+	LUT 6,11	LUT 4 di	LUT 1,2,3,5,7,8,9,10 dfip	--
15	SA4 F1 H+/- L+	LUT 7,9,10,11	LUT 1,2,4,5,8 dis	LUT 3,6 dfi	-
16	SA4 F2 H- L+	LUT 5,6,7,9,10,11	LUT 1,2,4,8 dfs	LUT 3 d	-
17	SA4 F2 H- L-	LUT 5,6,7,9,10,11	LUT 1,2,8 fs	LUT 4 d	LUT 3
18	SA4 F3 H+/- L+	LUT 6,11	LUT 4 di	LUT 1,2,3,5,7,8,9,10 dfis	-
19	SA4 F3 H- L+	LUT 6,11	LUT 4 di	LUT 1,2,3,5,7,8,9,10 dfs	-
20	SA4 F3 H- L-	LUT 6,11	-	LUT 1,2,4,5,8,9,10 dfs	LUT 3
21	MA F1 H+/- L+	LUT 11	LUT 4,5,7,9,10 dis	LUT 1,2,3,6,8 dfis	-
22	MA F1 H- L+	LUT 11	LUT 4,5,7,9,10 ds	LUT 1,2,3,6,8 dfs	-
23	MA F2 H- L-	LUT 11	LUT 5,6,7,9,10 s	LUT 1,2,4,8 dfs	LUT 3
24	MA F3 H+/- L+	LUT 11	LUT 4,6 dis	LUT 1,2,3,5,7,8,9,10 dfis	-
25	MA F3 H- L+	LUT 11	LUT 4,6 ds	LUT 1,2,3,5,7,8,9,10 dfs	-
26	MA F3 H- L-	LUT 11	LUT 6 s	LUT 1,2,3,5,7,8,9,10 dfs	LUT 3
27	VA F3 H+/- L+	-	LUT 11 s	LUT 10 fs	LUT 1,2,4, 5,6,7,8,9

*: for explanation of the land unit codes in Thanh Hoa see Table 5.9

Suitability classes: S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N = not suitable

Limiting factors:

d = possibility to drain land by tidal movement f = flood hazard

i = possibility to irrigate land by tidal movement p = potential acidity s = soil acidity

Land suitability

In Phung Hiep, land units in the non-acid part with shallow or medium floods are highly suited for land use types 1 (twice vegetables and rice), 7 (ratoon sugar cane), 9 (ginger and mungbean, followed by rice), 10 (cashew and pineapple) and 11 (Melaleuca). LUT 11 (Melaleuca) can be cultivated everywhere. Capital intensive and profitable systems such as 1,2,3 and 8 (i.e. triple crops of rice and vegetables, rice and shrimp or fruits and vegetables) are marginally suitable or unsuitable for the moderately and very acid land. The moderately acid land units with favourable water management conditions (units 21-23) are moderately suited for double rice (LUT 4 and 5), sugar cane (LUT 7), ginger/mungbean and traditional rice (LUT 9) and cashew/pineapple.

Table 5.20 Land suitability classification for Thanh Hoa District

Unit	Land Unit Code *	Suitability Classes S1	S2	S3	N
1	NA Fd3 Ft1 Su4 Wd1 Wf2	LUT 1,2,3,4,5	LUT 6 a	-	-
2	NA Fd1 Ft1 Su4 Wd1 Wf2	LUT 1	LUT 2,4,5 f	LUT 3,6 adf	-
3	NA Fd1 Ft2 Su4 Wd3 Wf3	LUT 1	LUT 2,4,5 f	LUT 3,6 adf	-
4	NA Fd1 Ft1 Su5 Wd2 Wf1	LUT 1	LUT 2,4,5 f	LUT 3,6 adf	-
5	NA Fd1 Ft1 Su5 Wd2 Wf2	LUT 1	LUT 2,4,5 f	LUT 3,6 adf	-
6	Na Fd1 Ft2 Su5 Wd3 Wf3	LUT 1	LUT 2,4,5 f	LUT 3,6 adf	-
7	MA1 Fd1 Ft2 Su4 Wd3 WF3	LUT 1	LUT 2,4,5 f	LUT 3,6 adfw	-
8	MA1 Fd1 Ft1 Su4 Wd1 Wf2	LUT 1	LUT 2,3,4,5 f	LUT 6 af	-
9	MA1 Fd1 Ft2 Su5 Wd3 Wf3	LUT 1	LUT 2,4,5 f	LUT 3,6 adfw	-
10	MA1 Fd1 Ft1 Su5 Wd2 Wf1	LUT 1	LUT 2,4,5 f	LUT 3,6 adf	-
11	MA1 Fd1 Ft2 Su5 Wd3 Wf1	LUT 1	LUT 2,4,5 f	LUT 3,6 adf	-
12	MA2 Fd3 Ft1 Su4 Wd1 Wf2	LUT 4	LUT 1,2,3,5 a	LUT 6 af	-
13	MA2 Fd1 Ft2 Su4 Wd3 Wf3	-	LUT 1,2,4,5 af	LUT 3,6 adfw	-
14	MA2 Fd1 Ft1 Su5 Wd2 Wf1	-	LUT 1,2,4,5 af	LUT 3,6 adf	-
15	MA2 Fd1 Ft2 Su5 Wd3 Wf3	-	LUT 1,2,4,5 af	LUT 3,6 adfw	-
16	VA1 Fd1 Ft1 Su4 Wd1 Wf2	LUT 1	LUT 2,4 f	LUT 3,5,6 afw	-
17	VA1 Fd1 Ft1 Su4 Wd3 Wf3	LUT 1	LUT 2,4 f	LUT 3,5,6 adfw	-
18	VA1 Fd1 Ft1 Su5 Wd2 Wf1	LUT 1	LUT 2,4 f	LUT 3,5,6 adf	-
19	Va1 Fd1 Ft2 Su5 Wd3 Wf3	LUT 1	LUT 2,4 f	LUT 3,5,6 adfw	-
20	VA2 Fd1 Ft2 Su4 Wd3 Wf3	-	LUT 4 f	LUT 1,2,3,5 adfw	LUT 6 a
21	VA2 Fd1 Ft1 Su5 Wd2 Wf1	-	LUT 4 f	LUT 1,2,3,5 afd	LUT 6 a
22	VA2 Fd1 Ft2 Su5 Wd3 Wf3	-	LUT 4 f	LUT 1,2,3,5 adfw	LUT 6 a
23	VA2 Fd1 Ft2 Su4 Wd3 Wf3	-	LUT 4 f	LUT 1,2,3,5 adfw	LUT 6 a

