DEVELOPING MANAGEMENT PACKAGES FOR ACID SULPHATE SOILS BASED ON FARMER AND EXPERT KNOWLEDGE

Field study in the Mekong Delta - Viet Nam

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Le Quang Tri

Proefschrift
ter verkrijging van de graad van doctor
in de landbouw- en milieuwetenschappen
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Dr. C.M. Karssen,
in het openbaar te verdedigen
op woensdag 19 Juni 1996
des namiddags te twee uur in de Aula
van de Landbouwuniversiteit te Wageningen.

To Hong Hoa and Quang Huy

"I dedicate this thesis to my late mother who sacrificed a lot for my future."

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STATEMENTS

1. When studying acid sulphate soils, it is important to regard them as part of a living, integrated system of land, water, crops and people.
   - This thesis

2. Farmers' experience is usually limited to the local area where they live and to observed effects of different management procedures. Experts have to play a crucial role in extending and generalizing this local expertise.
   - This thesis
   - Bouma, J., M.E.F. van Mensvoort, and L.V. Khoa, 1993. Ways and means of modeling acid sulphate soils. In Dent, D.L. and M.E.F. van Mensvoort (editors); Selected papers of the Ho Chi Minh City symposium on acid sulphate soils. ILRI publication No. 53; pp. 331-340.

3. The most important land and water management practice for growing upland crops in the acid sulphate soil areas of the Mekong Delta is the construction of raised beds.
   - This thesis

4. Application of land evaluation results are often focused on land use planning purposes rather than on use by farmers, even though the definition of land evaluation would certainly include such applications, which are becoming increasingly relevant for the farm level.
   - This thesis
   - Bouma, J., R.J. Wagenet, M.R. Hoosbeek, and J.L. Hutson, 1993. Using expert systems and simulation modeling for land evaluation on farm level. A case study from New York State. Soil Use and Management 9(4), pp.131-139.

5. Given the need for operational, technical data for farm production analysis and planning, it is something of a puzzle why comprehensive multidisciplinary research efforts have not been more numerous.
   - Jensen, H.R., 1978

6. Most poor farmers in the developing countries have tried to increase their food production for more profit without any concern for environmental side effects. The improvement of farming systems should, therefore, be environmentally balanced, even if they are only marginally economic in the short-run.

7. In the past, land evaluation planners lump all local experiences under the heading "low input" or "primitive" and concentrate on "scientific" technological miracles. But at present, the expertise of the local farmer is a cornerstone for a land evaluation survey in the Mekong Delta.

8. On the whole, traditional knowledge and skills have severely been eroded in the "modernization process" and the lack of relevant traditional skills when improving farming systems is often a constraint on development.

9. In the last two decades, intensification in crop production has offered better perspectives for income generation than diversification in the acid sulphate land of the Mekong Delta. In future, however, diversification will be the only remaining option, which is likely to decrease sustainability of land use and to increase environmental problems.

10. "Give me a fish and I eat for a day; teach me to fish, and I eat for a lifetime". The urban population wants to eat fish but does, unfortunately, not associate this any more with fishing.

11. An astronomer can exactly forecast where a certain star is at midnight, but he can not forecast where his teenage daughter is at 23^h00. Correspondingly, a simulation model may be able to predict the Al^{3+} concentration in soil water but may fall far short in characterizing complex agro-ecosystems.

Statements by Le Quang Tri for "Developing management packages for acid sulphate soils based on farmer and expert knowledge. Field study in the Mekong Delta, Viet Nam. Wageningen Agricultural University, Wageningen, The Netherlands. June 19, 1996.

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CONTENTS

Chapter 1

General introduction

The lower strata of the Mekong river cover an area of 6.7 million hectares in the Southern part of Cambodia and in Viet Nam. The part of the Delta belonging to Viet Nam comprises 3.9 million hectares and is a young land mass formed not more than 10,000 years ago. The combined actions of rivers and the sea have formed good alluvial soils on elevated levees along the river and acid sulphate soils in lower backswamp areas such as the Plain of Reeds, the Long Xuyen Quadrangle, and Ca Mau peninsula. In the Mekong Delta, an estimated 1.6 million hectares consist of potential or actual acid sulphate soils, of which about 400,000 ha are characterized by salt surface water intrusion during the dry season. These acid soils with unfavourable chemical, biological, and physical properties are difficult to cultivate and improve (Xuan, 1995). Acid sulphate soils have been studied for many years. Soil-related problems for crops in drained acid sulphate soils include increased solubility of toxic aluminium when pH drops below 4; unavailability of phosphate through fixation by iron and aluminium; low base status; and salinity (Dent, 1992; Breemen, 1993). The importance of studying on acid sulphate soils, not in isolation but as components of a living, integrated system of land, water, crops and people.

Acid sulphate soils are unfavourable for farming. However, subsistence farmers have long been using part of the land quite satisfactorily. By trial and error, they have found various ways to overcome soil acidity and have succeeded to produce food crops and use the land in such a way that sustainable conditions exist (Xuan *et al.*,1982; Tri, 1990; Xuan, 1993). Many farmers in the Mekong Delta are highly receptive to new technologies and they are among the first agricultural entrepreneurs to quit a subsistence life and live in greater prosperity. On a large scale, they have abandoned their single crop system of traditional rice for two crops of modern rice-varieties. On the severely acid sulphate soils, *Melaleuca spp.* and cashew can grow very well; pineapple, sugarcane, jute, yam, and cassava bring an income to new settlers. In areas with salt water influence, farmers have started mixed farming systems including breeding of shrimps (Xuan, 1993; Xuan, 1995). Farmers' experience is usually limited to the area where they live and to directly observed effects of different management procedures. Underlying processes are often not understood but the farmers' model does reflect the observed effects of natural processes at different locations and has, therefore, a certain diagnostic character (Bouma *et al.*, 1993).

In 1976 the Vietnamese authorities solicited assistance from the Netherlands through NUFFIC (Netherlands Universities Foundation for International Co-operation), notably the Wageningen Agricultural University, to formulate strategies for reclamation, improvement and management of Acid Sulphate Soils for agriculture. As a result, in 1980 a co-operation project (acronym VH10) between the Universities of Can Tho and Wageningen was started. The project passed through four phases from 1980 to 1992 yielding significant contributions to the development of marginal lands for agricultural production in the Mekong Delta (Xuan, 1995). In Viet Nam two major questions regarding the use of acid sulphate soil areas had to be answered. The first, raised by Government, was "How can acid sulphate soils best be surveyed, and how can these results be used to delineate areas where agricultural development would be feasible?". The second question, often asked by provincial and district authorities, and their extension service concerned the determination of optimal land use at farm level, indicating land use type and detailed soil and water management packages for land improvement (Bouma *et al.*, 1993). A soil map of the entire Mekong Delta was made (Ve *et al.*, 1990). Most important new aspects in this study were the application of aerial photos and the definition of the diagnostic horizons in acid sulphate soils of the Mekong Delta (Pons *et al.*, 1989; Xuan, 1995). Land evaluation is the process of assessing the suitability of land for a specified kind of land use. Tuong *et al* (1991) used hydrological conditions in the delta to indicate suitable areas for double rice cropping. Mensvoort *et al.*(1993) and Tri *et al.* (1993) used present land use by farmers as a basis for land evaluation studies in the Mekong Delta. This procedure is advisable because of the high creativity of farmers resulting in many new ideas on soil management to be further explored by scientific research. Locally, suitability at farm level may be very different from what is predicted for the zone as a whole (Mensvoort *et al.*, 1993). Land evaluation studies according to criteria of the FAO framework (1976) are more accessible and transparent to the user when decision trees are used rather than the usual matching tables (Bouma *et al.*, 1993).

Many data have been gathered during the last twelve years in the VH-10 project: "Research on the Management of Acid Sulphate Soils in the Mekong Delta" (1980-1992). The strength of this program has been the strong interaction between soil experts and farmers to the effect that productive agricultural systems have been developed for soil conditions that appeared to be quite adverse at first sight. Effective interaction between farmers' expertise and expert knowledge has been a unique element in this study, which has been quite elusive in development projects elsewhere. The general objective of this thesis is to describe the process of interaction between farmers and experts in defining actual conditions for major areas, including variability involved. This general objective is worked out by: (1) a characterization of the process of interaction between farmers and experts in developing innovative soil and water management schemes for Acid Sulphate Soils; (2) a description of actual cropping systems in four case study areas, including a characterization of soil and hydrological conditions during the growing season; (3) development of modified land-use systems based on interpretations of local soil and management data; (4) formulation of problems encountered when defining such modified systems, using field and laboratory measurements, based on existing methodologies; and, finally, (5) presentation of existing and innovative soil and water management schemes for four case study areas, using decision trees.

Chapter 2 of this thesis presents the locations of four case study areas (Tan Thanh, Tri Ton, Phung Hiep, and Hong Dan), Mekong Delta, Viet Nam. Soil and climate conditions of the study areas were studied as well as their hydrology, to obtain an in-depth understanding of the physical production environment. Agricultural problems in terms of cultural practices, physical constraints, infrastructure, and farmers' knowledge are also identified for each individual study area.

Chapter 3 mainly contains historic records of farmer's land use and soil-water management practices in each study area reflecting farmers' expertise. Present land use types under different physical conditions are identified for further studies on land evaluation to be discussed in chapter 4.

Chapter 4 presents recently acquired expert knowledge on soil and water management practices, as discussed in chapter 3. Results are reflected by decision support systems using decision trees for land evaluation at farm level in the different study areas.

Chapter 5 is concerned with field experimentation. Additional agronomic knowledge of experts about cultivation of pineapple, yam, and rice is reflected in the three sections of this chapter.

Chapter 6 presents optimal farm management packages for different acid sulphate soils in four areas. Possible land use types including most appropriate cultural practices and soil-water management are formulated based on farmers' expertise and expert knowledge.

Chapter 7 contains the general conclusions.

Chapter 2

Physical conditions and agricultural problems

2.1 Location of four study areas:

Four study areas are located in three major regions of the Mekong Delta, which are the Plain of Reeds, Long Xuyen Quadrangle and Ca Mau Peninsula. Study areas were selected to represent major conditions in the Delta in terms of climate, soil characteristics, and hydrology.

- The area No.1 belongs to the northern part of Long An province. It lies in the Eastern part of the Plain of Reeds and along the West of West Vam Co river (see map, Figure 2.1). The study area covers 2 districts, that is Thanh Hoa and Tan Thanh.
- The area No.2 belongs to the western part of An Giang province. It lies in the central part of the Long Xuyen Quadrangle (see map, Figure 2.1). The study area covers 1 district, that is Tri Ton.
- The area No.3 is part of Can tho province and lies in the eastern part of the Ca Mau peninsula of the Mekong Delta (see map, Figure 2.1). The study area touches 3 districts, Phung Hiep, Long My and Vi Thanh.
- The area No.4 belongs to the lowest part of Minh Hai province. It lies in the Southern part of the Ca Mau peninsula (see map, Figure 2.1). The study area covers of Hong Dan district.

2.2 Physical environment of four study areas:

2.2.1 Climatic conditions:

The climate of the Mekong Delta is a monsoon climate. It is characterized by two distinct seasons: dry and wet season. The dry season starts in December and ends in April, and has cool and dry weather in December, January and February, getting hotter and more humid towards April. The wet season, with heavy rainfall, starts in May and ends in November, average of 20 days rain per month. The heavy rainfall explains the occurrence of aquic soil moisture regime. Based on the data obtained during a long period, the number of rainy days is frequently rather limited in August due to drought spells in the middle of the rainy season. This problem affects the rainfed Summer-Autumn crops cultivated in the acid sulphate soil areas because it leads to the acidification of water in the fields and top soils, resulting in low yields of crops.

In the Mekong Delta, total annual rainfall is between 1200mm to 2400mm. The sum of the potential evaporation is relatively high, about 1560 - 2000mm per year. Average monthly evaporation varies from 150 - 200 mm. The temperatures are relative high, average monthly temperature varies between 25°C to 28°C. The difference between the hottest and the coolest month is less than 5°C. The plentiful average radiation is between 140 to 160 Kcal/cm^2/year, and there is about 2260 to 2700 hours of sunshine/year. Most climatic factors in the Mekong Delta are favorable for agricultural production.

In general, the four study areas have climatic characteristics similar to the rest of the Mekong Delta. Specific sites of each study area in the Mekong Delta have, however, different characteristics of rainfall and rainfall distribution, evaporation, and temperature that can be shown in table 2.1.

Table 2.1: *Mean monthly precipitation, potential evaporation, and temperature in the four study areas : Tan Thanh area (Tan An, Long An province, 1958 - 1975, Nedeco-Master plan, 1991); Tri Ton area (Long Xuyen climatic station, 1947 - 1975, L.V. Phuong, 9/1979); Phung Hiep area (L.Q. Minh, 1984); and Hong Dan area (Camau climatic station, 1957 - 1971).*

Climatic factors	Months												Year
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec	
Tan Thanh area:													
Temperature (°C)	26.0	26.7	28.0	29.5	29.3	28.8	28.4	28.0	28.0	28.1	27.6	26.4	27.9
Evaporation (mm)	112	126	132	129	96	87	90	90	75	75	87	93	1186
Rainfall (mm)	10.7	1.3	6.1	57.4	194.6	225.6	215	180.6	242.2	237.9	119	51.7	1532
Tri Ton area:													
Temperature (°C)	25.5	26.3	27.5	28.5	28.4	28.2	27.7	27.5	27.5	27.3	26.7	25.9	27.3
Evaporation (mm)	98	122	163	162	96	100	89	93	83	83	97	107	1293
Rainfall (mm)	9	4	12	65	161	153	211	164	198	251	133	57	1418
Phung Hiep area:													
Temperature (°C)	25.2	26.0	27.2	28.4	27.4	27.9	27.0	27.0	26.8	26.8	25.4	25.5	26.8
Evaporation (mm)	124	137.2	164.3	147.0	93.0	84.0	89.0	93.0	75.0	63.0	66.0	93.0	1228
Rainfall (mm)	8.6	1.9	13.6	64.2	224.4	247.2	248.2	246.5	266.7	284.4	171.6	40.8	1841
Hong Dan area:													
Temperature (°C)	24.9	25.4	26.6	27.6	27.4	27.1	27.0	26.8	26.8	26.5	26.2	25.5	26.5
Evaporation (mm)	164	182.3	195.3	189	111.6	129	124	133.3	129	108.5	126	148	1740
Rainfall (mm)	18.3	8.7	31.7	96.9	290.1	306.6	329.6	343.2	337.4	331.5	178.7	87.3	2360

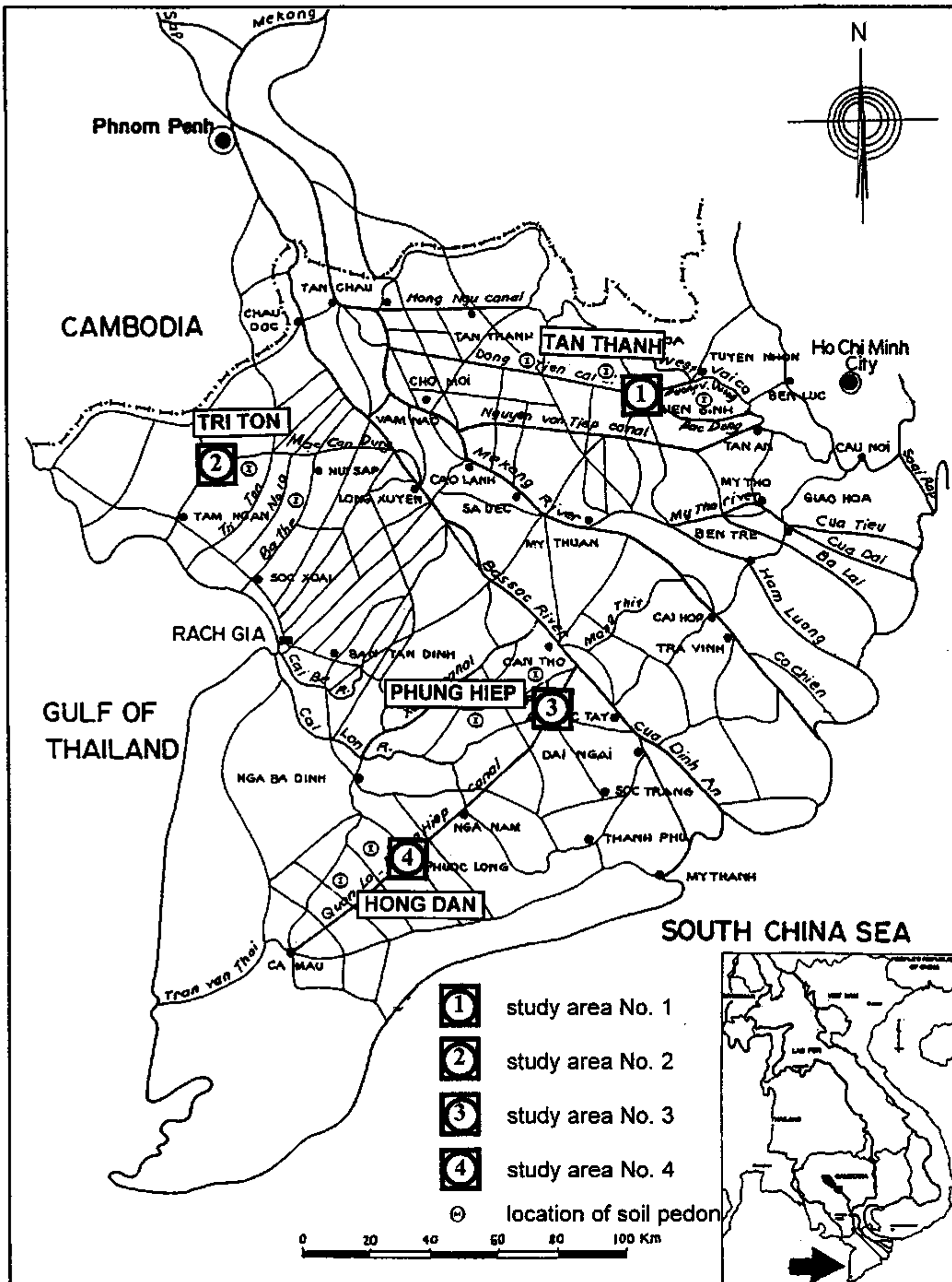


Figure 2.1: *Location of four case study areas with representative soil pedons and the canal network in the Mekong Delta, Viet Nam.*

2.2.2 Soil characteristics:

According to the soil map of the Mekong Delta (60B national project) 1/250,000 and the soil map of the provinces at scale 1/100,000, acid sulphate soils of the four study areas are identified as follows:

* **Area 1 - Tan Thanh**: Acid sulphate soils are dominant in this area with about 40% severely acid sulphate soils that have a sulfuric horizon occurring within 50cm from the soil surface (Typic Sulfaquepts and Hydraquentic Sulfaquepts), 30% moderately acid sulphate soils with a sulfuric horizon between 50 - 100cm (Sulfic Tropaquepts) and 20% slightly acid sulphate soils with a sulfuric horizon deeper than 100cm (Sulfic Tropaquepts, deep sulfuric phase) . Other soil types are non-acid alluvial soils, situated along the West Vam Co river, and some small areas of old alluvial soils of Pleistocene age, located in the northern part of the area. Detailed soil analysis data of severely and moderately acid sulphate soils are presented in tables 2.2, 2.3 and 2.4.