* for explanation of the land unit codes in Thanh Hoa see Table 5.10

Suitability classes: S1 = highly suitable; S2 = moderately suitable;
S3 = marginally suitable; N = not suitable

Limiting factors:
a = acidity (actual or potential)
d = possibility to drain land at the start of the end of flood period in order to start HY rice on time
f = flood (depth and/or duration)
w = availability of fresh irrigation water in dry season

In Thanh Hoa non-acid and moderately acid units (units 1-11 and 16-19) are highly suitable for double rice cultivation of high yielding and traditional rice (LUT 1). In the other units problems of fresh water availability and acidity make the land only moderately or marginally suitable. Twice high yielding rice (LUT 2) is more difficult, also in the non-acid and moderately acid areas, because of deep and long floods and acidity. Triple rice can only be practised successfully in unit 1, while unit 12 is marginally suited because of long and deep floods, problems of timely drainage at the end of the rainy season, and availability of irrigation water for irrigation. Yams can be cultivated in all land units but the non-acid and moderately acid land is only moderately suitable, and the very acid land marginally suitable because of floods and poor water availability. The deep flood is also a problem for sugar cane. On the acid land the potential acidity is a problem because high raised beds need to be made, disturbing the potentially acid soil. The entire Thanh Hoa area is moderately suited for Melaleuca. Deep floods prevent high suitability.

IX. CONCLUSIONS

Taking present land use as a basis for the description and selection of relevant land use types, land evaluation studies of acid and non-acid land in the Mekong delta demonstrate large differences in level of investment, gross margins and labour requirements.

The most important land and water management practices for rice cultivation are the use of varieties and selection of growth periods adapted to the local flood depth and flood duration, an optimal use of the irrigation and drainage possibilities offered by tidal movement. For upland crops the construction of raised beds to overcome floods and improve drainage is important. In Phung Hiep a land and water management system for combined rice and shrimp cultivation has been developed.

There is a surprisingly wide variety of land use systems on acid soils. Eleven land use types in Phung Hiep and six in Thanh Hoa were selected for land evaluation. After matching the requirements of the selected land use types and the land qualities of the land units showed that in Phung Hiep some land use types such as double rice, sugar cane and rice, cashew inter-cropped with pineapple and Melaleuca are highly or moderately suitable for the acid soil zone. In Thanh Hoa double rice is also possible on acid land, while yams, sugar cane and Melaleuca also are possible. For both districts limiting factors are acidity, flood hazard and lack of water for irrigation.

Chapter 6:

EPILOGUE

CONCLUSIONS AND RECOMMENDATIONS OR FUTURE RESEARCH

REFERENCES

SUMMARY IN ENGLISH, DUTCH AND VIETNAMESE

CURRICULUM VITAE

I. CONCLUSIONS

This thesis reflects part of the results, the methodologies applied and the change in approach to research of a project of co-operation (VH 10, 1980-1992) between the Universities of Can Tho, Mekong delta, Vietnam, and Wageningen, the Netherlands. The project focused on finding methods for improved management and use of acid sulphate soils in the Mekong delta. The thesis also reviews the recent literature on acid sulphate soils, and screens it for its applicability.

The review of the recent literature on acid sulphate showed that:

1. Identification and survey of acid sulphate soils remains invariably difficult because of: (I) the absence of morphological features indicating the potential acidity; (ii) the high spatial variability of the soil characteristics in both potentially acid and actual acid sulphate soils, which has the effect that more intensive sampling schedules do not yield better survey results; (iii) the need for field laboratory support; (iv) the difficult access of most of the terrain and (v) the dynamic nature of the soils.
2. Modelling has contributed to a better understanding of the chemical and physical processes in acid sulphate soils and has made prediction of the changes in chemical properties of such soils under different possible water management regimes, but so far it is only remotely possible to utilise the models for practical application in land use planning. It is advisable to let mathematical modelling play a role in quantifying some already known key processes, and not aim at an all-encompassing, complete model of dynamic processes in acid sulphate soils.
3. Indigenous knowledge on land use systems and soil/water management packages have only recently started to receive due attention in literature, while they were often developed after generations of trial and error, and are accepted by the local population.
4. There is a wide range of indigenous land use systems on acid sulphate soils, much wider than initially seemed possible. In the Mekong delta, Vietnam farmers showed it is possible to use this land for the cultivation of yam, sweet potato, cassava, pineapple, sugar cane, fruit trees and, of course, rice, but also for fish and shrimp ponds. The land use systems require high skills on soil and water management from the land users.