Table 2.2: *Soil analysis of extremely acid sulphate soils in the area number 1 (Tan Thanh).*
Soil type: Typic Sulfaquepts (USDA), Thionic Fluvisols (FAO)
Location : Thuy Dong, Thanh Hoa - Mekong Delta - VietNam.

Code	Depth	pH (H_2O) 1:5	pH (KCl) 1:2.5	EC ms / cm	OM %	Ntot %	P tot*	avP Truog ppm	avP Bray ppm	extr. Al**	Total acid **	Fe ox %
TH1	0-15	3.95	3.49	0.85	9.78	0.33	57	41	4.9	8.5	9.4	1.61
TH2	15-25	3.77	3.23	0.52	2.21	0.08	27	6.3	1.5	-	-	0.80
TH3	25-45	3.84	3.33	0.50	4.37	0.09	31	6.9	4.2	9.5	11.8	0.77
TH4	45-75	4.02	3.44	0.60	11.3	0.14	26	8.8	3.6	11.3	13.6	0.16
TH5	>75	2.67	2.27	7.20	20.9	0.15	26	26.2	1.5	35.8+	78.5+	2.26

* digestion with sulfuric and perchloric acid, in promille;

** KCl extract, meq/100g soil ; + pyrite was oxidized upon drying.

(continued Table 2.2)

Code	Depth (cm)	%sand	%silt	%clay	Ca^{2+} ex.*	Mg^{2+} ex*	Na^{+}ex *	K^{+}ex*	Mg^{2+}*	Ca^{2+}*	K^{+}*	Na^{+}*
TH1	0-15	7.32	65.24	27.43	0.52	4.94	1.86	0.32	-	-	-	-
TH2	15-25	9.78	35.28	54.95	0.39	3.05	0.70	0.69	0.05	0.85	0.04	0.64
TH3	25-45	6.12	57.79	37.10	0.44	4.36	3.60	0.38	0.04	0.95	0.05	0.74
TH4	45-75	4.12	45.43	50.44	0.52	4.68	0.95	0.31	0.07	0.93	0.04	0.73
TH5	>75	0.71	60.82	34.48	0.60	15.81	0.16	0.03	0.03	3.15	0.01	0.10

* in saturation extract, meq/100g soil.

Table 2.3: *Soil analysis of extremely acid sulphate soils in the area number 1 (Tan Thanh).*
Soil type: Typic Sulfaquepts (USDA), Thionic Fluvisols (FAO)
Location : Tan Thanh - Mekong Delta - VietNam.

Code	Depth	pH (H_2O) 1:5	pH (KCl) 1:2.5	EC ms / cm	OM %	Ntot %	P tot*	avP Truog ppm	avP Bray ppm	extr. Al**	Total acid**	Fe ox %
TT1	0-30	3.87	3.37	0.90	7.48	0.37	65	50	-	14.0	14.57	0.29
TT2	30-50	3.86	3.13	0.71	0.92	0.08	26	31.3	4.4	11.5	13.16	0.55
TT3	50-80	3.45	3.02	0.87	1.27	0.09	22	5.3	2.0	11.75	14.57	0.95
TT4	80-115	3.61	3.09	1.05	1.89	0.09	31	3.8	5.1	14.0	14.80	0.36
TT5	>115	2.95	2.59	4.00	6.32	0.09	26	15.6	0.7	30.0+	47.47+	1.74

* digestion with sulfuric and perchloric acid, in promille; ** KCl extract, meq/100g soil ;
\+ pyrite was oxidized upon drying.

Code	Depth (cm)	%sand	%silt	%clay	Ca^{2+} ex.*	Mg^{2+}ex*	Na^{+}ex *	K^{+}ex *	Mg^{2+}*	Ca^{2+}*	K^{+}*	Na^{+}*
TT1	0-30	2.06	57.23	40.72	0.42	3.37	0.35	0.16	2.79	0.10	0.02	0.71
TT2	30-50	1.69	36.06	62.25	0.51	4.23	0.27	0.26	1.39	0.09	0.06	0.32
TT3	50-80	4.86	34.71	60.40	0.58	4.29	0.30	0.27	1.35	-	0.05	0.28
TT4	80-115	1.63	36.08	62.29	0.65	5.53	0.28	0.35	1.59	0.08	0.09	0.33
TT5	>115	0.76	67.92	31.31	0.71	8.59	0.08	0.01	2.09	0.03	0.01	0.23

Table 2.4 : *Soil analysis of moderately acid sulphate soils in the area number 1 (Tan Thanh). Soil type: Sulfic Tropaquepts (USDA), Thionic Gleysols (FAO). Moc Hoa, Long An - Mekong Delta - VietNam. (*) Total acidity: H^+ and Al^{3+} : KCl extraction.*

Code	Depth (cm)	pH (H2O)	EC (mS/cm)	O.M. (%)	%N (tt)	%P (tt)	Exchangable cation (meq/100g soil)				Total acidity* (meq/100g soil)		Active iron
							Ca^{2+}	Mg^{2+}	Na^+	K^+	H^+	Al^{3+}	$\%Fe_2O_3$
MH1	0-30	3.72	0.74	6.20	0.256	0.056	15.82	3.83	1.04	0.039	4.05	2.0	2.12
MH2	30-55	4.04	0.26	2.38	0.067	0.021	14.97	6.50	0.38	0.068	1.35	00	2.23
MH3	55-80	3.85	0.22	2.22	0.048	0.051	13.44	5.81	0.23	0.055	1.80	0.5	2.88
MH4	>80	3.92	0.20	1.90	0.031	0.054	6.92	7.36	0.26	0.074	1.35	1.0	1.30

* **Area 2 - Tri Ton:** Acid sulphate soils are dominant in this area with about 60% severely acid sulphate soils that have a sulfuric horizon occurring within 50cm from the soil surface (Typic Sulfaquepts and Hydraquentic Sulfaquepts), 30% moderately acid sulphate soils with a sulfuric horizon between 50 - 100cm (Sulfic Tropaquepts) and 6% slightly acid sulphate soils with a sulfuric horizon deeper than 100cm (Sulfic Tropaquepts, deep sulfuric phase). Other soil types are non-acid alluvial soils, situated on the fringe of Bassac river levee, and about 4% of gray soils and mountain soils, located in the western part of the area. Detailed soil analysis data of severely and moderately acid sulphate soils are shown in tables 2.5 and 2.6.

Table 2.5 : *Soil analysis of extremely acid sulphate soils in the area number 2 (Tri Ton area). Soil type: Typic Sulfaquepts (USDA), Thionic Fluvisols (FAO). Location: Tri Ton, An Giang - VietNam.*

Code	Depth (cm)	pH (H2O)	EC (mS/cm)	O.M. (%)	%N (tt)	%P (tt)	Exchangable cation (meq/100g soil)				Total acidity (meq/100g soil)		Active iron
							Ca^{2+}	Mg^{2+}	Na^+	K^+	H^+	Al^{3+}	$\%Fe_2O_3$
AG11	0-25	2.96	0.65	12.15	0.220	0.039	-	1.06	-	-	15.21	14.5	2.17
AG12	25-40	2.86	0.74	7.03	0.087	0.028	-	1.10	-	-	14.23	12.0	2.82
AG13	40-60	2.80	0.80	8.15	0.097	0.032	-	1.24	-	-	14.62	11.5	2.55
AG14	60-95	2.75	1.07	6.87	0.076	0.019	-	1.52	-	-	16.57	13.0	2.06
AG15	>95	2.09	5.68	11.83	0.087	0.045	-	-	-	-	28.0	28.0	5.64

(*) Total acidity: H^+ and Al^{3+} : KCl extraction (-) No data

Table 2.6 : *Soil analysis of moderately acid sulphate soils in the area number 2 (Tri Ton area).*
Soil type: Sulfic Tropaquepts (USDA) - Thionic Gleysols (FAO)
Location : Tri Ton, An Giang - Mekong Delta - VietNam.

Code	Depth (cm)	pH (H2O)	EC (mS/cm)	O.M. (%)	%N (tt)	%P (tt)	Exchangable cation (meq/100g soil)				Total acidity (meq/100g soil)		Active iron
							Ca^{2+}	Mg^{2+}	Na^+	K^+	H^+	Al^{3+}	$\%Fe_2O_3$
AG21	0-18	3.35	0.61	9.84	0.318	0.063	7.08	0.88	0.08	0.53	12.60	10.50	2.17
AG22	18-60	3.12	0.71	4.84	0.085	0.028	6.80	1.42	-	0.53	14.10	12.50	2.82
AG23	60-102	2.74	1.17	1.77	0.076	0.021	7.15	2.01	0.01	0.59	15.51	12.50	2.55
AG24	102-145	2.12	4.80	4.25	0.070	0.021	7.85	6.68	0.17	0.59	48.41	25.00	2.06
AG25	>145	2.31	4.26	5.16	0.029	0.036	6.92	6.25	-	0.49	48.88	22.50	5.64

(*) Total acidity: H^+ and Al^{3+} : KCl extraction (-) No data

* **Area 3 - Phung Hiep**: Acid sulphate soils are dominant in this area with about 10% severely acid sulphate soils that have a sulfuric horizon occurring within 50 cm from the soil surface (Typic Sulfaquepts), 50% moderately acid sulphate soils with a sulfuric horizon between 50 and 100cm (Sulfic Tropaquepts) and 30% slightly acid sulphate soils that have a sulfuric horizon occurring deeper than 100cm from the soil surface (Sulfic Tropaquepts, deep sulfuric phase). The rest is non-acid alluvial soils, situated along the rivers or big canals and in locations with a high elevation. Soil profiles of acid sulphate soils are moderately structured, heavy clays, poorly to imperfectly drained. Soil analysis data of moderately and severely acid sulphate soils are shown in tables 2.7 and 2.8.

* **Area 4 - Hong Dan**: Acid sulphate soils are dominant soil in this area with about 40% severely saline acid soils that have a sulfuric horizon within 50 cm from the soil surface (Typic Sulfaquepts, salic phase), 35% moderately acid soils with a sulfuric horizon between 50 and 100cm (Sulfic Tropaquepts, salic phase) and 20% slightly acid soils with a sulfuric horizon deeper than 100cm (Sulfic Tropaquepts, deep sulfuric, salic phase). Some non-acid alluvial soils are situated along the big canals and in locations with high elevation. Profiles are weakly to strongly developed, clay to heavy clays, poorly to imperfectly drained. Soil

analysis data of saline moderately and severely acid sulphate soils in this area are shown in tables 2.9 and 2.10.

Table 2.7: *Soil analysis of extremely acid sulphate soils in the area number 3 (Phung Hiep). Soil type: Typic Sulfaquept (USDA), Thionic Fluvisols (FAO). Location : Hoa An - Phung Hiep. Mekong Delta - VietNam.*

Code	Depth	pH (H_2O) 1:5	pH (KCl) 1:2.5	EC ms. cm^{-1}	OM %	Ntot %	P tot*	avP Truog ppm	avP Bray ppm	extr. Al**	Total acid**	Fe ox % ***
HA1	0-20	4.18	3.81	1.50	12.92	0.49	61	11.9	1.6	9.75	10.81	0.55
HA2	20-38	4.03	3.53	0.90	7.80	0.26	54	40.2	2.6	12.50	14.33	0.24
HA3	38-45	3.81	3.29	0.93	1.68	0.09	33	11.9	4.1	12.25	13.86	0.90
HA4	45-90	3.51	2.95	1.28	0.91	0.08	50	6.9	2.5	10.75	13.63	0.11
HA5	90-125	3.74	3.19	1.76	1.32	0.10	00	33.5	6.1	10.25	11.28	1.05
HA6	>125	3.47	3.08	2.90	2.64	0.12	54	46.0	4.6	12.25+	14.57+	1.04

* digestion with sulfuric and perchloric acid, in promille; ** KCl extract, meq/100g soil ;

*** acid oxalate extractable Fe; + samples were analyzed after air drying.

Code	Depth (cm)	%sand	%silt	%clay	Ca^{2+} ex.	Mg^{2+}ex	Na^{+}ex *	K^{+}ex *	Mg^{2+}*	Ca^{2+}*	K^{+}*	Na^{+}*
HA1	0-20	1.04	53.48	45.49	0.67	-	3.14	0.27	-	-	-	-
HA2	20-38	1.05	59.75	39.20	0.53	-	0.94	0.21	-	0.51	0.01	-
HA3	38-45	2.95	59.65	37.38	0.59	-	0.93	0.28	1.85	0.09	0.05	0.64
HA4	45-90	1.88	37.08	61.05	0.56	-	0.93	0.21	2.15	0.08	0.04	1.27
HA5	90-125	1.24	36.53	62.24	0.75	-	2.80	0.20	-	-	0.05	-
HA6	>125	2.31	72.28	25.40	1.02	-	1.25	0.05	0.02	0.10	0.03	1.54

* in saturation extract, meq/100g soil.

Table 2.8 : *Soil analysis of moderately acid sulphate soil in the area number 3 (Phung Hiep).*
Soil type: Sulfic Tropaquept (USDA), Thionic Gleysols (FAO) . Code : CT_{1-6}
Location : Can Tho - Mekong Delta - VietNam.

Code	Depth (cm)	pH (H2O)	EC (mS/cm)	O.M. (%)	%N (tot)	%P (tot)	Exchangable cation (mmol(+).kg^{-1})				Total acidity (meq/100g soil)		Active iron
							Ca^{2+}	Mg^{2+}	Na^+	K^+	H^+	Al^{3+}	$\%Fe_2O_3$
CT1	00-30	4.35	0.47	2.94	0.085	0.072	4.69	-	2.00	0.007	1.8	00	0.54
CT2	30-45	3.73	0.50	2.94	0.101	0.022	2.09	-	0.96	0.005	7.17	6.5	1.41
CT3	45-85	3.62	0.52	0.65	0.113	0.065	2.04	-	0.95	0.065	8.20	7.5	-
CT4	80-120	3.55	0.80	1.31	0.119	0.061	1.49	-	1.04	0.040	7.38	7.0	0.65
CT5	120-150	3.61	0.85	0.49	0.036	0.057	1.49	-	1.41	0.060	6.56	6.0	0.65
CT6	>150	2.77	2.40	3.34	0.071	0.050	1.30	-	0.63	0.007	15.17	10.0	3.58

(*) Total acidity: H^+ and Al^{3+} : top KCl extraction/bottom H_2O extraction ; (-) No data

Table 2.9 : *Soil analysis of moderately saline acid sulphate soils in the are number 4 (Hong Dan).*
Soil type: Typic Sulfaquepts - salic phase (USDA), Sali-Thionic Fluvisols (FAO) .
Location : Thi Tran - Phuoc Long - Hong Dan - Mekong Delta - VietNam

Code	Depth (cm)	pH (H2O)	EC (mhos/cm)	O.M. (%)	%N (tt)	%P (tt)	Exchangeable cation (meq/100g soil)				Total acidity * (meq/100g soil)		Active iron
							Ca^{2+}	Mg^{2+}	Na^+	K^+	H^+	Al^{3+}	$\%Fe_2O_3$
TTR1	00-25	3.50	7.58	2.94	0.113	0.047	7.31	0.33	-	0.51	10.81	8.5	0.35
TTR2	25-80	3.97	1.29	2.94	0.046	0.026	12.19	14.36	-	2.26	0.94	0.0	1.67
TTR3	80-120	3.33	2.42	0.65	0.029	0.041	-	-	15.40	1.49	2.35	1.5	1.60
TTR4	>120	2.92	5.89	3.34	0.036	0.058	-	-	10.60	0.83	13.16	5.0	4.44

* KCl extract (1: 5)

Table 2.10: *Soil analysis of saline acid sulphate soils in the area number 4 (Hong Dan).*
Soil type: Typic Sulfaquepts - salic phase (USDA), Sali-Thionic Fluvisols (FAO).
Location : Phong Thanh Nam - Hong Dan - Mekong Delta - VietNam

Code	Depth	pH (H_2O) 1:5	pH (KCl) 1:2.5	EC ms / cm	OM %	Ntot %	P tot*	avP Truog ppm	avP Bray ppm	extr. Al**	Total acid**	Fe ox % ***
HD1	0-25	4.82	4.53	3.30	10.57	0.33	80	57.2	2.4	2.75	5.62	0.85
HD2	25-50	3.65	3.27	3.00	3.91	0.14	36	-	1.9	5.00	7.87	0.57
HD3	50-80	3.50	3.17	3.20	2.52	0.12	41	11.6	2.0	8.00	11.02	0.54
HD4	80-110	3.50	3.22	3.30	1.69	0.12	45	31.3	3.7	7.75	9.90	0.26
HD5	110-140	3.48	3.26	3.60	2.32	0.11	62	181.1	4.1	12.25	17.10	0.70
HD6	>140	6.18	5.76	3.00	3.14	0.10	62	184.5	2.5	0.00	0.00	0.69

* digestion with sulfuric and perchloric acid, in promille; ** KCl extract (1: 5), meq/100g soil ;
*** acid oxalate extractable Fe; + samples were analyzed after air drying.

Code	Depth (cm)	%sand	%silt	%clay	Ca^{2+} ex.	Mg^{2+}ex	Na^+ex	K^+ex	Mg^{2+}*	Ca^{2+}*	K^+*	Na^+*
HD1	0-25	1.31	48.96	49.72	1.52	-	22.58	1.04	-	-	-	-
HD2	25-50	4.12	52.58	43.29	0.67	-	9.95	0.28	-	-	-	-
HD3	50-80	4.23	51.35	43.41	0.76	-	3.33	0.19	-	-	-	-
HD4	80-110	1.65	53.74	44.61	0.84	-	13.08	0.10	3.12	0.02	0.02	0.39
HD5	110-140	1.20	39.96	58.83	1.30	-	14.12	0.06	-	-	-	-
HD6	>140	1.43	40.84	57.72	1.85	-	26.29	0.08	0.02	-	-	-

* in saturation extract, meq/100g soil.

The locations of these soil pedons are indicated on the map of the Mekong Delta (Figure 2.1)

2.2.3 Hydrological conditions:

* **Area 1 - Tan Thanh:** Since the completion of the Hong Ngu canal in the North of the Plain of Reed, the Northern part of the area can be supplied with fresh water through the Duong Van Duong canal and the Bac Dong canal (Figure 2.1). Acidification of water, however, always occurs in the early rainy season (from the end of April to June) when rain water leaches acidity from the

soil into the canals and rivers. It is impossible in the present situation to supply fresh water to the Southern part of the area due to lack of canals.

In addition to the limitation of fresh water in the dry season, most of the area is deeply flooded annually from September 1 to November 30. Depths of flooding of the study area ranges from 60 cm to 150 cm (Figure 2.2) and flooding starts late, (which enables extending the period during which the Summer-Autumn and Winter-Spring rice crops are grown). However, because about 80% of the total area is flooded to a depth of 1.0m or more, perennial crops can not be cultivated in the area even on raised beds.

The influence of the tidal regime of the South China Sea extends to the area via the West Vam Co river. Despite the fact that the study area lies rather far inland, it is also affected by saline water intrusion from the South China Sea, via the West Vam Co river. The salt affected period extends from January to May (Tuong *et al.*, 1993). The isoline of 4g NaCl/l in March is situated about 9km East of Tuyen Nhon town and in April about 9km East of Tuyen Nhon (Figure 2.3).

* **Area 2 - Tri Ton:** Since the completion of the Mac Can Dung canal that connected the Bassac river and the inland of the Central of Long Xuyen Quadrangle. From that, the area can be supplied with fresh water through Tri Ton canal, the Xang Moi-Ba The canal and the number 10 canal. Acidification of water, however, always occurs in the early rainy season (from the end of April to June) when the rain water leaches acidity from the soil into the canals and rivers. It causes problems for Summer-Autumn rice cultivation. In some other areas, at present, it is impossible to supply fresh water due to lack of canals.

In addition to the limitation of fresh water in the dry season, most of the area is flooded annually from August 15 to December 1. Depths of flooding of the study area range from 1.2 m to more than 2.5 m (Figure 2.2) and flooding starts rather early, (which does not allow extending the period of Summer-Autumn and Winter-Spring rice crops). However, because nearly 100% of the total area (except the settlements) is flooded to a depth of more than 1.0 m, perennial crops can not be cultivated in the area even on raised beds.

The influence of the tidal regime of the South China Sea extends to the area via the Bassac river and many big canals as the study area lies rather far inland, it is not affected by saline water intrusion during the dry season (Figure 2.3).

* **Area 3 - Phung Hiep:** The area is dissected by a great number of creeks and canals. Most of the canals were dug for the purpose of opening up new land and for transportation. These waterways are very important for irrigation and drainage during the dry and wet season, respectively. In part of the area, the water levels at high tide and low tide permit irrigation and drainage by gravity.

The tides in the area (influenced by the South China sea) are semi-diurnal, but the mean, maximum, and minimum tide levels change from month to month, as they are influenced by the Mekong river, and local rainfall. Three cycles influence the local tides: a yearly cycle, a monthly cycle and a daily cycle (Minh, 1985). The highest water levels occur in October coinciding with the flood period of the Mekong river and with highest rainfall, so that large parts of the study area, especially the depression areas, are flooded and can not be drained by gravity. Although the effect of the tide is strong in the area, the available water is fresh all year (Figure 2.3).

* **Area 4 - Hong Dan:** Similar to the Phung Hiep area, this area is also dissected by a great number of creeks and canals. Most of the canals were dug for the purpose of opening up new land and for transportation. The Quan Lo-Phung Hiep canal is a main waterway, crossing the area to the Ca Mau town (Figure 2.1). From this canal, many secondary canals were excavated into the area. These waterways are very important for drainage during the wet season and for supplementary irrigation in the early dry season when water is still fresh in the big canals.

The tides in the area are under the influence of the semi-diurnal South China sea tides. The maximum and minimum mean tide levels change from month to month through the influence of the Mekong river discharge, and local rainfall. The highest maximum water levels occur in September to October coinciding with the flood period of the Mekong river and with the highest rainfall, so that large parts of study area, especially the depressed areas, are flooded and can not be drained by gravity. The tidal movement is strong in the area; salt water intrudes during the dry season (Figure 2.3). In the low part, the soil surface is flooded daily with tidal saline water during dry season.

In summary, the four sites are characterized by climatic conditions, soil characteristics and hydrological conditions as follows (Table 2.11):

* Area No.1: Tan Thanh: low precipitation, low potential evaporation. Acid sulphate soils mainly occur with sulfuric horizons within 50 cm and between 50-100cm from the soil surface. Deep flooding (60-150cm deep) during the rainy season.

* Area No.2: Tri Ton: low precipitation, medium potential evaporation. Acid sulphate soils mainly occur with sulfuric horizons within 50 cm from the soil surface. Very deep flooding (100-200cm deep) during the rainy season.

* Area No.3: Phung Hiep: medium precipitation, medium potential evaporation. Acid sulphate soils mainly occur with sulfuric horizons between 50 -100 cm from the soil surface. Shallow flooding (30-100cm deep) during the rainy season.

* Area No.4: Hong Dan: high precipitation, high potential evaporation. Acid sulphate soils mainly occur with sulfuric horizons within 50 cm and between 50 -100 cm from the soil surface. Shallow flooding (30-100cm deep) during the rainy season, and salt water intrusion during the dry season.

Table 2.11: *Summary of physical characteristics of the four study areas in the Mekong Delta, Viet Nam. (ASSs: acid sulphate soils; J : sulfuric horizon)*

Physical characteristics	Study areas			
	Tan Thanh	Tri Ton	Phung Hiep	Hong Dan
Climatic conditions:				
- Precipitation (mm)	1532	1418	1841	2360
- Pot. Evaporation (mm)	1186	1293	1228	1740
Soil characteristics:				
- Severely ASSs (J < 50cm)	40%	60%	10%	40%
- Moderately ASSs (J : 50-100cm)	30%	30%	50%	35%
- Slightely ASSs (J : 100-150cm)	20%	6%	30%	20%
- Non ASSs	10%	4%	10%	5%
Hydrological conditions:				
- Depth of flooding (cm)	60 - 150	100 - 200	30 - 100	30 - 100
- Salt water intrusion	A part of area in the end of the dry season	No	No	Whole area during the dry season

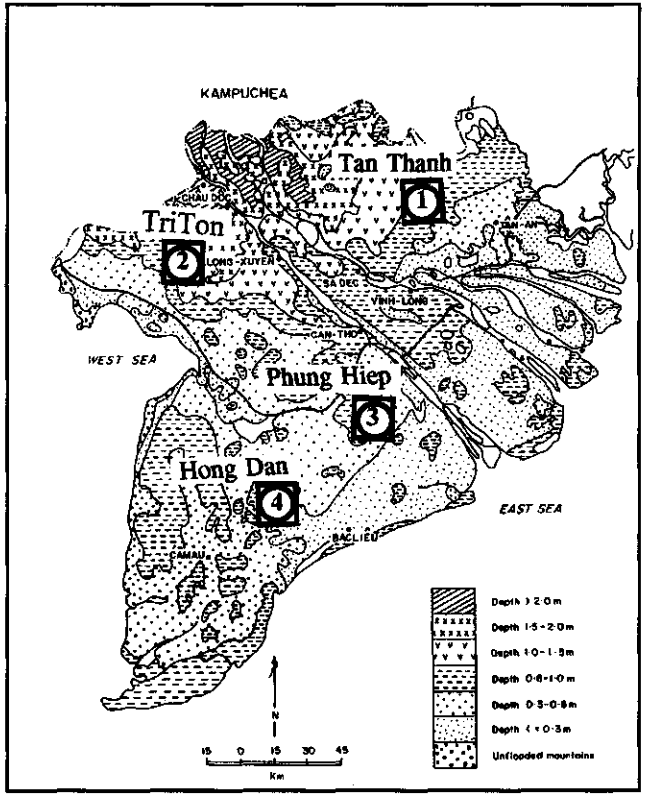


Figure 2.2 : *Maximum inundation depth in the Mekong Delta, Viet Nam (Tuong et al., 1991)*

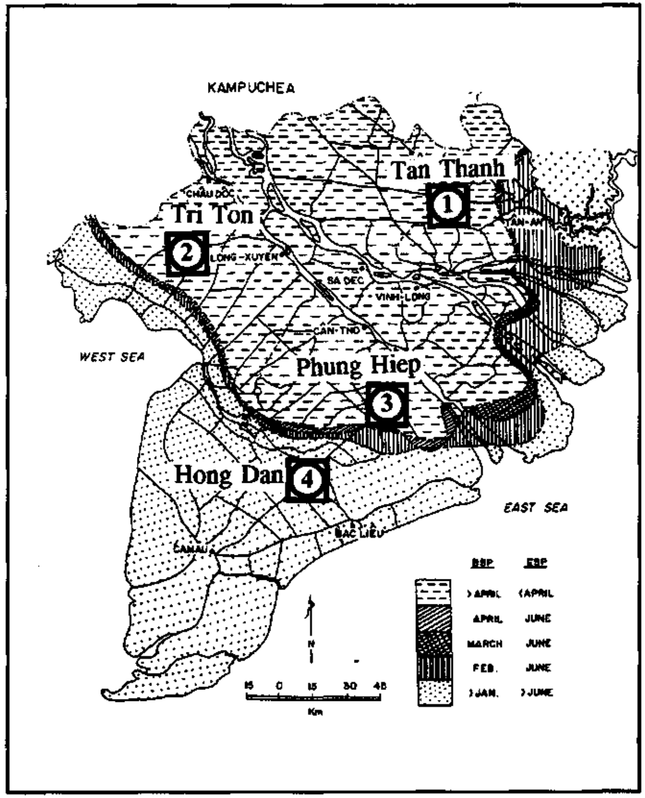


Figure 2.3 : *Salinity intrusion in the Mekong Delta, Viet Nam. BSP: beginning of the salinity period; ESP: end of salinity period (Tuong et al., 1991)*

2.3 Agricultural problems in four study areas:

- In the severely acid sulphate soils, some innovative cropping systems are being developed which can increase the income of farmers. Many farmers in the area, however, are still poor. They produce enough food for their family but there is no surplus for the market and therefore no funds for other purposes (e.g. purchase of fertilizers, pesticide and farm implements...). (Applies to all areas)
- New cultivation techniques and new cropping systems that can increase crop production and income are popularized through learning of "farmer to farmer", without assistance of extension services. Consequently, the modern practices or new cropping patterns are applied incompletely and at unequal levels.(Applies to areas 1 and 2).
- Soil acidity coincides with high flooding depth and long flooding duration, which causes physical constraints as well for intensification of rice and upland cash crops growing. (Applies to areas 1, 2 and 3).
- Lack of secondary and tertiary canals for irrigation and drainage in places where new cropping patterns could be developed. (Applies to areas 1, 2, and 3).
- Shortage of capital for farm production and price fluctuations of farm products. (Applies to all areas).
- New cultivation techniques and new cropping systems that can increase production and income of farmers are not popularized in the moderately acid soils where they would be most successful. Most of the farmers in these areas still only grow single crops of traditional rice with low yields. (Applies to area 4).
- Soil acidity and salt water intrusion, together with the absence of fresh water during the dry season, cause physical constraints for growing of rice crops and upland cash crops. These constraints make it difficult to improve these systems (Applies to area 4).

Chapter 3

Farmer level

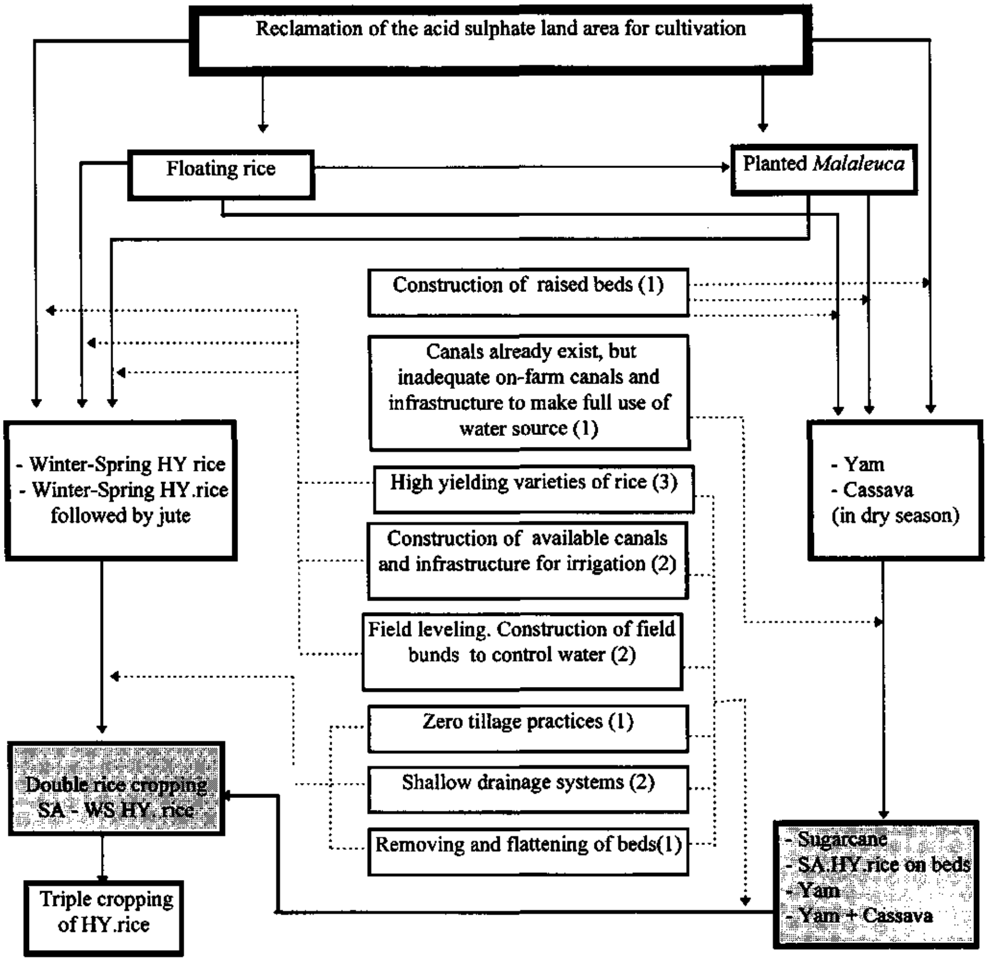
3.1 History of farmer's land use and soil-water-crop management practices:

Acid sulphate soils are very unfavorable for farming. Farmers have learned this the hard way and will not start farms in areas where raw acid sulphate soils have just been drained (Bouma *et al.*, 1993). However, by trial and error, farmers have found various ways to overcome the acidity of their soils to produce food crops or have found other suitable uses (Xuan *et al.*, 1982, Tri, 1989). Farmers have thus devised innovative systems to improve conditions for crop growth (Bouma, *et al.*, 1993). The so-called: " farmer model" in four study areas of acid sulphate soils can be characterized as follows:

*** Area No. 1 - Tan Thanh:**

Since 1931 (farmer's interview, 1991), farmers in the area started to reclaim the acid sulphate soil for cultivation. At first, the farmers tried to grow rice for subsistence. Floating rice is therefore the natural first crop to be cultivated because of deep flooded conditions. The yield of floating rice was very low, some crops completely failed due to extreme acidity in the early growing season and very deep flooding in some years. Floating rice was therefore not attractive to farmers. Most of the acid sulphate land was abandoned. *Melaleuca* was planted for fire wood and for foundations of houses.

Six to ten years later, farmers did again try to produce food crops. The acid sulphate areas were reclaimed again, specifically the natural *Melaleuca* forest, with the objective to cultivate cassava. Cassava was successfully grown on raised beds. Then in 1960, yam, which is also grown on raised beds was introduced into the area, but the area was small because of the war. During the post-war period, this crop has strongly expanded. These land use types were present in the initial phase of use of the severely acid sulphate soils in this area. After 2 to 3 years, ratoon cropping of sugarcane was practised on the raised beds that had been used for yam or cassava before. Ratoon cropping of sugarcane required construction of dikes in order to obtain protection against flood during the inundation period. Most of ratoon sugarcane was grown in the shallow flooded areas (less than 100cm deep).