The VH 10 project shifted its research focus from a top-down approach based on specialist knowledge to a more bottom-up approach, with priority for incorporation of knowledge of farmers and local experts in the experimental set-up. This shift in research approach paid off: results were more directly applicable in the second half of the project period. A balanced knowledge exchange between farmers, local experts and acid sulphate soil specialists has been the basis of the project's working methodology.

Research results, notably the recommendations for farmers, were invariably applicable at a detailed scale. This is due to the high variability of the soils, and the intricate measures to be taken for proper management. For rice cultivation, for instance, meticulous timing of drainage and irrigation, a dense network of ditches and good levelling are needed to obtain reasonable yields. Such recommendations cannot be adopted by extensive, large state farms. The shift in research approach (see above) happened at the time of introduction of the "doi moi" policy of economic liberalisation by the Vietnamese government. One of the consequences was the abandonment of large state farms, which were replaced by reclamation of acid sulphate land by private settlers. This change in land use pattern made the results of VH 10 much more widely applicable.

The strong embedding of the Faculties of Agriculture and Water Management of CU in the rural society of the Mekong delta by means of an intricate network of contacts with local authorities, extension services, state farms and private farmers was a precondition for the proper execution of VH 10. But other special aspects of the co-operation also contributed: long-term continuity of staff and means, no foreign expert permanently stationed in Vietnam, genuine interest of both partners in the project results, and the acceptance of the principle of mutual learning.

Evaluation of acid sulphate land can best be achieved by incorporation and integration of knowledge and expertise of farmers (land use types, management practices), experts (soil and hydrological surveys, fertiliser recommendations) and specialists (processes and properties of acid sulphate soils, methodology).

II. A RECOMMENDATION FOR FUTURE RESEARCH

Land evaluation studies are static, and the framework for land evaluation is a rigid, not always very accessible system, presenting the important information in large tables. A major step ahead can be presentation of results by means of decision trees as they are now in development, but even those are static. Acid sulphate soils with their dynamic nature would require a more dynamic way of presentation, and should leave choices to those interested in using the information. At this moment, the application of crop simulation models for acid sulphate soil conditions is not very useful since the soil-plant relationships, i.e. the reaction of plants to the dynamics of acid sulphate soils, are not yet well understood.

Instead of aiming for such models, the development of a dynamic system might be pursued to support the decisions which have to be taken by farmers and local experts in the Mekong delta, who are engaged in acid sulphate land use. Such a system can be built in a bottom-up way, similarly to the research approach presented in this thesis and elsewhere in literature, linking land management measures, to existing spatial knowledge such as soil and hydrological surveys by means of a Geographic Information System. In the first place, the system should yield decision support for the farmers, and should supply answers to questions such as: what are the properties of my land, what crop is most suited for the land, what crop gives the best economic return, which investments need to be made, which soil and water management measures need to be taken to optimise the proposed crop, etc. At a higher level of aggregation, e.g. for district or provincial planning offices, the information from a decision support system at farmer level can be used for extension and local or regional market analysis. At that level, however, the system should also support different types of decision making, not directly aimed at the interest of any individual farmer. One might think of information on the environmental consequences of proposed crop and management measures. For instance, if the system advises individual farmers to improve their land through construction of raised beds for annual or perennial upland crops this will entail pollution of the surface water. So regional restrictions may have to be applied.

In order to succeed, the development of such a decision support system should apply a bottom-up methodology using intensive exchange with farmers and local experts. Only then can the system make proper use of the treasure of information on land, land use, soil and water management present among Mekong delta farmers.

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IV. SUMMARY

Half the Mekong delta in Vietnam, i.e. around 2 million hectares, suffers soil related problems due to acid sulphate soils. These soils generate sulphuric acid due to the oxidation of pyrite after aeration. Pyrite is most easily formed in tidal swamps. Human interference through land drainage is the most important way in which the acidification takes place. The processes of pyrite formation, of acidification and of the solution chemistry of these soils have been well explained (e.g. van Breemen 1976, Dent 1986). The translation of this knowledge into practical recommendations for farmers is still problematic.

The Can Tho University (CU), the only institution for higher education in the delta, saw it as its duty to assist the farming community on these soils and come up with practical recommendations for improved agricultural use. From 1980 - 1992 a project of co-operation between CU and the Wageningen Agricultural University, particularly the Soil Science Department, where specialised knowledge on the processes of formation and the chemistry of these soils was present, was carried out. Objectives of the project were (1) to train CU staff in acid sulphate soils formation and survey; (2) to carry out research for improved management of these soils and (3) to equip CU with the necessary facilities for such a research and training programme.

The aims of this thesis are:

1. to review the recent literature on acid sulphate soils in order to screen the methodological developments for survey and identification, for chemical and physical support in field and laboratory, for simulation and mathematical modelling of the soil processes, for management and land use and for acid sulphate land evaluation;
2. to screen the recent literature, particularly the information supplied by the world's leading specialists in acid sulphate soils in the form of the proceedings of the three most recent conferences on this subject, for its practical applicability by other groups involved with acid sulphate soils: farmers and local experts;
3. to describe the way the project VH 10, a project of co-operation between the Universities of Can Tho (CU), Mekong delta, Vietnam, and Wageningen Agricultural University (WAU) carried out research for improved management of acid sulphate soils between 1980 and 1992 with particular emphasis on the balanced exchange of knowledge between the three groups of people involved: farmers, local experts and specialists;
4. to describe the way the VH 10 project operated in view of the emphasis it placed on farmer-expert-specialists knowledge exchange, its strong outreach component towards the farming community and its special ways of operation;
5. to give some examples of studies which combine farmers, local expert and specialists knowledge to evaluate the acid sulphate land in the Mekong delta.

The review of the recent literature (chapter II of this thesis) shows how difficult the diagnosis of acid sulphate land is. Some indications can be expected from the vegetation or the drainage patterns. Coastal wetlands, inland marshes and swamps and mine spoils

are the land forms where potential acid sulphate soils occur. Surface water usually gives a first warning of acidification having taken place by an oily skin at the surface (iron) or suspicious water clarity (acidity and aluminium). Identification of acidified soils is usually easy through the appearance of pale-yellow jarosite mottles, but is much more difficult in potential acid sulphate soils (pyrite is invisible) or in acidified soils without jarosite. Field tests such as oxidation by hydrogen peroxide for potential acidity, or the azide-soap and the red lead paint for sulphide may help in identification. Moist incubation for prolonged periods is recommended to make sure. Soil survey is difficult because of land inaccessibility, high spatial variability of the diagnostic characteristics and the need for specialised laboratory assistance to identify acid sulphate components. The dynamic modelling of acid sulphate soils received much attention in recent years and resulted in sophisticated models encompassing the processes but inevitably requiring many detailed data for model application. Regardless of all research efforts many management decisions have still to be taken after the problems have already become manifest. Local farmers have, particularly in Southeast Asia, succeeded in adapting to the situation and they have developed interesting management systems for cultivation of rice, shrimp and fish, yams, pineapples, sugar cane and fruit trees.

The proceedings of the three last conferences dedicated to acid sulphate soils show that most knowledge is communicated specialists to specialists; that some attention is paid to generating knowledge suited for the needs of the local experts such as soil survey methodologies and for the needs of the farmers and the extension workers such as fertiliser recommendations, on-farm water management strategies and crop choice. Only in a few cases, however, the indigenous knowledge of the farmers has been used to its full potential. It is particularly in the Mekong delta that the local farmers' knowledge has played a dominating role in acid sulphate soils research for practical application.

The VH 10 project of CU and WAU profited from the strong embedding of CU, in particular its Faculties of Agriculture and of Water Management and Rural Engineering, in the rural society of the Mekong delta. The network of contacts with provincial and district agricultural services, with state farms and with private farmers could be used for gathering local farmer knowledge, for experimentation in line with farmers experience, for extrapolation of the findings to other locations in the delta and for knowledge dissemination through workshops and TV programmes.

The research set-up of the project changed from a top-down technology driven approach in the early and mid-eighties to a system of a balanced knowledge exchange between farmers, local experts and soil/water specialists in the late eighties and early nineties. This approach generated much more successful recommendations for farmers than the top-down approach.

The project had a number of deviating organisational aspects which might be interesting for application elsewhere: (1) no permanent foreign staff present in Vietnam; (2) large share of the responsibility for the execution of the project left with the Vietnamese counterparts; (3) long term continuity of the project with the same staff (twelve-and-a-half years); (4) mutual interest in project objectives by both partners; (5) applying the principle of learning from each other.

The project profited from the political change of economic liberalisation in Vietnam in the second half of the eighties since recommendations for improved use of acid sulphate soils, emphasising small-scale development, could much better applied by small farmers than by large scale state farms.

Two evaluation studies of the acid sulphate land in the Mekong delta (chapter V) showed that fresh water availability is the most important constraint to farming. Moderately and slightly acid land, characterised by a sulphuric horizon deeper than 50 cm, of which large tracts are present in the Mekong delta, can become suited for rice and tolerant upland crops such as yam, cassava or sweet potato when fresh water is available. However, severely acid land will only become marginally suited and should therefore not be given priority for development. Well constructed raised beds can improve the land and makes moderately acid land highly suited for pineapple and sugar cane, provided the coastal salt intrusion in the dry season is short (less than 3 months) and the annual Mekong river flood does not exceed a depth of about 60 cm. Both evaluation studies describe in detail farmers' practices of an unexpected wide variety of land use types and thereby emphasise the main focal point of this thesis which is the major input of farmer's expertise in developing innovative management schemes for these problem soils.

V. SAMENVATTING

Slechts de helft van de Mekong delta, Vietnam bestaat uit vruchtbare gronden. De andere helft wordt gekenmerkt door probleemgronden, met name potentiele en actuele kattekleien. Zwavelzuur komt vrij uit potentiele kattekleien, door oxidatie van pyriet na drainage. De drainage is in het overgrote deel van de gevallen, en ook zo in de Mekong delta, het gevolg van menselijk ingrijpen. De vorming van pyriet, en de verzuringsprocessen na drainage zijn bekend uit de wetenschappelijke literatuur, maar de vertaling van deze kennis naar praktische aanbevelingen voor boeren die van dit land gebruik willen, of beter: moeten, maken is nog steeds problematisch, met name in Vietnam waar tienduizenden boeren families op dit land zijn aangewezen.

De Universiteit van Can Tho (CU), de enige instelling voor hoger onderwijs in de Mekong delta, beschouwde het als een plicht om de boerenbevolking in de kattekleigebieden te adviseren, en praktische aanbevelingen te ontwikkelen voor beter gebruik van deze gronden. Van 1980 tot 1992 heeft een samenwerkingsproject (codenaam: VH 10) tussen CU en de Landbouwuniversiteit Wageningen LUW (met name de vakgroep Bodemkunde en Geologie waar de basiskennis over de vorming van kattekleien aanwezig was) getracht te werken aan kattekleiverbetering in de Mekong delta. Doelstellingen van het project waren kennisoverdracht, het uitvoeren van onderzoek naar verbeteringmethoden voor kattekleigronden en het voorzien in faciliteiten voor CU.