SA : Summer-Autumn; WS : Winter-Spring; HY: high yielding
(1) transferred from experts (2) farmer's experiment and experts (3) experts

Present promising land use types in the area — require the water and management practices for land use types

Former and present land use types in the area — coming to the land use types

Water and soil management practices in the area

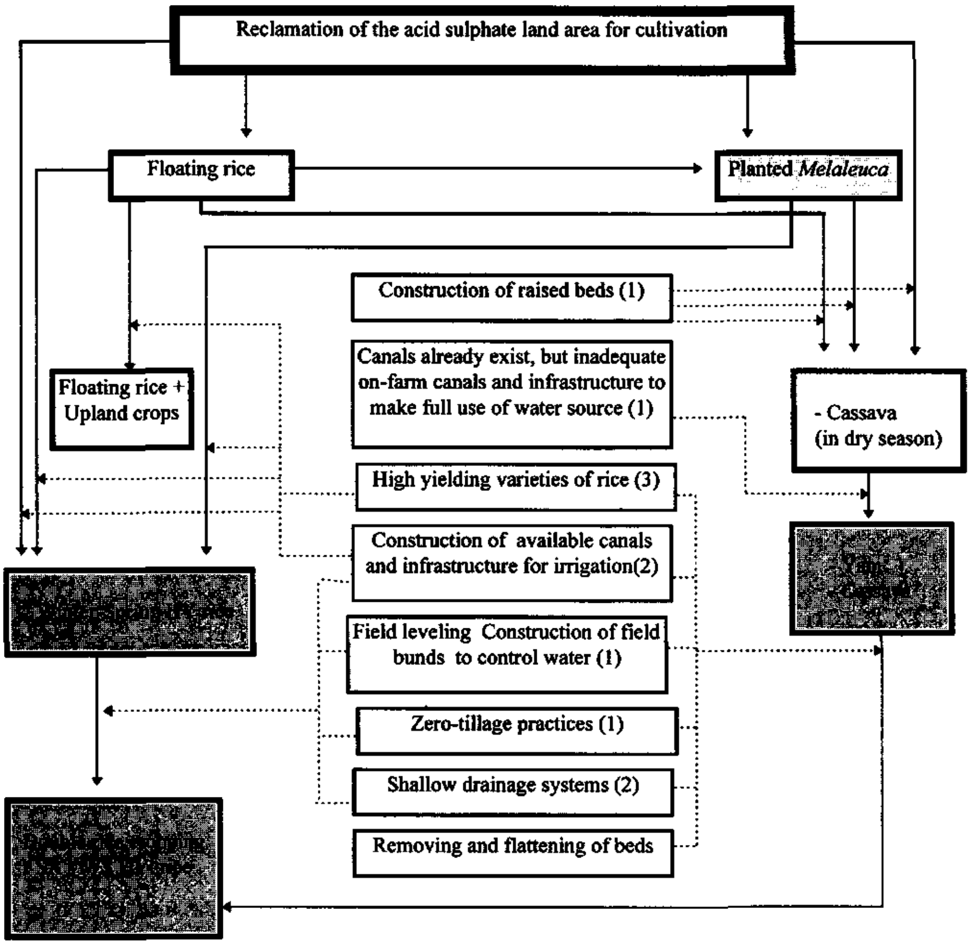
Figure 3.1 : *Scheme of the history of farmer's land use and soil-water-crop management practices in the area No.1, Tan Thanh-Long An.*

Before 1984 when canals were not excavated yet, floating rice was still dominant in the area. Between 1985 and 1990, the canal network in the Plain of Reeds was extended rapidly. Large scale irrigation and drainage systems were constructed for modern short duration rice varieties in order to increase single cropping of floating rice to double cropping of high yielding rice. In the first few years after canal construction, single cropping Winter-Spring (WS) high yielding (HY) rice and double cropping of WS HY. rice followed by jute have been practised. Next, more detailed water and soil management practices were introduced such as: infrastructure for irrigation, intensive shallow drainage systems, leveling of fields, construction of bunds and sluice gates, and zero tillage. This allowed double cropping of WS HY.rice and Summer-Autumn(SA) HY. rice which was introduced into the area by the farmers. This land use type has expanded on a large scale in areas where the canals have been dug. At present, in the moderate and slightly acid sulphate soil areas with short inundation length, triple cropping of HY rice has been practised when infrastructure for irrigation is completed.

The scheme of the history of farmer's land use and soil-water-crop management practices in the deep flooding acid sulphate land area No.1 is shown in figure 3.1.

*** Area No.2 - Tri Ton:**

Most of the area had been covered by dense *Melaleuca* forests, since 1945 (farmer's interview, 1994). Farmers in the area started to cut *Melaleuca* for rice cultivation in the fringe of the area where moderately acid sulphate soils were found .In 1960, the *Melaleuca* forest was cut in larger areas. At first, the farmers tried to grow rice for subsistence, floating rice being the natural first crop to be cultivated because of deep flooded conditions. The yield of floating rice was low, some crops completely failed due to acidity in the early growing season and very deep flooding in some years. Floating rice was less attractive to farmers but the farmers still continued to grow floating rice for consumption, while the extremely acid sulphate land remained in *Melaleuca* forest. Since 1975 to 1980, most of *Melaleuca* forest in the area was destroyed due to the demand for



SA : Summer-Autumn; WS : Winter-Spring; HY: high yielding
(1) transferred from experts (2) farmer's experiment and experts (3) experts

Present promising land use types in the area

Former and present land use types in the area

Water and soil management practices in the area

require the water and management practices for land use types

coming to the next land use types

Figure 3.2 : *Scheme of the history of farmer's land use and soil-water-crop management practices in the area No.2, Tri Ton - An Giang.*

fire wood and wood for construction. In the land without forest, farmers did try to produce food. Many state-farms were established for the cultivation of rice.

Before 1982 when canals were not excavated yet, floating rice was still dominant in the area. Between 1982 and 1990, the canal network in the Long Xuyen Quadrangle was extended at a fast rate. The irrigation and drainage systems were constructed for modern short duration rice varieties in order to increase single cropping of floating rice to double cropping of high yielding rice as in area 1.

The scheme of the history of farmer's land use and soil-water-crop management practices in the deep flooding acid sulphate land area No.2 is shown in figure 3.2.

*** Area No.3 - Phung Hiep:**

Since 1931, the Quan Lo-Phung Hiep canal was dug for transportation and for exploitation of new areas. Farmers came to remove the natural *Melaleuca* forest for the cultivation of traditional rice along the new canals. Some farmers failed or got low yields in the first few years because of the acidity of soils. During the war (1960 - 1975), the acid sulphate soil areas were sparsely populated. Most land was fallow. Access was and is very difficult. Agricultural activities are only traditional rice cultivation and natural fishing. Then in 1968, high yielding rice varieties were introduced. The double cropping of HY rice followed by traditional rice was practised on non-acid and slightly acid sulphate soil areas. Most farmers, however, still grew one traditional rice variety with low yield. Upland crops such as pineapple and sugarcane were grown on high raised beds in the moderately acid sulphate soil area. After 1975 (end of the war), farmers returned to their land. Since then agriculture has developed strongly. For the first few years, farmers tried to grow rice for subsistence. Traditional rice and rainfed short duration Summer-Autumn rice was cultivated. Rainfed short duration summer-autumn rice and traditional rice gave very low yields. Some crops completely failed due to extreme acidity in the early growing season or to

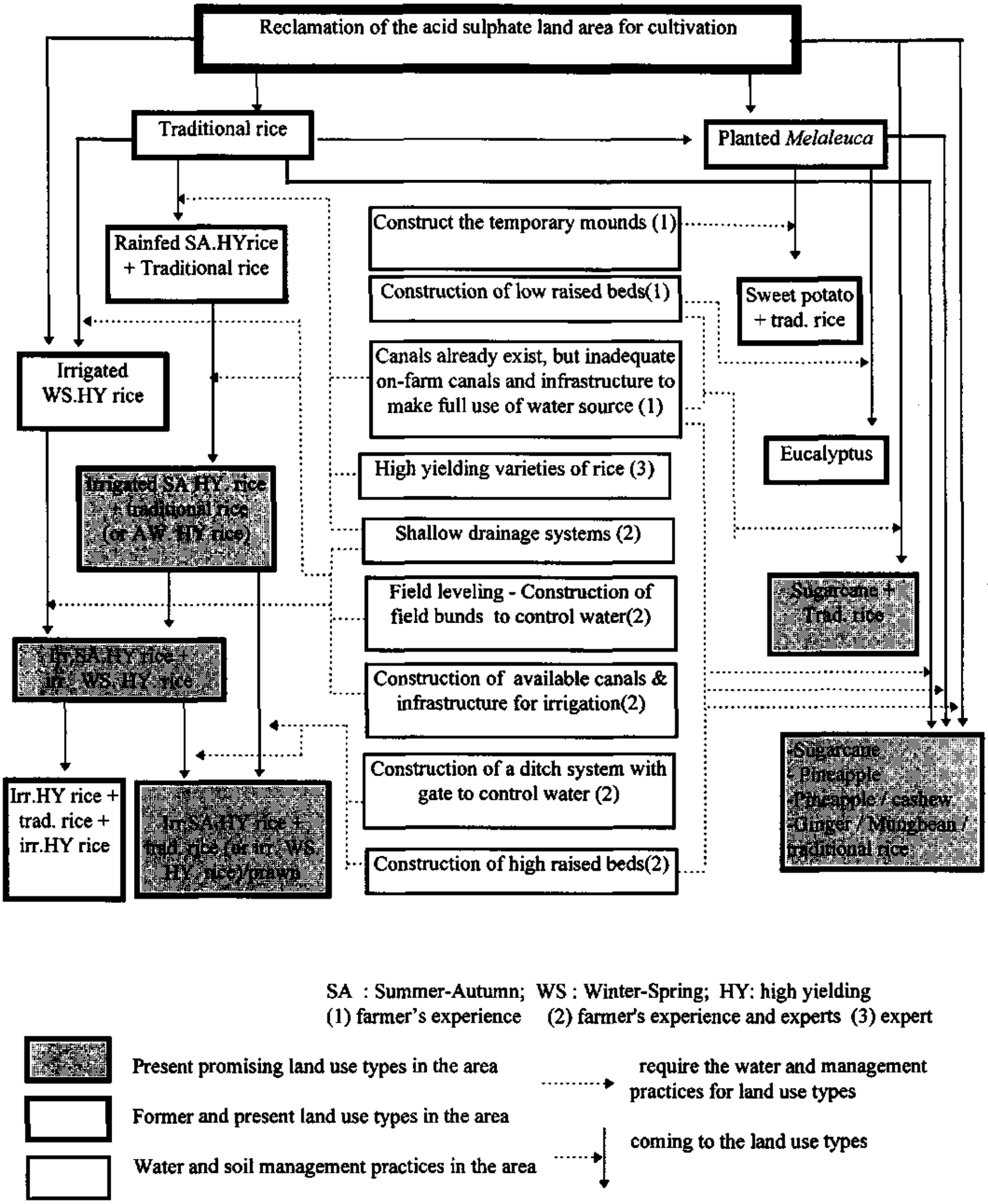


Figure 3.3 : *Scheme of the history of farmer's land use and soil-water-crop management practices in the area No.3, Phung Hiep, Can Tho.*

deep floods. Rainfed Summer-Autumn high yielding variety (SA.HY) rice and traditional rice were not attractive to farmers in the acid sulphate soil areas. Some farmers attempted to grow rice in the wet season followed by sugarcane on low raised beds with supplementary irrigation in the dry season and they produced about 2.0 tons rice per ha. Sugarcane and pineapple cultivation on high raised beds expanded on a large scale. Eucalyptus was planted on low raised beds in extremely acid sulphate soils. *Melaleuca* was planted for fire wood and construction.

Between 1978 - 1988, new cultivation techniques were introduced to the farmers by experts of Agricultural Universities and Institutes. With the extension of the canal network, the cropping patterns changed from single traditional rice to double cropping of Summer-Autumn (SA) HY rice followed by traditional rice. Irrigation and drainage systems were constructed in order to grow modern short duration rice varieties. In the first few years after canal construction, single cropping of irrigated Winter-Spring HY rice was practised. Double cropping of irrigated SA HY rice followed by irrigated WS HY rice was introduced and practised in the area requiring high quality of water and soil management practices such as: infrastructure for irrigation, shallow drainage systems, field leveling, construction of bunds and sluice gates. These land use types have expanded on a large scale in areas where canals have been dug. However, the double cropping of (irrigated) SA HY rice followed by traditional rice is still attractive to farmers because of low capital investments and inadequate irrigation systems.

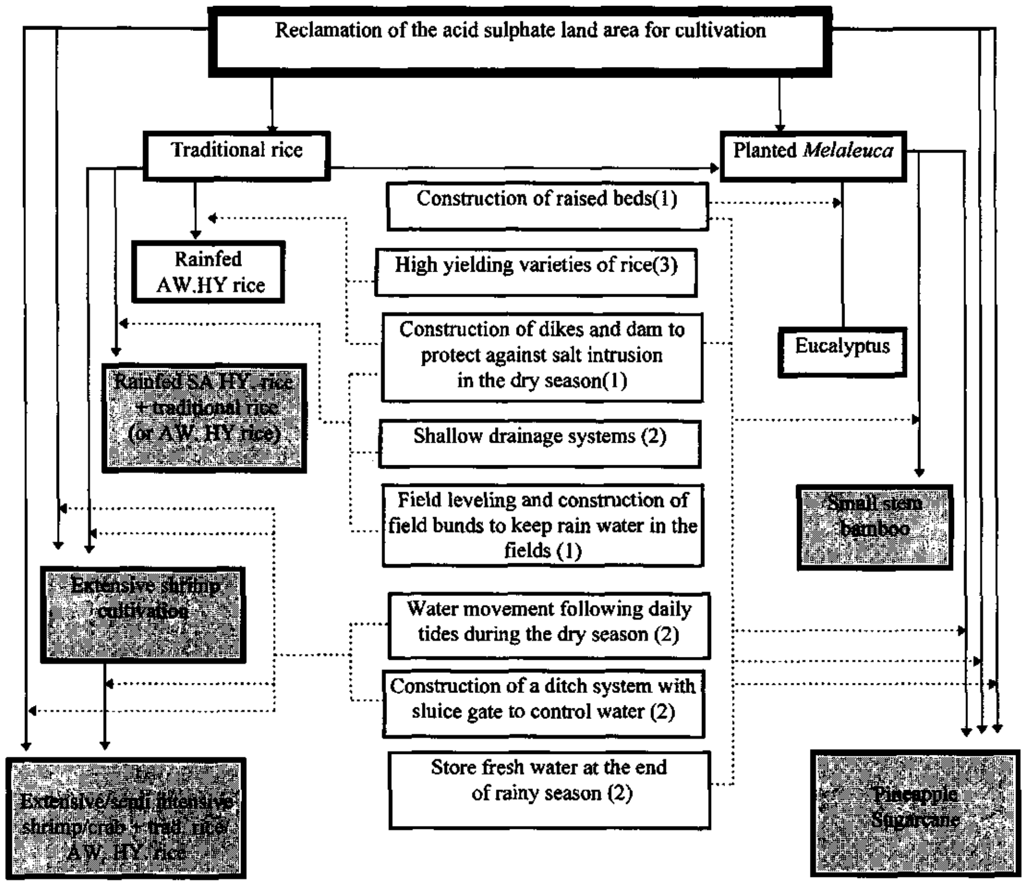
The scheme of the history of farmer's land use in the acid sulphate soil area No.3 is shown in figure 3.3.

*** Area No.4 - Hong Dan:**

More than 100 years ago, the area was a mangrove forest swamp. People from areas in VietNam with land shortage migrated to this area for exploitation of the land. Those pioneers settled in locations most suitable for rice production, leaving the acid soils untouched. Rainfed traditional rice with a long growing period was practised. Since 1931, the Quan Lo-Phung Hiep canal was dug for transportation purposes and for exploitation of the new land. More people came to cut the natural *Melaleuca* forest and started cultivation of traditional rice along the new canals. Some farmers failed or got low yields in the first few years because of soil acidity. The war further prevented the development of the area. During the war, people moved away and the acid sulphate soil area remained remote and sparsely populated. Most land was fallow for many years. Accessibility was and is very difficult. Agricultural activities were only traditional rice cultivation and natural fishing. Some farmers attempted to grow upland crops such as pineapple, and sugarcane on high raised beds surrounding their houses in moderately acid sulphate soils. After 1975, however, farmers returned to their land. Since then agriculture has started to develop in the acid sulphate soil areas. For the first few years, farmers tried to grow rice for subsistence. High yielding variety rice with short growing duration was introduced in the area 2 to 3 years (1977 - 1978) after the war. One reason was the high local food demand. Traditional rice and rainfed short duration Summer-Autumn rice were cultivated. Between 1978 - 1988, new techniques of cultivation were taught to the farmers by the experts from Agricultural Universities and Institutes. With the extension of the canal network for drainage, cropping patterns changed from single cropping of traditional rice to double cropping of Summer-Autumn (SA) HY rice followed by traditional rice. This land use type was mainly practiced in the North-East of the area where soils are moderately acid and saline water intrusion comes late. In the extremely acid soils, elsewhere, rainfed short duration summer-autumn rice and traditional rice gave very low yields, some crops completely failed due to extreme acidity in the early growing season and deep flooding in some years. Rainfed summer-autumn high yielding (SA.HY) rice and traditional rice were not attractive to farmers. Some farmers attempted to grow upland crops such as sugarcane, and pineapple on raised beds in the wet season with supplementary irrigation in the dry season. Because of a reasonable success, sugarcane and pineapple grown on high raised beds, have expanded on a large scale in the area. Eucalyptus and small stem bamboo were also planted on raised beds in extremely acid soils. *Melaleuca* was planted for fire wood and construction.

Meanwhile, in the lower area with the same soil conditions, but with early salt water intrusion in the early dry season and flooding by daily tide during the dry season, the land still remained mangrove forest for a long time. In the beginning of the exploitation of this area (some 40 years ago), some farmers, after clearing the land, kept it flooded during the dry season with saline surface water. They could catch shrimps and fish. For shrimp cultivation, the farmers constructed a dike surrounding the field. Some farmers attempted to cultivate rice on the field during the rainy season and were able to produce about 2 to 3 tons/ha. With this result, the farmers were encouraged to expand rice cultivation. The rice variety used, however, was a traditional rice type with a long growing period. Such varieties of rice are easily affected by salinity during the ripening stage of the crop in the early dry season, so production was erratic and low. The high yielding variety rice with short growing duration was introduced in 1980-1982 in order to replace the local rice varieties in the shallow flooded areas. In this system, rice can only be cultivated on the field after 4 years of growing shrimp, due to the fact that after 4 years, the sediment layer formed on the soil surface is thick enough for rice. Through the years, farmers were able to optimize production of rice and shrimp. Currently, half of the farmers in the study area grow shrimp in the dry season only, without rice in the wet season because of the higher profit that can be obtained from shrimp cultivation. Without rice, farmers can start with the intake of fries in the early dry season and the cumulative shrimp yield is much higher than in the combined rice-shrimp system. During the last three years, several farmers quit the shrimp cultivation and started to raise crabs instead. At present as the market for crabs is increasingly good, this system is becoming more and more popular. The system is practised similarly to the rice-shrimp system.

The scheme of the history of farmer's land use in the acid sulphate soil area No.4 is shown in figure 3.4.



SA : Summer-Autumn; AW : Autumn-Winter; HY: high yielding
(1) farmer's experience (2) farmer's experience and experts (3) experts

Present promising land use types in the area

Former and present land use types in the area

Water and soil management practices in the area

require the water and management practices for land use types

coming to the land use types

Figure 3.4 : *Scheme of the history of farmer's land use and soil-water-crop management practices in the area No.4, Hong Dan, Minh Hai.*

3.2 Present land use types:

The activities in land evaluation that are specifically concerned with land use comprise two parts: description of the types of land use, and assessment of the land use requirements. The types of land use which are relevant for consideration in the area must first be identified. They are then elaborated and refined, leading to full descriptions which form part of the results of the land evaluation (FAO, 1983). Present land use can form a basis and good starting point for selection and description of relevant land use types in land evaluation for acid sulphate soils in the Mekong Delta (Tri, 1990). Because these land use types are already practised and, therefore, are (i) to some extent physically adapted to local land resources; and (ii) socially acceptable and economically attractive to at least some groups of local land users (farmers). The present land use types of four study areas are identified as follows:

*** In the Area No.1 - Tan Thanh:** The land is mostly covered by unused weeds of *Cyperus* and *Eleocharis* and *Melaleuca cajuputi* forest (*Melaleuca spp.*). Distillation of *Melaleuca cajuputi* leaves for *cajuputi* oil is practised. Some *Melaleuca leucodendron* plantations are found. The stems can be used for foundation and timber. The area is mainly used for the cultivation of upland crops (yam, sugarcane, cassava). Short duration rice has been recently introduced into the area. This land use type is practised only in areas along the canals where irrigation and drainage are possible. Upland crops such as yam and cassava are now rapidly expanding because of its usefulness in the severely acid sulphate soils (Tri, 1993). The present land use types in the area can be identified as follows (Figure 3.1):

1. Single cropping of yam.
2. Double cropping of yam followed by cassava.
3. Single cropping of cassava.
4. Ratoon cropping of sugarcane.
5. Double cropping of irrigated high yielding rice.
7. Double cropping of irrigated WS.HY.rice followed by SA.jute.
8. Triple cropping of HY.rice.
8. Single cropping of irrigated WS.HY rice.

9. Planted *Melaleuca.*
10. *Melaleuca cajuputi.*

(WS : Winter-Spring; SA : Summer-Autumn; HY: high yielding)

*** In the Area No.2 - Tri Ton:** The land is mostly covered by unused weeds of Cyperus and Eleocharis and Ischaemum. Some *Melaleuca leucodendron* plantations are found. The stems can be used for foundation and timber. Eucalyptus are also planted on mounds or raised beds and they can survive during the flooding period. Eucalyptus can be used as raw material of paper factories. The cropping system in the area is very simple. Rice is mainly grown in most of the acid sulphate land. Short duration rice has been recently introduced into the area (1990-1991). This land use type is practised only in areas along the canals where irrigation and drainage are possible. Upland crops such as sesame, mungbean, maize, water melon and cassava are planted immediately following harvesting of floating rice when the soil is still moist, which is especially, the case in the slightly acid sulphate soils of the area. The present land use types can be identified as follows (Figure 3.2):

1. Double cropping of irrigated WS.HY.rice-SA.HY.rice.
2. Double cropping of floating rice followed by upland crops (maize, sesame, water melon, mungbean, cassava).
3. Single cropping of irrigated WS.HY. rice.
4. Planted *Melaleuca* or *Eucalyptus*.

(WS : Winter-Spring; SA : Summer-Autumn; HY: high yielding)

*** In the Area No.3 - Phung Hiep:** Double cropping of high yielding rice and double cropping of HY rice followed by traditional rice are the common land use types presently practised extensively. Single cropping of traditional rice is still practiced giving low yields. Upland crops such as sugarcane, pineapple are planted on high raised beds. The present land use types can be identified in the acid sulphate soil area as follows (Figure 3.3):

1. Triple irr.SA.HY.rice followed by traditional rice and irr.WS.HY.rice.
2. Double irrigated WS.HY.rice-SA.HY.rice.
3. Irrigated HY rice followed by traditional rice.
4. Rainfed HY rice followed by traditional rice.

5. Double irr.WS.HY.rice-SA.HY.rice combined with prawn cultivation.
6. Double irr.SA.HY.rice - traditional rice combined with prawn cultivation.
7. Sweet potato followed by traditional rice.
8. Sugarcane followed by traditional rice.
9. Ginger intercropped with mungbean and traditional rice.
10. Single irrigated WS.HY rice.
11. Single traditional rice.
12. Ratoon cropping of Sugarcane.
13. Cashew intercropped with Pineapple.
14. Pineapple.
15. *Eucalyptus*.
16. Planted *Melaleuca*.

(WS : Winter-Spring; SA : Summer-Autumn; HY: high yielding; irr.: irrigated)

*** In the Area No.4 - Hong Dan:** Wetland rice is the major form of land use in the study area. Double cropping of high yielding (HY) rice followed by traditional rice is mainly practiced in the North-East where saline water intrusion comes relatively late. The HY rice is grown from early May to August. The subsequent traditional rice will be transplanted after harvesting the first crop. The second crop is harvested in January. Locally, however, where shallow (less than 60 cm deep) flooding occurs in the wet season, double cropping of HY rice can be seen. The second crop of HY rice is grown from late September to early January. Single cropping of HY rice or traditional rice is practiced in places far from canals or where salt water intrudes early in the dry season. The HY rice is practiced in the shallow flooded area (depths of 30 to 50cm) and traditional rice is grown in the medium flooded area (depths of about 60cm). Main upland crops are pineapple and sugarcane, grown on high raised beds in the moderately and severely acid sulphate soil areas. At present, land flooded by a daily salt water tide in the dry season is used for extensive shrimp or semi-intensive crab cultivation combined with single wetland rice in the rainy season, or shrimp/crab cultivation during the dry season alone. This type of land use has become more and more popular among farmers in the area. In the severely acid sulphate soil areas without drainage canals, *Melaleuca*, *Eucalyptus* and small stem bamboo is planted. The present land use in the acid sulphate land of the study area can be identified as follows (Figure 3.4):

1. Double rainfed SA.HY.rice-AW.HY.rice.
2. Rainfed SA.HY rice followed by traditional rice.
3. Single rainfed AW.HY rice.
4. Single traditional rice.
5. Ratoon cropping of sugarcane.
6. Pineapple.
7. Extensive shrimp/semi-intensive crab culture.
8. Extensive shrimp/semi-intensive crab culture followed by traditional rice.
9. Small stem bamboo.
10. *Eucalyptus*.
11. Planted *Melaleuca*.

(AW : Autumn-Winter; SA : Summer-Autumn; HY: high yielding)

3.3 Current land and water management practices:

-The most important land and water management practice for growing upland crops in the area is the construction of raised beds. Raised beds are different in different soil types and also depend on the types of crops. In general, there are two types of raised beds: low and high. Cassava, Yam, Sugarcane, Pineapple, Cashew, and small stem bamboo are grown on high raised beds in the area. The principle of raised bed construction is that the top soil horizon (without acidity) is placed on the top of the raised beds. The construction of raised beds is carried out in the dry season and plant cultivation starts at end of the first rainy season for yam, cassava. After planting, the top of the raised beds should be covered by grasses or straw. (relates to Area No.1, Area No.3, and Area No.4).

- Low beds are constructed for growing upland crops during the dry season and early rainy season when the water does not yet flood the beds, and for rice growing during the rainy season when the beds are flooded. The ditches between the low raised beds should not be deeper than the depth at which the acid horizon in the soil starts. Crops grown on this type of raised bed form the unusual sequence of sugarcane, grown as annual crop during 7-8 months in the dry season and early rainy season, followed by traditional rice in the wet season. *Eucalyptus* is also planted on low raised beds. (relates to Area No.2 and Area No.3).

-The shallow drainage system is applied for rice cultivation in the extremely acid sulphate soil areas, particularly in fields of double rice crops. This land management practice which is widely applied in the saline and saline acid sulphate soil areas recently was introduced into the study area. Shallow ditches are constructed in the field at intervals of 10 to 50 meters (depend on different areas), resulting in only a few ditches found in a field for drainage. This system is connected to a deep ditch dug around the field to be used for drainage and irrigation. Besides, a dike is also constructed outside the field in order to control the water level in the field. (relates to Area No.1, Area No.2, Area No.3, and Area No.4).

-Zero tillage technique is also applied for rice cultivation in the acid sulphate soil areas with a long inundation period. No soil tillage takes place between the WS.HY rice crop and the SA.HY rice crop in order to save time. After harvesting the WS HY. rice crop, the rice field is burnt and the water is let into the field for SA HY. rice crop. Ploughing is carried out only one time, after harvesting the Summer-Autumn rice crop, to take advantage of the flood water for washing the acidity out of the soil. (relates to Area No.1and No.2).

-Field leveling and construction of rice field bunds is also important. In order to grow modern short duration rice varieties, the fields should be leveled during the land preparation. The bunds surrounding rice field are repaired after each crop. (relates to Area No.1, Area No.2, Area No.3, and Area No.4)

-The most important land and water management practices for crop cultivation in salt affected areas is the construction of dikes and dams or sluice gates. Proper maintenance and use of the dike, dam or sluice gate during the dry season is of crucial importance for crop cultivation. When the rainy season comes, the dam or sluice gate is often removed to be constructed again in the next dry season. (relates to Area No.4).

- The ditch system is needed for the combination of growing prawn in ditches surrounding rice fields and rice on the same fields at the same time. (Area No.3).

-A ditch system is needed for the combined raising of shrimp in the ditches surrounding the rice field in the dry season and rice cultivation on the same field in the rainy season. When the ditches are dug, the excavated material is used to build a dike surrounding the field. During the dry season (November to April), shrimp fries are taken in at every high tide and left to grow naturally, feeding on phytoplanktons. As soon as the rain comes, saline water is drained out of the polder until the soil is free from salt. Rice cultivation can start by transplanting traditional rice or direct seeding of a 120 days rice variety. Annually, new sediment has to be removed from the bottom of the ditches. It is placed on the surrounding dike. (relates to Area No.4).

3.4 Experiences of farmers:

Under the different influences of physical constraints, the farmers in four study areas have, by trial and error, developed various practices to overcome the constraints of their lands. The practical experiences of farmers in using acid sulphate soils center on:

(1) Selection of the best cropping calendar of various crops such as: rice, yam, cassava, sugarcane...

(2) Irrigation and shallow drainage systems for high yielding rice cultivation.

(3) Construction of raised beds for upland crops.

(4) Construction of low raised beds for sugarcane followed by traditional rice.

(5) Adding a grass or straw mulch on the top of raised beds after planting upland crops.

(6) Using zero-tillage for double high yielding rice cultivation.

(7) Construction of dikes, dams or sluice gates in the salt water intrusion areas.

(8) Construction of ditch systems for rice-prawn cultivation in fresh water areas.

(9) Construction of ditch systems for shrimp/crab cultivation in the salt water intrusion areas.

These experiences can be further illustrated for the above nine items from the farmer's view point as follows:

(1) The cropping calendars of rice and uplands crops are arranged so as to keep clear of (i) the early rainy season (end of April and May) and (ii) the flooding season (from September to the beginning of December) to avoid the extreme acidification of soil and water during the first rains and very deep flooding, respectively. However, fresh water supply from new main canals and shallow drainage systems, have made possible double cropping of Winter-Spring and Summer-Autumn rice, even in the early rainy season. In the salt water intrusion areas during the dry season, cropping calendars of rice and uplands crops are arranged so as to keep clear of (i) the early rainy season (end of April and May) and (ii) the salinity period (from December to early May) to avoid the extreme acidification of soil and water during the first rains and salt water intrusion, respectively.

(2) Fresh water plays a key role for rice cultivation in the dry season. Water levels can be kept close to the surface of the soil to prevent acidification. Shallow drainage systems are connected with the main canals in order to leach out acidity in the early rainy season. The secondary and tertiary canals are required for irrigation in the dry season.

(3) The main reasons for the construction of raised beds are: (i) to lift the soil surface during the flooding period, (ii) create what appears to be a favourable soil structure for plant growth, and (iii) to leach out acidity and salt from the surface of the raised beds.

(4) The main reasons for construction of low raised beds are to raise the surface of the soil in the deep flooding areas to a higher level that make it possible to grow rice during the flood period.

(5) The aim of farmers to cover the top of raised beds with grasses or straw after planting is to restrict evaporation from the top soil and keep

the top soil moist, thereby preserving moisture.

(6) Zero tillage practices are applied widely to shorten the duration of rice cultivation and to ensure harvest before the beginning of the long flooding period.

(7) The main reasons for the construction of dikes, dams or sluice gates are: (i) to prevent salt water intrusion during the dry season, (ii) to prevent the field from inundation in the wet season and (iii) accelerate leaching of salt and acid water in the early rainy season. In this way, farmers can maintain fresh water most of the year or all year, even though their farms are located in the salt water intrusion area. Farmers can then cultivate rice, raise fresh fish in ponds or cultivate upland crops during the rainy season and in the early dry season. When the rainy season comes, water in the rivers and canals becomes fresh, and farmers open the dam or sluice gates to leach out of saline or acid water from their fields.

(8) The reason of construction of the ditch system for prawn cultivation in the fresh water areas is to control : (i) water movement following daily tides during the whole growing season, (ii) flood protection by means of high dikes surrounding the fields; and (iii) gravity tidal irrigation and drainage facilities during the flooding period..

(9) The main reason of construction of the ditch system for shrimp cultivation in salt water intrusion areas is to control daily tidal saline water during the dry season. Sluices with flapgates were used to let brackish or saline water into the polder in order to keep the soil wet at all times to prevent acidity during the dry season and to facilitate intake of fries or to harvest shrimps.

3.5 Knowledge gaps:

Farmers' experience is usually limited to the local area where they live and to observed effects of different management procedures (Bouma *et al.*, 1993). Farmers' experiences were described in section 3.4 of this chapter. They area still confronted with many problems, however, in implementing new soil and water management systems. The following problems may be distinguished:

- Available new technology was not transferred to them because they had no access to this technology and their education levels are rather low.
- Farmers working in non-acid soils want to expand their land into the acid sulphate soil areas. They have no experience to build on.
- Farmers do not focus on single crops but on integrated cropping systems with different crops. They have no experience with this and would benefit from expert knowledge generated elsewhere.
- Farmers always want to increase and improve their crop production. A wide variety of water and soil management techniques can be applied for different land use types. Also many techniques relating to fertilization, planting density, and using different seed varieties are being used and developed elsewhere. Farmers experiment with some of these techniques but would benefit from having access to expert expertise based on experiences obtained elsewhere.
- In newly reclaimed acid sulphate soils, infrastructure of irrigation and drainage canals is poor for developing new cropping systems or land use types. Guidance is needed for developing an effective drainage infra-structure.
- Most farmers are poor. They have no capital for initial investment. How they adopt new techniques that are both cheap and effective.

By trial and error, farmers in the Mekong Delta have developed various management systems and combined several crops, for a range of soils. They made more or less successful attempts to match land use with land and improve land qualities by management. However, during their practices, many questions were raised. Some of these questions can be answered by expert studies on acid sulphate soils made elsewhere in the last decade which should be presented in a systematic way through land evaluation schemes. These results will be reviewed in chapter 4. Other questions cannot be answered using available data and require additional experiments which will be presented in chapter 5.

Chapter 4

Expert level

4.1 Some results of recent studies by experts:

Innovative land use systems have been developed by farmers in the Mekong Delta as discussed in the previous chapter. However, several problem remain and many processes are poorly understood. In this chapter we raise the question whether existing research results can be used to solve these problems.