Het doel van dit proefschrift is:

1. een overzicht te geven van de recente literatuur over kattekleien, met name de ontwikkeling van methodieken die kunnen leiden tot betrouwbare kartering en identificatie, de chemische analyse in het veld en het laboratorium, het simuleren van de bodemprocessen door middel van dynamische wiskundige modellen, en het beheer, het gebruik en de evaluatie van de kattekleigronden;
2. deze literatuur kritisch te bekijken wat betreft zijn praktische toepasbaarheid voor andere groepen geinteresseerden, met name de boeren en de lokale experts zoals voorlichters en district/provinciale landgebruiksplanners;
3. de methode van onderzoek aan de kattekleiverbetering te beschrijven zoals die is gehanteerd in het VH 10 project, waarin de nadruk is gelegd op een gebalanceerde uitwisseling van kennis tussen boeren, experts en specialisten.
4. de speciale manier van opereren in het project, met name de grote veldcomponent die het gevolg was van deze onderzoeksaanpak, aan te geven;
5. twee voorbeelden te geven van studies die de kennis van boeren, experts en specialisten combineren ten behoeve van de evaluatie van het kattekleiland in de Mekong delta.

De recente literatuur (hoofstuk II) geeft aan dat de diagnose van met name de potentiele kattekleien nog steeds problematisch is. Indicaties voor het voorkomen kunnen worden gezien aan vegetatie en drainage patronen. Natte kustgebieden, maar ook moerasgebieden in het binnenland en de afvalbergen van mijnen zijn de plaatsen waar potentiele kattekleien voorkomen. Het oppervlaktewater geeft vaak de eerste indicaties van verzuring: een olieachtig laagje op het water (ijzer) of kraakheder water waar dat niet te verwachten is (aluminium). Eenmaal verzuurd is de identificatie doorgaans eenvoudiger via stro-gele jarosietvlekken die zijn ontstaan, maar op veel plaatsen (Indonesie, Vietnam, West-Afrika) zijn kattekleien zonder jarosiet aangetroffen. Eenvoudige chemische veldproeven (oxidatie van pyriet door waterstof peroxide, azide of loodmenie voor sulfiden) kunnen helpen bij identificatie van potentiele kattekleien. Het vochtig incuberen gedurende langere tijd geeft een betrouwbaarder beeld van de mogelijke verzuring. Het karteren van met name potentiele kattekleigebieden is problematisch vanwege de toegankelijkheid van het terrein, de hoge ruimtelijke variabiliteit van de bodemeigenschappen waardoor zij niet betrouwbaar te karteren zijn en de noodzaak van gespecialiseerde laboratoria voor chemische ondersteuning. Het dynamisch simuleren van de bodemprocessen kreeg veel aandacht in de recente literatuur en resulteerde in geavanceerde modellen die de veranderingen in chemische samenstelling van kattekleien ten gevolge van hydrologische ingrepen kunnen voorspellen, maar deze modellen zijn tot op heden nog ver verwijderd van praktische toepassing voor landgebruiks planning. De meeste maatregelen voor de kattekleien moeten nog steeds worden genomen nadat het kwaad al is geschied en de verzuring heeft plaatsgevonden. Met name in Zuid-Oost Azie zijn boeren er in geslaagd hun landgebruik aan te passen, en hebben een verrassend breed scala aan landgebruikssystemen ontwikkeld voor gewassen als rijst (soms in combinatie met vis- of garnalenteelt), yams, zoete aardappelen, cassava, ananas, suikerriet en vruchtbomen.

De verslagen van de laatste drie speciaal aan kattekleien gewijde conferenties geven aan dat de meeste daarin vastgelegde informatie bedoeld is van specialist voor specialist; dat een deel van de informatie geschikt is om door lokale experts te worden gebruikt, bijvoorbeeld aanbevelingen voor verbetering van de kwaliteit van karteringen en dat een nog kleiner deel kan worden gebruikt voor advisering van en toepassing door boeren, bijvoorbeeld aanbevelingen voor kunstmestgiften, waterbeheer of keuze van gewassen. Er zijn slechts enkele voorbeelden te vinden van studies die zijn begonnen bij de boeren zelf, en die de kennis van de boeren aanwenden om te komen tot aanbevelingen voor verbeterd landgebruik.

Het VH 10 project van CU en LUW heeft kunnen profiteren van de sterke binding tussen CU (met name de faculteiten van Landbouw en Waterbeheer/Rurale techniek) en de rurale bevolking in de Mekong delta. Het netwerk van contacten met de landbouwdiensten van districten en provincies, met staatsbedrijven en met individuele boeren is aangewend om de kennis over het gebruik van kattekleien, opgebouwd door een generaties lange "struggles for life", te verzamelen, maar ook om experimenten uit te voeren gestoeld op deze kennis, om de uitkomsten van de experimenten te extrapoleren naar andere gebieden in de delta, en voor het doorgeven van de nieuw gegenereerde projectkennis via bijeenkomsten en TV programma's.

Het onderzoek in het project veranderde in de loop van de tijd van een centralistische, top-down aanpak in de eerste helft van de tachtiger jaren naar een veel meer gebalanceerd systeem, waarin de drie belanghebbende groepen (boeren, experts en specialisten) kennis uitwisselden. Deze veranderde aanpak leverde veel meer direct toepasbare aanbevelingen voor landgebuik op.