Acid sulphate soils have been studied for many years. Problems for crops in drained acid sulphate soils include: toxicity, due to the increased solubility of aluminium when pH drops below 4; unavailability of phosphate caused by iron and aluminium-phosphate interactions; low base status; and salinity (Dent, 1992; Breemen,1993). In the Mekong Delta, an estimated 1.6 million hectares consists of potential or actual acid sulphate soils, of which about 400,000 ha are characterized by salt water intrusion during the dry season. These acid soils are difficult to cultivate and improve (Xuan, 1995). Many experiments were carried out by experts on acid sulphate soils during the last twelve years via VH10 project, other international projects such as EEC, SAREC and national/local project. These experiments play an important role for understanding more about acid sulphate soils and crops grown on it. Different acid sulphate soil areas have different land use systems and water/soil management as well as cultural practices. In this section, all previous studies on acid sulphate soils in the four study areas are reviewed in order to supply data to better understand the underlying processes in these acid sulphate soils, to support a systematic land evaluation for all areas and for defining additional field experiments that can fill still existing knowledge gaps.

*** In the Area No.1 - Tan Thanh:**

- Studies on the cultivation of rice showed that in freshly reclaimed acid sulphate soil areas of the Tan Thanh district, the single cropping of Winter-Spring rice gave a good response to P fertilizer. Regardless of the N, K fertilizers, the yield of rice can reach 2.5 tons/ha with $90kgP_2O_5$ in comparison with treatment without P (0.7tons/ha). Highest yields of rice (5.8tons/ha) were obtained in this experiment after the application of 100kgN + $90kgP_20_5$ + $30kgK_2O$ (Ren *et al.* 1993).

- Study on the soil and water management practices for yam cultivation such as construction of raised beds, mulching, maintaining water in the ditches showed that there is little variation of pH of the two depths: 0-20cm, 20-40cm with time. The soil pH was about 4.0. Similarly, there was no marked difference in free iron and Al^{3+}. Mulching results in higher soil moisture contents in surface soil. Maintaining water level in ditches in combination with an irrigation of 10mm per week reduced differences between the soil moisture contents among different ways of managing surface soil. Mulching with grass treatments gave higher yields. Maintaining water in ditches in combination with mulching gave highest yields (20.25 tons/ha) and had significantly different yields as compared with treatments without controlling water in ditches. An extra yield of nearly one ton per hectare was obtained by giving a supplementary irrigation of 10mm/week in the period from 75 to 110 days after planting. Then a 17% tuber yield increase can be obtained (Sen *et al.*, 1987).
- Yam gave a good response to P and K fertilizers. In order to increase tuber yield of yams in the acid sulphate soils, P, K should be applied in addition to N. Highest tuber yields of yams (47.2tons/ha) were obtained after application of 160kg P_2O_5 /ha and 100kg K_2O/ha (Sen *et al.*, 1987).

*** In the Area No.2 - Tri Ton:**

There are very few experimentation and cultural practice studies in the acid sulphate soil area of Tri Ton. The farmers learned themselves from the experiences of other farmers in different acid sulphate soil areas for rice cultivation. In 1992, a research program on the reforestation in the extremely acid sulphate soil area, paid much attention to growing of *Melaleuca* and *Eucalyptus* (Poynton, 1995; Kelly *et al.*, 1995). This project was funded by Australian Government via the Mekong Committee Secretariat. The results of the study are presented as follows:

- A study on the environmental impacts of *Melaleuca* forest planted on the extremely acid sulphate soil in Long Xuyen Quadrangle showed that (i) the pH of the ground water in the 8 years old non-ponded *Melaleuca* forest and in wastelands remained relatively constant over the sampling period (early rainy season: July); (ii) higher pH of water was recorded in the ponded forest than in the non ponded areas; (iii) Water quality in the non ponded areas was unsuitable for a wide range of uses but water from the ponded forest was acceptable for recreational and agricultural use and for some industrial purposes (based on Australian Water Quality Guidelines); (iv) for all data combined, variation in pH water was related to depth of inundation, the greater the depth of inundation the higher the pH ($R^2 = -0.659$) (John Simpson, 1995).

- Another study on the environmental impact of acid release from newly constructed raised beds for *Eucalyptus* planting in Long Xuyen Quadrangle was carried out by Tinh (1995). He showed that in the acid sulphate soil profile, the lower part (at 30-60cm: sulfuric horizon) has a very high amount of acidity. If this layer is turned over to make the beds, the amount of leached acidity is high and adversely affects the river/canal water. The acidity in water is high enough to kill fish (Tuan, 1995) and also to effect crops. He predicted that if more land would be used for *Eucalyptus* plantation, the impact on the environment will be quite negative.

Since 1992-1993, an experimental station was established by Can Tho university to identify and transfer new cultural techniques and promising land use types to the acid sulphate soils area. After 3 years, some results of the studies were presented and were transferred to the farmers. More details of these studies will be shown in the chapter on field experimentation in this thesis.

***In the Area No.3 - Phung Hiep:**

In the period 1980 - 1992 most attention was paid to rice in the acid sulphate soils, because it is the major staple food in Vietnam. Fertility experiments using nitrogen, phosphorus, potassium and lime for rice on acid sulphate soils were carried out (Ren *et al.*, 1993) reported that:

- In severely acid sulphate soils (Typic Sulfaquept, sulfuric horizon within 50cm from soil surface, pH: 3.5, exchangeable Aluminium: 138 mmol/kg), the first crop of rice (wet season) failed completely within 15 days after transplanting. During the following dry season about one third of the crop survived but there were no reliable yield data. Growth improved during the third and fourth crops (subsequent wet and dry seasons) with applications of 50-100kgN + 45-90kgP_2O_5

per hectare, giving yields between 2.7-2.9tons/ha. This is probably due to repeated leaching of the soil surface with irrigation water before transplanting and during the rice cultivation period.

+ Four consecutive experiments investigated the effect of sources and rates of P fertilizers. Fertilization with superphosphate and thermophosphate resulted in higher yields than apatite. In general, when the soil was improved by liming, plants showed a good response at 30kg to 60kg P_2O_5 ha^{-1}, but increasing P to 90 kg ha^{-1} did not further increase the yield. The experiments also showed that the various application methods and application times gave no difference in rice yield.

+ Liming under good management and with NPK fertilizers greatly increased rice yield in four consecutive crops (6 to 10 tons ha^{-1}). Even at low doses (1.0 ton ha^{-1}), lime showed a positive effect. Results indicate that the yield increase at low dosage is mainly due to improved calcium nutrition and depressed uptake of iron. The authors concluded that the application of lime is economically unattractive because of high prices in the Mekong Delta.

- In the moderately acid sulphate soil areas (Sulfic Tropaquepts, sulfuric horizon between 50 - 80cm), twelve experiments were carried out at different locations in the Mekong Delta. Results show that rice yields increased significantly after applying 50kg to 100 kgN ha^{-1} and 30kg to 60kg P_2O_5 ha^{-1}. Potassium had no significant effect on yield.

- In the slightly acid sulphate soil areas (Sulfic Tropaquepts, sulfuric horizon is deeper than 80 cm), the highest yield (6.0 - 6.5 tons ha^{-1}) was obtained applying 120kg N ha^{-1} and 30kg P_2O_5 ha^{-1}. There was no response to potassium.

Besides fertilization, water management of rice on this soil type has also received attention in research. Water management experiments showed:

- In Hoa An (Phung Hiep district) with extremely acid sulphate soils (sulfuric horizon < 50cm from soil surface), experiments were carried out during the dry season of 1990 and 1991 to develop a package of agronomic and water management strategies for farmers. The field was not leveled and rice was broadcast and continuously irrigated until maturity. The mean yield obtained was

2 tons ha^{-1} in a Winter-Spring crop. In 1991, the redox effect with an alternating submerged/dry practice and shallow drainage systems was investigated. Results indicate that no significant differences were found as a function of drain distance, but strong evidence was found confirming the "redox effect" on plant performance, as compared to leaching. Yield can reach up to 3..9 tons ha^{-1} (Hanhart *et al.*, 1993).

Upland crops such as sugarcane, and pineapple have long been profitable crops on acid sulphate soil areas in the Mekong Delta. Experiments on cultural practices of sugarcane and pineapple show:

- Growth and yield of pineapple in Hoa An, Phung Hiep (fresh water area), is affected by high concentrations of aluminum. Pineapple is planted on high raised beds constructed in a simple way where subsoil became the top of the raised beds. Pyrite oxidation occurred on the bed surfaces. There was no fertilizer application. The average yield varied from 8 to 11 tons ha^{-1} (Nga *et al.*, 1994)
-Results of a comparable study in the acid sulphate soil areas of Tan Lap are quite different. In the latter area, the raised beds were constructed in such a way that the top of the surface soil (without acid) is placed on the top of the raised beds. Fertilization rates were: 300kg Urea ha^{-1} + 300kg Thermophosphate ha^{-1} + 100kg KCl ha^{-1} during the growing period and the yield of pineapple reach up to 20 tons ha^{-1} (Nga *et al.* 1994). A recent study in Tan Lap farm showed that phosphorus and lime play an important role in increasing pineapple yield. The highest pineapple yields of Queen and Smooth Cayenne (44 tons ha^{-1} and 74 tons ha^{-1}, respectively) were at an application of 10g N + 5g P_2O_5 + 10g K_2O per plant for Queen and 10g N + 7g P_2O_5 + 10g K_2O per plant + 1 ton lime ha^{-1} for Smooth Cayenne (Guong *et al.*, 1995).
- Sugarcane can grow in acid sulphate soils with pH 3.5 - 5.0 and KCl extractable aluminum up to 17.0 cmol(+) kg^{-1} soil. In the moderately acid sulphate soils of Phung Hiep - Vi Thanh, sugarcane is planted on high raised beds. Fertilizer application for each crop varied from 50 to 250 kgN ha^{-1}, no P and K. The maximum yield registered was about 100 tons raw cane ha^{-1}, and average yields range from 60 to 80 tons ha^{-1}. Cultivation of sugarcane on acid sulphate soils is perfectly feasible when attention is paid to water and nutrient requirements (Nga *et al.* 1993).

*** In the Area No.4 - Hong Dan:**

Large areas in the Mekong Delta remain uncultivated because the soils are acid or potentially acid with salt water intrusion during the dry season. Besides noting the farmer's experiences in using saline acid sulphate soils, experts have investigated land use systems and carried out experiments in this type of land.

- A study on rice cultivation using an intensive shallow drainage system in the saline and acid sulphate soils (Xuan *et al.*, 1982) showed that rice is grown successfully on low beds drained by an intensive network of shallow ditches. For construction, one side of the field is divided into four strips of 9 by 36 meter. Between each strip a ditch of about 1 meter width and 0.3 to 0.6 meter depth is excavated by hand, the slices of soil are being spread evenly over the land to make low raised beds. Each shallow ditch opens at one end to a main drainage canal. Leaching commences with the first heavy rains (in April). Rain water leaches the oxidized sulfidic soil material on the ridges and removes toxic substances and salts. These substances concentrate in the shallow ditches and in the drainage canals. The outlet gates remain closed until the drained water reaches the level of the surface of the raised beds. When the next rain comes, the accumulated water is allowed to run through the canal and out to the river at low tides. The cycle is repeated two or three times before the entire region is naturally flooded, and drainage is no longer possible. Rice is transplanted into the flooded beds. Saline and acid tolerant, medium duration rice varieties are used. Yields on soil without shallow drainage systems are only 0.2 to 0.5 tons/ha, but after using the shallow drainage system about 4 tons/ha is obtained.
- A study on the rice - shrimp cropping system in the saline acid sulphate soils indicates that under natural conditions, farmers now can grow a safe crop of rice during the rainy season, then raise a crop of shrimp during the dry season (Xuan, 1993). After surveying 20 different farming systems, the results show that such a high production of the rice - shrimp system can only be obtained if the following conditions are met: soil should be flooded daily with tidal saline water; tidal water should be rich in silt (about 0.25 g/l) and in shrimp fries (about 70 fries/l) of the Penaeus spp. and Metapenaeus spp.; the soil should be empoldered, each polder should not be more than 10 ha having complete sluices with flapgates to facilitate intake of fries or harvesting shrimps, while keeping the soil wet at all

times to prevent soil oxidation during the dry season. Cumulative yields of shrimp can reach up to 690 kg/ha/year. Rice yields up to 4 tons/ha are obtained (Xuan *et al.*, 1986).

- Cultivation of pineapples was studied in the severely acid sulphate soil areas of the Binh An village with salt water intrusion in the dry season, rainfall about 2000 mm/year, and shallow flooding. These poor conditions affected growth and yield of pineapple. Pineapple was planted on high raised beds. The high raised beds were constructed in a simple way meaning that the subsoil (with acid) became the top of the beds. The oxidation of pyritic material occurred on the bed surfaces. 300kg Urea ha^{-1} + 300kg Thermophosphate ha^{-1} + 400kg KCl ha^{-1} was applied and the yield of pineapple ranges from 16 to 18tons ha^{-1} (Nga *et al.* 1993).

The farmer's activities mentioned in chapter 3 and many experiments reviewed in this chapter so far, provide an overwhelming quantity of data that are difficult to schematize and generalize. Here, a system analysis is necessary, as provided by land evaluation schemes, as presented by FAO (1976, 1983).

4.2 Land evaluation study on farm levels:

4.2.1 Introduction:

Land evaluation techniques have been applied widely to assess the capacity or suitability of land for various land uses (FAO,1976; Beek,1984; Fresco *et al.*, 1990; Tuong et al, 1991). The process of assessing the suitability of land for alternative uses includes (i) the identification, selection and description of land use types relevant to the area under consideration (section 4.2.2 of this chapter); (ii) the mapping and description of the different types of land units expressed in term of land quality that occur in the area (section 4.2.3 of this chapter); and (iii) the assessment of the suitability of the different land units for the selected land use types (section 4.2.4 of this chapter) (FAO,1976).

Overall suitability of land (section 4.2.4 of this chapter) is expressed in two suitability orders: suitable land and not suitable land. The orders have been further subdivided into two to three classes. For suitable land (S) three classes have been distinguished; highly suitable land (S1), moderately suitable land (S2), and marginally suitable land (S3). Unsuitable land has been divided into land having limitations that might be surmountable (N1: currently not suitable), and land with limitations that cannot be improved (N2: permanently not suitable) (FAO, 1976).

Using the FAO Framework for land evaluation, a coarse land evaluation exercise is carried out for acid sulphate soils of the Mekong Delta showing that conditions are often very variable. Locally, the suitability at farm level may be very different from what is predicted for the zone as a whole (Mensvoort *et al.* 1993).

As defined, land evaluation is scale independent. Still, applications are mostly made at regional level involving a relatively large number of different units which are being compared in terms of their relative suitability for a given type of land utilization. Thus, applications are often focused on land use planning purposes rather than on use by farmers as a decision support system, even though the definition of land evaluation would certainly include such applications (Bouma *et al.* 1993).

A study on using expert systems and simulation modeling for land evaluation on farm level (a case study from New York State) indicates that land evaluation according to criteria of the FAO frame work is more accessible and transparent to the user when decision trees are used rather than the usual matching tables (Bouma, *et al.*, 1993).

4.2.2 Selected promising land use types for land evaluation:

A systematic land evaluation study of acid sulphate land (Tri, 1990) indicates that present land use can be the basis and a good starting point for selection and description of relevant land use types in land evaluation for acid sulphate soil area in the context of the Mekong Delta.

Continuation of present land use in the extremely acid sulphate soil areas and some parts of moderately acid sulphate soil areas will, however, lead to: (a) under utilization of large area, with only uncultivated land, (b) restricting the production capacities of the area, which is now already reclaimed and used, and (c) increasing un(der)employment of the increasing local population.

Based on present land use systems including land and water management practices, agricultural problems are defined as described in chapter 2 (farmers level) and in section 4.1 of this chapter. In all four study areas, we conclude that there are 16 promising land use types to be selected for further analysis and to be generalized by land evaluation procedures. Double cropping of modern rice varieties and *Melaleuca* are selected in all study areas. Yam and pineapple are selected for high flooding areas (areas1 and 2) and shallow flooding areas (areas 3 and 4), respectively. Selected land use types of prawn and shrimp are more promising land use for areas 3 and 4 because of specific physical conditions. The selected land use types in the four study areas are shown in table 4.5.

Table 4.5 : *Identification of promising land use types in four study areas of acid sulphate soils in the Mekong Delta.*(**Y** : *land use type is selected).*

Selected land used types \ study areas	Area No.1	Area No.2	Area No.3	Area No.4
-LUT1: Irrigated WS.HY. rice + SA.HY.rice	Y	Y	Y	-
-LUT2: Irrigated SA.HY. rice + traditional rice.	-	-	Y	-
-LUT3: Rainfed SA.HY. rice + AW. HY. Rice	-	-	-	Y
-LUT4: Rainfed SA.HY.rice + traditional rice.	-	-	Y	Y
-LUT5: Rainfed floating rice + upland crops	-	Y	-	-
-LUT6: Single irrigated WS.HY.rice	Y	Y	-	-
-LUT7: Irrigated SA.HY.rice + traditional rice (or WS.HY.rice) combined with prawn	-	-	Y	-
-LUT8: Rainfed HY.rice or trad.rice + shrimp (crab) culture	-	-	-	Y
-LUT9: Ginger intercropped with mungbean and traditional rice	-	-	Y	-
-LUT10: Shrimp (crab) culture	-	-	-	Y
-LUT11: Sugarcane followed by traditional rice	-	-	Y	-
-LUT12: Ratoon cropping of sugarcane	Y	-	Y	Y
-LUT13: Upland crops: Cassava, Yam	Y	Y	-	-
-LUT14: Pineapple	-	-	Y	Y
-LUT15: Small stem bamboo/ *Eucalyptus*.	-	-	-	Y
-LUT16: *Melaleuca*	Y	Y	Y	Y

Table 4.5 indicates that there are five, five, nine, and eight promising land use types to be selected for areas 1, 2, 3, and 4, respectively. These selected land use types in each area are shown as follows:

- **<u>In the study area No.1</u>**:
  - LUT1 : Double WS and SA irrigated HY.rice.(*)
  - LUT6 : Single WS irrigated HY.rice.(*)
  - LUT12 : Ratoon cropping of Sugarcane.
  - LUT13 : Upland crops: Cassava, Yam
  - LUT16 : Planted *Melaleuca.*

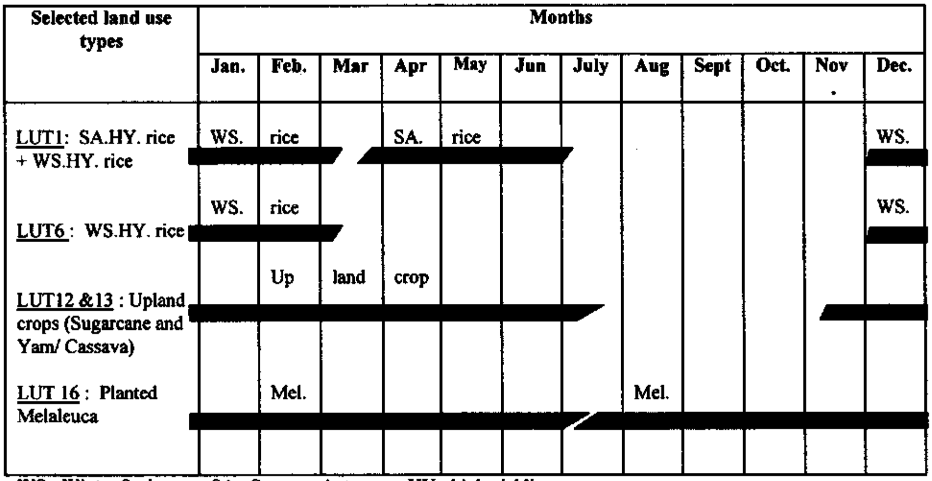
  ((*): WS: Winter-Spring; SA: Summer-Autumn)

- **<u>In the study area No.2</u>** :
  - LUT1 : Double cropping of irrigated WS. and SA.HY.rice.(*)
  - LUT5 : Double rainfed floating rice followed by upland crops (**)
  - LUT6 : Single cropping of irrigated WS.HY.rice.(*)
  - LUT13 : Upland crops: Cassava, Yam
  - LUT16 : Planted *Melaleuca.*

  ((*): WS: Winter-Spring; SA: Summer-Autumn ; (**): Sesame, Mungbean, Maize, Water Melon)

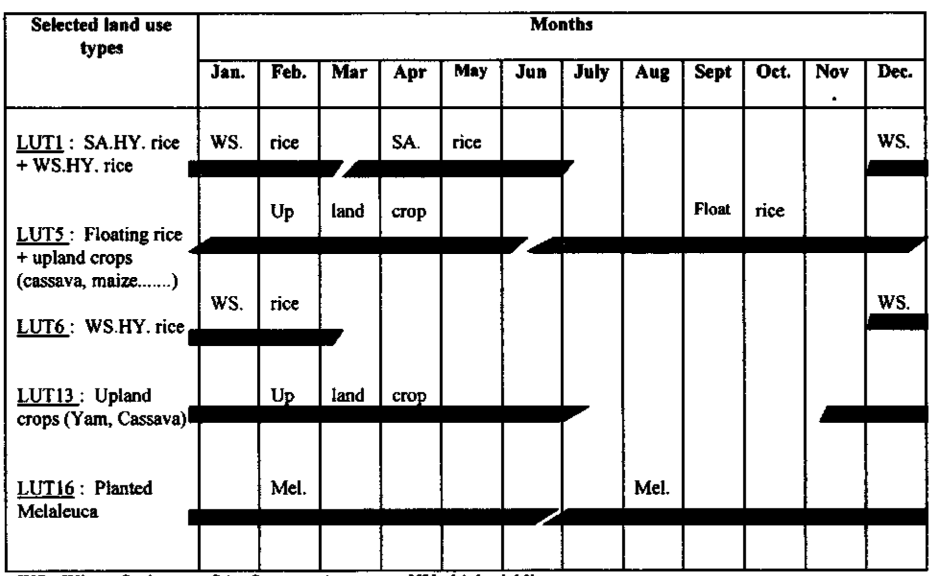
- **<u>In the study area No.3</u>** :
  - LUT1 : Irrigated WS.HY. rice followed by SA HY.rice.(*)
  - LUT2 : Irrigated SA.HY. rice(*) followed by traditional rice.
  - LUT4 : Rainfed SA HY rice followed by traditional rice.
  - LUT7 : Irrigated SA.HY.rice followed by traditional rice / HY.rice combined with prawn.
  - LUT9 : Ginger intercropped with mungbean and traditional rice.
  - LUT11 : Sugarcane followed by traditional rice.
  - LUT12 : Ratoon cropping of Sugarcane.
  - LUT14 : Upland crops: Pineapple, Cashew.
  - LUT16 : Planted *Melaleuca.*

  ((*): WS: Winter-Spring; SA: Summer-Autumn; HY: high yielding).



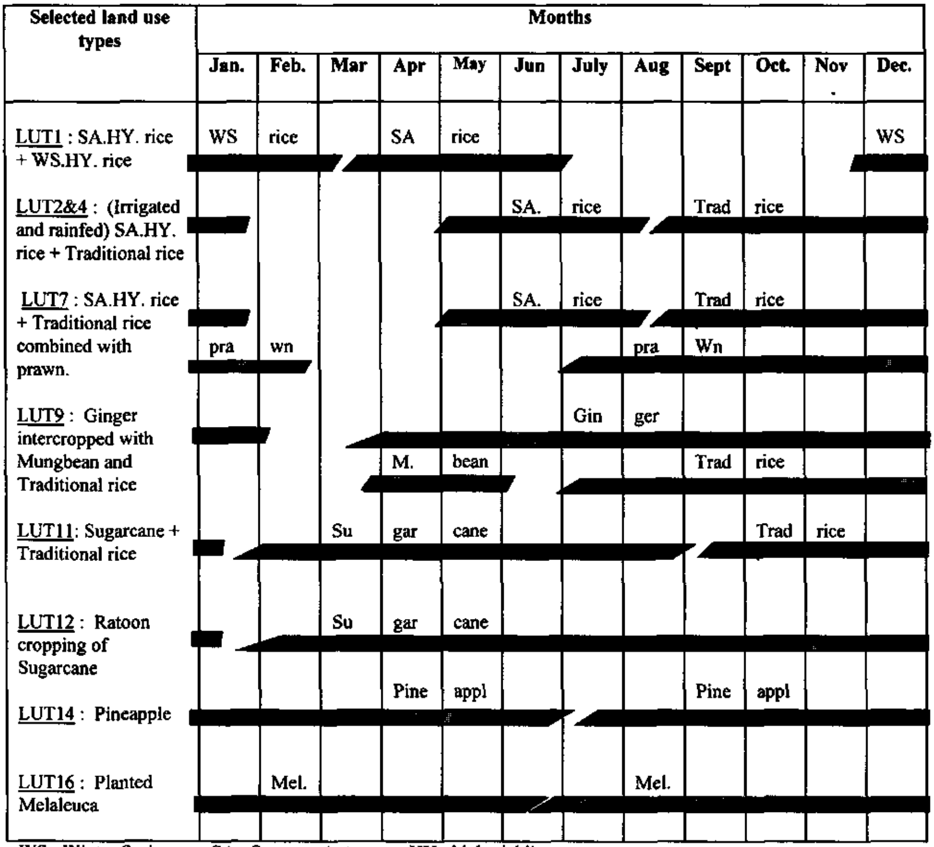
WS : Winter Spring SA : Summer Autumn HY : high yielding

Figure 4.1 : *Cropping calendar of the promising land use types in the area number 1 (Tan Thanh)*



WS : Winter Spring SA : Summer Autumn HY : high yielding

Figure 4.2 : *Cropping calendar of the promising land use types in the area number 2 (Tri Ton)*



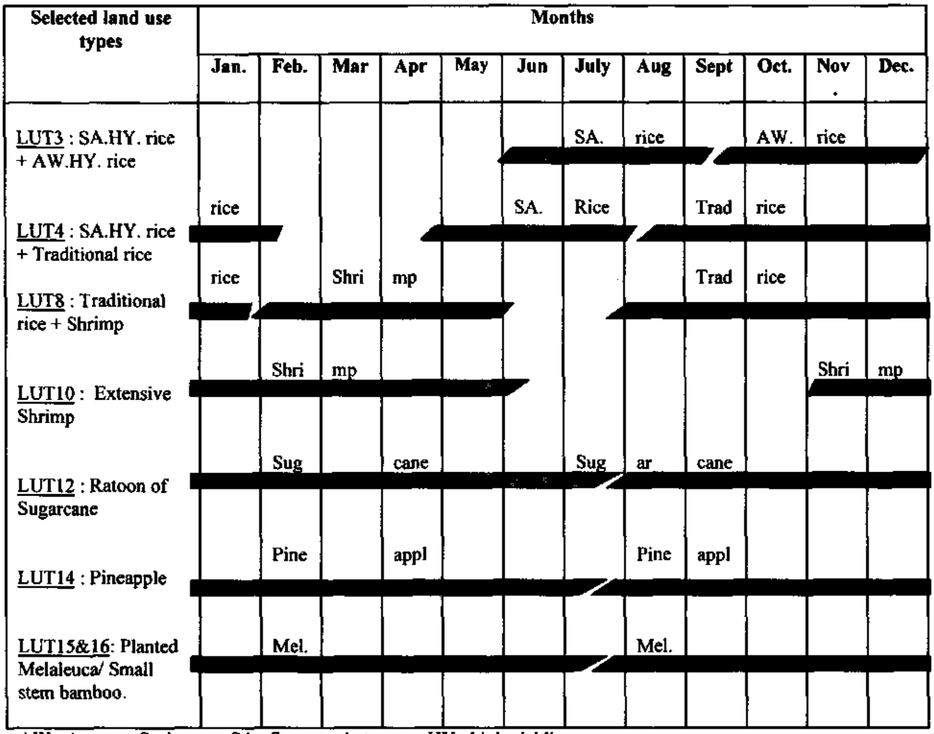
WS : Winter Spring   SA : Summer Autumn   HY : high yielding

Figure 4.3 : *Cropping calendar of the promising land use types in the area number 3 (Phung Hiep)*

- **<u>In the study area No.4</u> :**

  - LUT3 : Rainfed SA.HY. rice followed by AW. HY. rice.(*)
  - LUT4 : Rainfed SA.HY.rice(*) followed by traditional rice.
  - LUT8 : Rainfed (HY rice) or traditional rice followed by shrimp (crab) culture.
  - LUT10 : Shrimp (crab) culture.
  - LUT12 : Ratoon cropping of sugarcane.
  - LUT14 : Pineapple.
  - LUT15 : Small stem bamboo/*Eucalyptus*.
  - LUT16 : *Melaleuca*.

  ((*): AW: Autumn-Winter; SA: Summer-Autumn; HY: high yielding).



AW : Autumn Spring SA : Summer Autumn HY : high yielding

Figure 4.4 : *Cropping calendar of the promising land use types in the area number 4 (Hong Dan)*

The cropping calendar of these selected land use types of four study areas is showed in figure 4.1, 4.2, 4.3, 4.4, respectively. The factor rating in this study is based on the results of experiments, previous studies and farm observation.

4.2.3 Selected land qualities and characteristics:

A suitability evaluation starts with a purpose-related identification of relevant land use types (LUTs) (as discussed in the previous section of this chapter) and a selection of relevant land qualities. Land qualities are "complex attributes of land which act in a distinct manner in its influence on the suitability of land for a specific land of use" (FAO, 1976). Land qualities cannot be measured directly and they are therefore usually defined in terms of land characteristics, which are "attributes of land that can be measured or estimated"

(FAO, 1976). Land qualities provide information on what land units have to offer. At the same time land use requirements for each specific LUT have to be defined. They refer to the set of land qualities that determine production and management conditions of a given LUT (FAO,1976). Matching of qualities and requirements allows expressions in terms of relative soil suitabilities or limitations for a given type of land use. Characteristic descriptions of limitations are: "none or slight", moderate", severe" and "very severe".

Eight land qualities of the four study areas in the Mekong Delta were distinguished: (1) "potential soil acidity", (2) "soil acidity", (3) "flooding hazard", (4) "drought hazard" (in the rainy season for rice cultivation), (5) "salt water intrusion", (6) "potential for tidal irrigation and drainage", (7) "potential for daily tidal flood and drainage", and (8) "fresh water availability". These land qualities are expressed in terms of the following land characteristics which are expressed in a number of classes as indicated in tables 4.1, 4.2, 4.3, and 4.4.

1. The land quality: "potential soil acidity" was derived from the land characteristic: " depth of sulfidic layer".
2. The land quality: " soil acidity" was derived from the land characteristic: "depth of sulfuric horizon".
3. The land quality: "flooding hazard" was derived from the land characteristics: "maximum inundation depth", "beginning of inundation period", and "end of inundation period".
4. The land quality: "drought hazard" was derived from the land characteristic: "rainy season drought spell".
5. The land quality: "salt water intrusion" was derived from the land characteristic: "beginning and end of salinity period".
6. The land quality: "potential for tidal irrigation and drainage" was derived from the land characteristics: "high tide level in relation to soil surface", and " low tide level in relation to soil surface".
7. The land quality: "potential for daily tidal flood and drainage" was derived from the land characteristics: "high tide level in relation to soil surface", and " low tide level in relation to soil surface".
8. The land quality: "fresh water availability" was derived from the land characteristics: "length of rainfed period", "available water supply".

Table 4.1: *Land quality and ratings of land characteristics for land evaluation in the acid sulphate land area No.1, Tan Thanh - Mekong Delta-Viet Nam. (Adapted after Tuong et al., 1991)*

LAND QUALITY	RATING OF LAND CHARACTERISTICS
Soil acidity	(i) Sulfuric horizon occurs at < 50cm
	(ii) Sulfuric horizon occurs at 50 - 100cm
	(iii) Sulfuric horizon occurs at 100 - 150cm
Flooding hazard	(i) Maximum inundation depth < 30 cm
	(ii) Maximum inundation depth 30 - 60 cm
	(iii) Maximum inundation depth 60-100 cm
	(iv) Maximum inundation depth > 100 cm
	(v) Beginning of inundation period after 15/9
	(vi) Beginning of inundation period from1/9 - 15/9
	(vii) Beginning of inundation period from 15/8 - 1/9
	(viii)Beginning of inundation period before 15/8
	(ix) End of inundation period before 15/11
	(x) End of inundation period from 15/11 - 15/12
	(xi) End of inundation period from 15/12 - 15/1
	(xii) End of inundation period after 15/1
Drought hazard (in the rainy season for rice cultivation)	(i) Early and mid season drought spell
	(ii) Early season drought spell
	(iii) Mid season drought spell
	(iv) No drought spell
[illegible]	(i) Beginning and end of salinity period: [illegible] and before April
	(ii) Beginning and end of salinity period:April/Feb.and May/June
	(iii) Beginning and end of salinity period: February and June
	(iv) Beginning and end of salinity period:before Jan.and after June
Fresh water availability	**- In the rainfed areas:**
	(i) Length of rainfed period : 7 months
	(ii) Length of rainfed period : 6 months
	(iii) Length of rainfed period : 5 months
	(iv) Length of rainfed period : 4 months
	- In fresh water area: dry season
	(i) High: Adequate canals and infrastructure for irrigation
	(ii) Medium: incomplete feeder canals or on-farm structures exist.
	(iii) Low : No feeder canals or on-farm structures exist
	(v) No: No fresh water supply

Table 4.2 : *Land quality and ratings of land characteristics for land evaluation in the acid sulphate land area No.2, Tri Ton-Mekong Delta-Viet Nam. (Adapted after Tuong et al.,1991)*

LAND QUALITY	RATINGS OF LAND CHARACTERISTICS
Soil acidity	(i) Sulfuric horizon occurs at < 50cm (ii) Sulfuric horizon occurs at 50 - 100cm (iii) Sulfuric horizon occurs at 100 - 150cm
Flooding hazard	(i) Maximum inundation depth < 30 cm (ii) Maximum inundation depth 30 - 60 cm (iii) Maximum inundation depth 60-100 cm (iv) Maximum inundation depth > 100 cm (v) Beginning of inundation period after 15/9 (vi) Beginning of inundation period from 1/9 - 15/9 (vii) Beginning of inundation period from 15/8 - 1/9 (viii)Beginning of inundation period before 15/8 (ix) End of inundation period before 15/11 (x) End of inundation period from 15/11 - 15/12 (xi) End of inundation period from 15/12 - 15/1 (xii) End of inundation period after 15/1
Drought hazard (in the rainy season for rice cultivation)	(i) Early and mid season drought spell (ii) Early season drought spell (iii) Mid season drought spell (iv) No drought spell
Fresh water availability	**- In the rainfed areas:** (i) Length of rainfed period : 7 months (ii) Length of rainfed period : 6 months (iii) Length of rainfed period : 5 months (iv) Length of rainfed period : 4 months **- In fresh water area: dry season** (i) High: Adequate canals and infrastructure for irrigation (ii) Medium: incomplete feeder canals or on-farm structures exist. (iii) Low: No feeder canals or on-farm structures exist (v) No : No fresh water supply

Table 4.3 : *Land quality and ratings of land characteristics for land evaluation in the acid sulphate land area No.3, Phung Hiep - Mekong Delta - Viet Nam. (Adapted after Tuong et al., 1991)*