Het project had een aantal afwijkende organisatorische aspecten die het vermelden waar zijn, en positief hebben gewerkt bij de projectuitvoering: (1) geen Nederlander(s) permanent in Vietnam; (2) een groot deel van de verantwoordelijkheid van het project gelaten bij de Vietnamese counterparts; (3) continuiteit door lange projectduur en dezelfde stafbezetting met name van Vietnamese kant; (4) het belang in het onderzoek voor beide partijen en (5) de wederzijdse overtuiging dat er van elkaar veel te leren valt.

Het project profiteerde in feite ook van de economische liberalizatie die in de tweede helft van de tachtiger jaren plaatsvond in Vietnam daar de aanbevelingen, gevonden op basis van het onderzoek vrijwel uitsluitend op kleine schaal uitvoerbaar zijn. Voorbeelden: voor rijst is een dicht net van sloten, volledig waterbeheer, nauwkeurige timing van irrigatie en drainage, en een perfect vlak veld nodig, terwijl voor niet-geinundeerde gewassen bedden op de juiste manier moeten worden aangelegd en doorgespoeld. Dit soort aanbevelingen waren niet toepasbaar voor de grote staatsbedrijven die eind jaren zeventig, begin jaren tachtig op de kattekleigebieden waren opgezet.

De twee landevaluatie studies (hoofstuk V) laten zien dat de aanwezigheid van zoet water het meest belangrijke struikelblok is voor de landbouw op kattekleigronden in de delta. Kattekleien met de zure horizont dieper dan 50 cm in het profiel, waarvan honderdduizenden hectaren aanwezig zijn de de delta, kunnen geschikt gemaakt worden voor rijstbouw en voor het verbouwen van yam, cassava of zoete aardappelen indien zoet water beschikbaar is. Kattekleien met de zure horizont hoog in het profiel, binnen 50 cm, zullen slechts marginaal geschikt worden voor deze gewassen, en dienen dus geen ontwikkelingsprioriteit te krijgen. Goed geconstrueerde bedden met de bovengrond weer aan het oppervlakte zorgen voor versnelde afvoer van oplosbare zure componenten en maken de gronden met zure horizont dieper dan 50 cm zeer geschikt voor langjarige gewassen als ananas en suikerriet, mits men zich beperkt tot gebieden waar de zoutintrusie in het droge seizoen korter dan 3 maanden duurt, en de jaarlijkse overstroming door de Mekong rivier niet dieper is dan 60 cm. De beide evaluatiestudies beschrijven de boerenpraktijk in detail, laten een onverwacht breed scala aan landgebruiksmogelijkheden zien en benadrukken het belangrijkste punt in dit proefschrift: het belang van het incorporeren van boerenkennis in het ontwikkelen van methoden voor verantwoord gebruik van deze probleemgronden.

TÓM TẮT

(Summary in Vietnamese)

Phân nữa Đồng Bằng Sông Cửu Long thuộc Việt Nam, khoảng 2 triệu ha, phải chịu những khó khăn về đất phèn. Đất phèn sinh ra phèn là do sự oxít hóa chất sinh phèn sau khi đất đã được thoáng khí. Chất sinh phèn thường hình thành dễ dàng ở những bải thủy triều. Tác động can thiệp của con người thông qua việc thoát nước là yếu tố quan trọng làm sản sinh ra chất phèn. Tiến trình hình thành chất sinh phèn, sự phèn hóa và các tiến trình hóa học trong dung dịch đất của các loại đất phèn khác nhau đã được giải thích đầy đủ (van Breemen, 1976; Dent, 1986). Truyền đạt những kiến thức về đất phèn này vào sản xuất thực tế của người nông dân thì vẫn còn là vấn đề cần nghiên cứu.

Trường Đại Học Cần Thơ (CU), cơ quan duy nhất đào tạo Đại Học ở Đồng Bằng, đã nhìn thấy vấn đề và trách nhiệm của mình trong việc giúp đỡ cộng đồng nông dân trên những vùng đất phèn này và cũng để hướng đến những đề xuất thực tế trong các hoạt động nông nghiệp có cải tiến. Từ năm 1980 đến 1992, một đề án hợp tác giữa Trường Đại Học Cần Thơ (CU) và Trường Đại Học Nông Nghiệp Wageningen, đặc biệt là Bộ Môn Khoa Học Đất, nơi đã có các kiến thức chuyên môn về đất phèn và đang nghiên cứu các tiến trình hình thành và các biến đổi hóa học trong các lọai đất phèn. Mục tiêu của đề án là: (1) đào tạo chuyên môn cho cán bộ Đại Học Cần Thơ; (2) tiến hành nghiên cứu và cải tạo đất phèn, và (3) trang bị cho Đại Học Cần Thơ (CU) những trang thiết bị cần thiết cho chương trình nghiên cứu và đào tạo.

Mục đích của luận án này là:

1. tổng hợp các tư liệu mới nhất về đất phèn để nghiên cứu hình thành phát triển các phương pháp cho khảo sát và nhận diện đất phèn, hổ trợ về mặt lý hóa học ở ngoài đồng và trong phòng thí nghiệm, mô hình giã định và toán học về các tiến trình xảy ra trong đất, việc quản lý sử dụng và đánh giá đất đai cho đất phèn.
2. sàn lọc ra các tư liệu mới nhất, đặc biệt là các thông tin được cung cấp bởi những chuyên viên hàng đầu trên thế giới về đất phèn được tập hợp trong các tuyển tập của 3 hội nghị gần đây nhất về chuyên đề này, cho thấy khả

năng áp dụng thực tế trong các nhóm khác nhau liên quan đến lảnh vực đất phèn đó là: nông dân và các chuyên gia địa phương;

3. mô tả cách thức hoạt động của đề án VH10, một đề án hợp tác giữa Trường Đại Học Cần Thơ (CU) ở Đồng Bằng Sông Cửu Long, Việt Nam và Trường Đại Học Nông Nghiệp Wageningen (WAU) để tiến hành thực hiện các nhiên cứu trong việc quản lý cải tạo đất phèn từ năm 1980 đến 1992, đặc biệt là nhấn mạnh đến sự trao đổi cân bằng về kiến thức chuyên môn giữa 3 nhóm nhân sự có liên quan nhau: nông dân, chuyên gia địa phương và các chuyên viên khoa học;
4. mô tả cách hoạt động của đề án VH10 nhấn mạnh đến các hoạt động trao đổi kiến thức chuyên môn giữa nông dân-chuyên gia địa phương-chuyên viên khoa học, thành phần mạnh của nó để hướng đến cộng đồng nông thôn và những phương cách đặc biệt của nó trong hoạt động.
5. trình bày những thí dụ nghiên cứu về việc kết hợp kiến thức giữa nông dân, chuyên gia địa phương và chuyên viên khoa học để đánh giá đất đai cho đất phèn vùng Đồng Bằng Sông Cửu Long.

Tổng hợp các tư liệu mới nhất (chương II của luận án) cho thấy những khó khăn như thế nào trong việc chẩn đoán đất phèn. Một vài yếu tố chỉ định có thể dự đoán được dựa vào thực vật hoặc kiểu hình dòng chảy. Đất bồi ven biển, đầm lầy và đầm là những dạng hình đất đai mà đất phèn tiềm tàng có thể xảy ra. Lớp nước mặt cũng báo trước được sự phèn hóa như hiện diện lớp ván phèn trên bề mặt (phèn sắt), hoặc nước trong xanh (chua và phèn nhôm). Sự nhận diện đất phèn thường dễ dàng nhờ vào sự hiện diện của các đóm phèn jarosite màu vàng nhạt, nhưng lại gặp khó khăn trong việc nhận diện đất phèn tiềm tàng (do chất sinh phèn pyrite không nhìn thấy được) hoặc đất phèn mà tầng phèn không có đóm jarosite. Các thử nghiệm ngòai đồng như dùng chất H_2O_2 để oxít hóa phèn tiềm tàng, hoặc dùng chất azide-soap và màu đỏ cho sulphide cũng có thể giúp để nhận diện đất phèn được. Dùng phương pháp ủ ở điều kiện ẩm trong thời gian dài cũng đã được đề nghị để khẳn định chắc chắn hơn về đất phèn. Khảo sát đất là vấn đề khó khăn do sự biến động và không đồng nhất của đất đai và những biến động cao theo không gian các đặc tính chẩn đoán và đòi hỏi phải có sự hổ trợ của phòng thí nghiệm chuyên biệt để nhận diện các thành phần của đất phèn. Những mô hình về động thái đất phèn cũng đã được quan tâm chú ý trong những năm gần đây và đã cho những kết quả với những mô hình phức tạp hàm chứa các tiến trình trong đất tuy nhiên nó cũng đòi hỏi quá nhiều số liệu chi tiết cho việc áp dụng các mô hình này. Không kể tất cả các cố gắng nghiên cứu về nhiều quyết định về quản lý đất phèn vẫn phải còn đang được tính đến sau khi đã thấy được những khó khăn đã hiển nhiên đó. Những nông dân địa phương, đặc biệt là ở vùng Đông Nam Châu Á, đã thành công trong việc quản lý canh tác thích nghi với điều kiện hiện tại của đất phèn và họ đã phát triển những hệ thống quản lý đầy thú vị cho việc canh tác lúa, nuôi tôm và cá, khoai mỡ, dứa, mía và cây ăn trái.

Những tuyển tập của ba hội nghị quốc tế vừa qua chú tâm đến đất phèn đã cho thấy hầu hết các kiến thức về đất phèn đã được thông tin lẫn nhau giữa các chuyên viên khoa học; chỉ có vài sự chú ý quan tâm trong việc hình thành nên các kiến thức mà nó phù hợp cho những nhu cầu cần thiết của các chuyên gia địa phương như phương pháp khảo sát đất phèn và những kiến thức cần thiết khác cho nông dân, cán bộ khuyến nông như khuyến cáo phân bón, chiến lược quản lý nước trong các nông hộ, và chọn lựa các loại cây trồng. Tuy nhiên một vài trường hợp thì những kiến thức kinh nghiện của nông dân đã và đang làm được xem như là một tiềm năng đáng kể. Đặc biệt là ở Đồng Bằng Sông Cửu Long, kiến thức kinh nghiệm người nông dân đóng một vai trò chính trong các lảnh vực nghiên cứu đất phèn cho ứng dụng thực tế.

Đề án VH10 giữa Trường Đại Học CầnThơ (CU) và Trường Đại Học Nông Nghiệp Wageningen (WAU) đã mang lại nhiều thuận lợi cho Đại Học Cần Thơ (CU), đặc biệt là Khoa Nông nghiệp và Khoa Thủy Nông Cải Tạo Đất, và cho cả khu vực nông thôn ở Đồng Bằng Sông Cửu Long. Mạng lưới liên kết giữa các bộ phận khuyến nông của Tỉnh và Huyện, Nông trường Quốc doanh, và với nông dân đã được áp dụng để thu thập các kinh nghiệm kiến thức của nông dân địa phương, để từ đó làm cơ sở bố trí các thí nghiệm nghiên cứu và truyền bá các kiến thức này sang các vùng địa phương khác ở Đồng Bằng và đồng thời các kiến thức này cũng được mở rộng ra thông qua các buổi hội thảo và chương trình truyền hình.

Những nghiên cứu được xây dựng trong đề án đã làm thay đổi từ kỹ thuật theo phương pháp trên-dưới trong những năm đầu đến giữa những năm 80 thành một hệ thống trao đổi kiến thức cân bằng giữa người nông dân, chuyên gia địa phương và các chuyên viên khoa học về đất/nước trong cuối những năm 80 và những năm đầu 90. Phương pháp này đã khuyến cáo đến nông dân rất thành công hơn là phương pháp “trên-dưới”.

Đề án đã hình thành một số vấn đề khá lý thú về mặt phân chia tổ chức thực hiện để có thể áp dụng ở các nơi khác: (1) chuyên gia nước ngoài không phải hiện diện thường xuyên ở Việt Nam; (2) bộ phận đối tác của Việt Nam được phân chia giữ một số trách nhiệm lớn trong việc thực hiện đề án; (3) có tính liên tục của đề án cũng như các thành viên tham gia (mười hai năm rưỡi); (4) cùng đáp ứng đúng mục tiêu của cả hai phía hợp tác; (5) áp dụng nguyên tắc học tập lẫn nhau.

Đề án đã phát triển có chiều hướng thuận lợi theo sự thay đổi chính sách kinh tế thị trường ở Việt Nam trong sau giữa những năm 80, từ những khuyến cáo trong việc sử dụng cải tạo đất phèn, nhấn mạnh đến việc nên phát triển ở tỉ lệ nhỏ, có thể tốt hơn nhiều khi áp dụng những kết quả nghiên cứu bởi những người nông dân hơn là áp dụng cho cả Nông Trường Quốc Doanh rộng lớn.

Hai kết quả đánh giá thích nghi đất phèn ở Đồng Bằng Sông Cửu Long (chương V) cho thấy khả năng về nước tưới là yếu tố hạn chế quan trong nhất cho nông nghiệp. Đất phèn trung bình và nhẹ, được đặc tính hóa bởi độ sâu xuất hiện tầng phèn hơn 50 cm từ bề mặt, chiếm một vùng rộng lớn ở Đồng Bằng Sông Cửu Long trở nên thích nghi cho lúa và các cây trồng cạn chịu phèn như: khoai mỡ, khoai mì hay khoai lang, khi có đủ nước tưới. Tuy nhiên đất phèn nặng thì trở nên thích nghi kém và do đó không nằm trong diện ưu tiên để phát triển. Đào mương lên liếp có thể cải tạo được loại đất này và làm cho đất phèn trung bình có tính thích nghi cao với dứa và mía đối với vùng đất nhiễm mặn ngắn (ít hơn 3 tháng) và có độ sâu ngập hàng năm bởi sông Cửu Long khoảng 60cm. Cả hai nghiên cứu về đánh giá thích nghi đất đai đều mô tả chi tiết tính thực tiễn của nông dân trong những thay đổi về mặt đất đai không dự tính trước được của các loại sử dụng đất đai, và do vậy điểm chính của luận án này là muốn nhấn mạnh đến việc đầu tư chính về kiến thức trí tuệ của nông dân trong việc phát triển các mô hình quản lý tiến bộ cho đất có vấn đề.

VII. CURRICULUM VITAE

Martinus Eugene Franciscus van Mensvoort was born on August 8, 1945 at Vught, the Netherlands. After completion of the secondary school (HBS-B , St. Janslyceum, Den Bosch) he started his study at Wageningen Agricultural University (WAU) in 1964. He spent a one year practical period at the CSIRO Division of Irrigation Research in Griffith, New South Wales, Australia. He graduated in january 1973 with specialisations soil survey, soil fertility and agrohodrology.

After military service he worked for 5 years (1974-1979) in the FAO/UNDP Soil Resources Project, Ekona, Cameroon, three years as an associate expert and two years as an expert.

At the end of 1979 he returned to the Netherlands. On January 1 1980 he started as co-ordinator of the NUFFIC (Netherlands University Foundation for International Co-operation) sponsored project VH 10 of WAU and Can Tho University (CTU). The project carried out research for the management of acid sulphate soils in the Mekong delta. In 1988 he became a permanent staff member of the Department of Soil Science and Geology of WAU and remained responsible for VH 10 until the project termination in 1992.

From 1990 to 1993 he managed a second project with CTU, sponsored by the Science and Technology for Development Programme (STD-2) of the EC. This project involved, besides WAU and CTU, also the Belgian Universities of Louvain-la-neuve and Gembloux, and the Insitute of Agricultural Sciences at Ho Chi Minh City. The project investigated physical aspects and cultivation techniques of dryland crops on acid sulphate soils.

Together with his Vietnamese counterparts he organised the Fourth International Symposium on acid sulphate soils held at Ho Chi Minh City in March 1992, the final activity of the VH 10 project, and he was editor of the Symposium Proceedings.

He acted as a consultant to a number of national and international organisations: the World Bank, FAO, the Mekong Secretariat at Bangkok, and NEDECO consultants.

In 1995 a new project was started with CTU, sponsored again by NUFFIC through the MHO (Medefinanciering Hoger Onderwijs) programme. This project is one of a series of nine between CTU and Dutch Universities. He is project leader from the Dutch side and the project aims at integrated management of the vulnerable coastal fringe of the Mekong delta and involves knowledge transfer and research.