LAND QUALITY	RATINGS OF LAND CHARACTERISTICS
Soil acidity	(i) Sulfuric horizon occurs at < 50cm (ii) Sulfuric horizon occurs at 50 - 100cm (iii) Sulfuric horizon occurs at 100 - 150cm
Potential soil acidity	(i) No sulfuric horizon, sulfidic layer occurs at 50 - 100cm (ii) No sulfuric horizon, sulfidic layer occurs at 100-150cm
Flooding hazard	(i) Maximum inundation depth < 30 cm (ii) Maximum inundation depth 30 - 60 cm (iii) Maximum inundation depth 60-100 cm (iv) Maximum inundation depth > 100 cm (v) Beginning of inundation period after 15/9 (vi) Beginning of inundation period from1/9 - 15/9 (vii) Beginning of inundation period from 15/8 - 1/9 (viii)Beginning of inundation period before 15/8 (ix) End of inundation period before 15/11 (x) End of inundation period from 15/11 - 15/12 (xi) End of inundation period from 15/12 - 15/1 (xii) End of inundation period after 15/1
Drought hazard (in the rainy season for rice cultivation)	(i) Early and mid season drought spell (ii) Early season drought spell (iii) Mid season drought spell (iv) No drought spell
Fresh water availability	**- In the rainfed areas:** (i) Length of rainfed period : 7 months (ii) Length of rainfed period : 6 months (iii) Length of rainfed period : 5 months (iv) Length of rainfed period : 4 months
	- In fresh water area: dry season (i) High: Adequate canals and infrastructure for irrigation (ii) Medium: incomplete feeder canals or on-farm structures exist. (iii) Low : No feeder canals or on-farm structures exist (v) No : No fresh water supply
Potential for tidal irrigation and drainage (during cropping period)	**- High tide level in relation to soil surface** (i) above soil surface (ii) below soil surface **- Low tide level in relation to soil surface** (iii) above soil surface (iv) below soil surface

Table 4.4: *Land quality and ratings of land characteristics for land evaluation in the acid sulphate land area No.4, Hong Dan-Mekong Delta-Viet Nam. (Adapted after Tuong et al., 1991)*

LAND QUALITY	RATINGS OF LAND CHARACTERISTICS
Soil acidity	(i) Sulfuric horizon occurs at < 50cm (ii) Sulfuric horizon occurs at 50 - 100cm (iii) Sulfuric horizon occurs at 100 - 150cm
Flooding hazard	(i) Maximum inundation depth < 30 cm (ii) Maximum inundation depth 30 - 60 cm (iii) Maximum inundation depth 60-100 cm (iv) Maximum inundation depth > 100 cm
Salt water intrusion	(i) Beginning and end of salinity period after and before April (ii) Beginning and end of salinity period : April to June (iii) Beginning and end of salinity period : March to June (iv) Beginning and end of salinity period February to June (v) Beginning and end of salinity period: before January and after June.
Drought hazard (in the rainy season for rice cultivation)	(i) Early and mid season drought spell (ii) Early season drought spell (iii) Mid season drought spell (iv) No drought spell
Fresh water availability	**- In the rainy season:** (i) Length of rainfed period : 7 months (ii) Length of rainfed period : 6 months (iii) Length of rainfed period : 5 months (iv) Length of rainfed period : 4 months
Potential for daily tidal flood and drainage (during the dry season for shrimp cultivation)	**- High tide level in relation to soil surface** (i) above soil surface (ii) below soil surface **- Low tide level in relation to soil surface** (iii) above soil surface (iv) below soil surface

The land quality: " soil acidity" was recognized as dominant land quality for all land use types selected. Land qualities: "flooding hazard", "drought hazard", "salt water intrusion", and "fresh water availability" were important for double cropping of modern rice varieties. Land qualities: "potential for tidal irrigation and drainage" and "potential for daily tidal flood and drainage" are critical for raising of prawn in fresh water areas and shrimp in salt water intrusion areas during the dry season, respectively. Land qualities and land characteristics distinguished in four study areas are showed and rated in tables 4.1, 4.2, 4.3, 4.4.

4.2.4 Use of decision trees:

The available knowledge on acid sulphate soils from all two levels (farmers, and experts) was used to identify the most suitable land characteristics representing the land qualities. These characteristics were chosen in such away that they could be used for a farm level evaluation. One land quality, notably soil acidity, represented by the land characteristic: "depth to the sulfuric horizon" is important for all land use types selected. The land qualities: "flood hazard", "drought hazard", "salt water intrusion" and "fresh water availability", presented by the land characteristics: "length and depth of inundation", "available water supply", "beginning and end of salinity period", and available water supply", respectively, are all important for the double cropping of modern rice varieties.

Decision trees are made for each promising selected land use type. The decision trees are organized in the following manner: (i) vertical direction indicates the N, S3, S2, and S1 suitability as defined by FAO (1976), (ii) horizontal direction indicates the land characteristics used to represent the land qualities. The most important characteristic is evaluated first at the top of the page.

Arrows move in three directions:

- Vertically from top to bottom. In this case the suitability remains at the same level.

- Diagonally from right to left. The maximum limitation method is applied. Each land characteristic is examined for the degree to which it poses a limitation and the suitability moves to a lower level.

- Diagonal lines moving from left to right. These lines indicate the possibilities of upgrading suitability to a higher level. The arrows end at the conditional suitability level, i.e. the suitability after one or more specifications of the land unit or attributes of the land use have been modified (Driessen and Konijn, 1992). Conditions for upgrading were identified by improved soil and water management practices. These practices are indicated by codes, explained in the subsequent table.

- In the area number 1: Tan Thanh

Figures 4.5 and 4.8 present the decision trees of LUT1 and LUT6. These decision trees start with land quality: "fresh water availability" expressed in terms of the land characteristic: "available water supply". The land suitability classification will be N (non suitable) if there is no infrastructure for irrigation. However, it will be S1 (highly suitable) if canals for irrigation are constructed. Because it is impossible to grow double modern rice without irrigation . "Salt water intrusion" expressed in terms of the land characteristic: "beginning and the end of salinity period" is the second land quality for these decision trees. The period in April and May of the dry season with no fresh water for irrigation results in poor suitability. If the salinity starts before April and continues until after May is not possible to apply LUT1. There are no possibilities for improvement of this land characteristic under the present conditions of the area. "Flooding hazard" is the next land quality of this decision tree. It is expressed in terms of the land characteristic: "number of inundated months" for LUT1 and "time of the end of the inundation period" for LUT6. The land is highly suitable when the inundation period is less than 4 months, and is not suitable if this period is longer than 5 months for LUT1. Improvement of this land characteristic and upgrading of the land suitability is possible by construction of dikes surrounding the rice field in order to pump water out in the early rainy season (for LUT1 and LUT3) and application of zero-tillage practices (for LUT1).

Figures 4.6 and 4.7 present the decision trees of LUT13 and LUT12, respectively, (upland crops: yam/cassava and sugarcane). The "beginning and the end of the salinity period" is used to express the land quality: "salt water intrusion". The decision trees of these LUTs start with an analysis of this land characteristic. Beginning and end of the salinity period, respectively, before February and after May is distinguished as being crucial for growing upland crops on raised beds (LUT13). A way for improvement of this land characteristic is to construct a dam to protect against saline water intrusion and to store fresh water in the ditches and canals for water supply. However, the land suitability classification is only upgraded from non-suitable (N), marginally suitable (S3) to moderately suitable (S2), because the drought hazard still remains during crop growth. The second land quality that also play key role, is "fresh water availability" expressed in terms of land characteristic "available water supply". The requirement of upland crops for supplementary irrigation was necessary sometime during the dry season. If not, the land is considered to be unsuitable (class N) because crops cannot survive in long dry season. The possibilities for improvement of this land characteristic are to store water in the ditches and surrounding canals or to construct the canal systems in order to convey fresh water from main canals into the ditches. The application of these practices for upgrading land suitability is imperative. "Flooding hazard" is the next land quality of this decision tree. It is expressed in terms of the land characteristic: "beginning and end of inundation period". It is very high suitable (S1) with such a period of after August, 15 and before November, 15 and marginally suitable (S3) with a period of before August, 15 and after January, 15. For improvement of this land characteristic a dike can be constructed surrounding the field in order to protect against water inundation or water can be pumped out.

The land quality: "soil acidity" is expressed by the "depth of the sulfuric horizon" and is relevant for all land use types. The depth of sulfuric horizon within 50cm from soil surface is distinguished as being crucial for growing sugarcane (LUT12). The classification of land considering this land quality varies from marginally suitable (< 50cm) to highly suitable (> 100cm) for the rest of the selected land use types. To upgrade land suitability, there are many possibilities such as shallow drainage systems, and raised bed construction.

The present suitability for four promising land use types is thus determined, and also the conditional suitability after the most important constraints have been removed. These conditions for upgrading land suitability are showed in table 4.6, 4.7, 4.8 and 4.9.

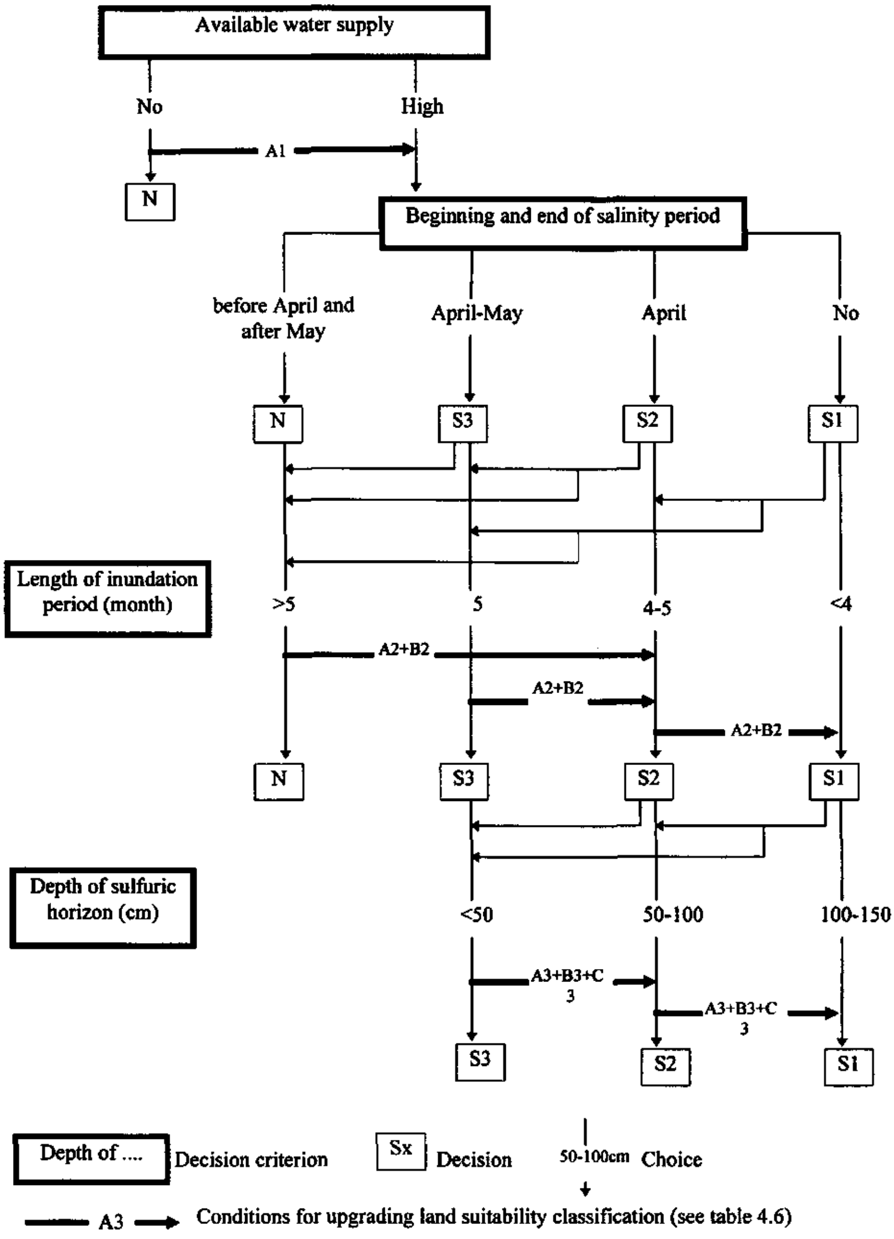


Figure 4.5: *Decision tree of Double cropping of Summer-Autumn and Winter-Spring HY. Rice (LUT1) in area 1 - Tan Thanh.*

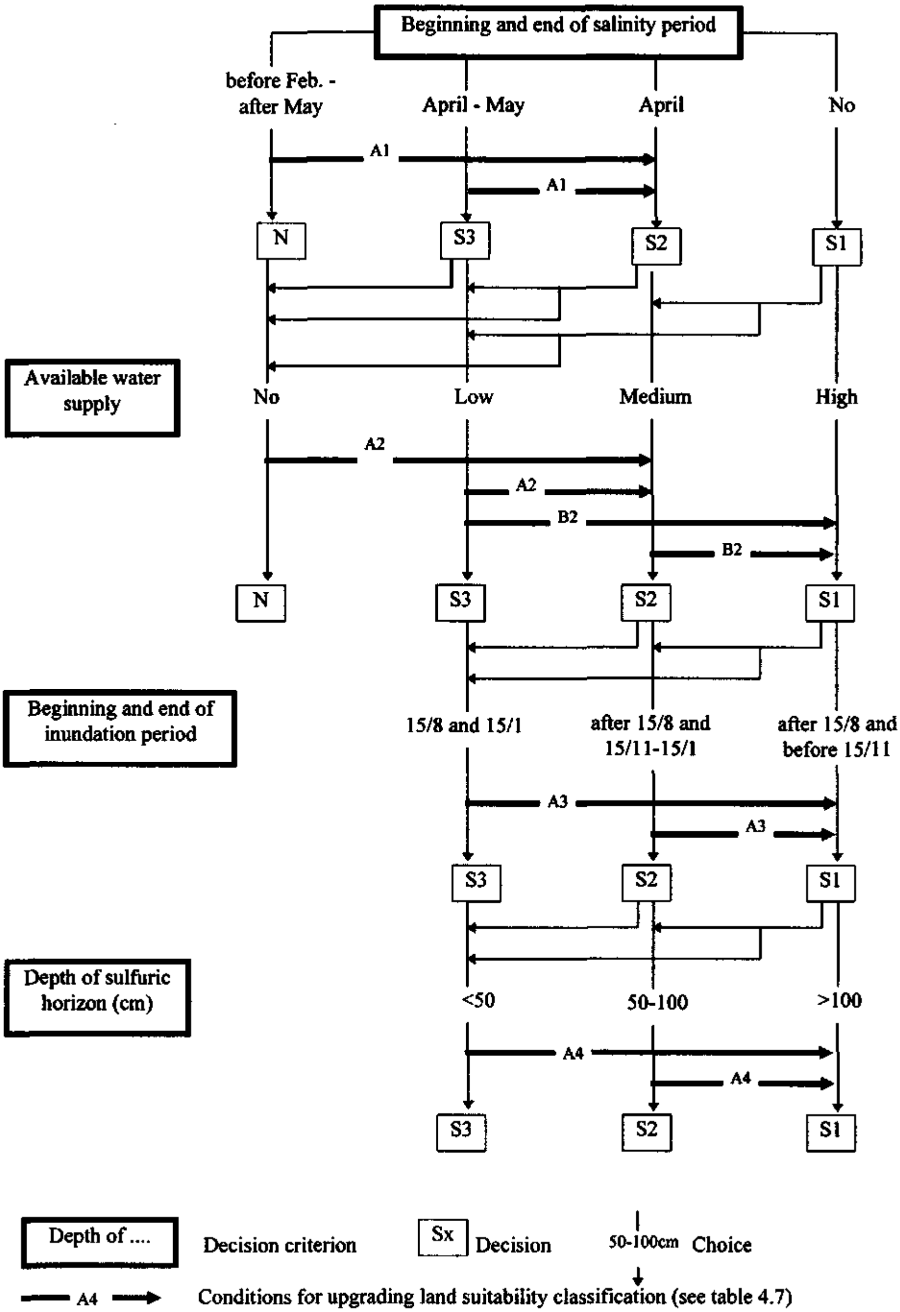


Figure 4.6: *Decision tree of single cropping of Yam (LUT13) in the area 1-Tan Thanh.*

Table 4.6: *Conditions of water and soil management practices for upgrading land suitability of double cropping of SA-WS HY.rice(LUT1) in the area No.1-Tan Thanh.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Available water supply: A1. Construction of canals and infrastructure for irrigation	N	S1	No constraints
2. Length of inundation period: A2.Construction of surrounding dike of the field in order to pump water out. B2 . Zero-tillage practices	S2 N, S3	S1 S2	No constraints Flooding in the end of SA crop
3. Depth of sulfuric horizon: A3.Construction of shallow drainage systems B3. Field leveling C3. Construction of field bunds and flapgate in order to control water.	S2 S3	S1 S2	No constraints Acidity in the beginning of SA crop

Table 4.7: *Conditions of water and soil management practices for upgrading land suitability of single cropping of Yam (LUT13) in the area No.1 - Tan Thanh.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Beginning - end of salinity period: A1.Construction of dam to protect against saline water intrusion and store fresh water in the ditches and canals for water supply.	N, S3	S2	Drought hazard some time during crop growth.
2. Available water supply: A2.. Store fresh water in the ditches and surrounding canals and cover on the surface of raised beds with grass in order to reduce the evaporation in the early stage of crop growth.. B2 . Construct the available canals in order to convey fresh water from main canals into the ditches	N, S3 S3, S2	S2 S1	Drought hazard some time during crop growth. No constraints
3.Beginning-end of inundation period: A3.Construction of surrounding dike of the field in order to pump water out in the early dry season.	S3, S2	S1	No constraints
4. Depth of sulfuric horizon: A4. Place the good top soil layer on the top of raised beds when constructed	S2 S3	S1 S2	No constraints Acidity in the first few years

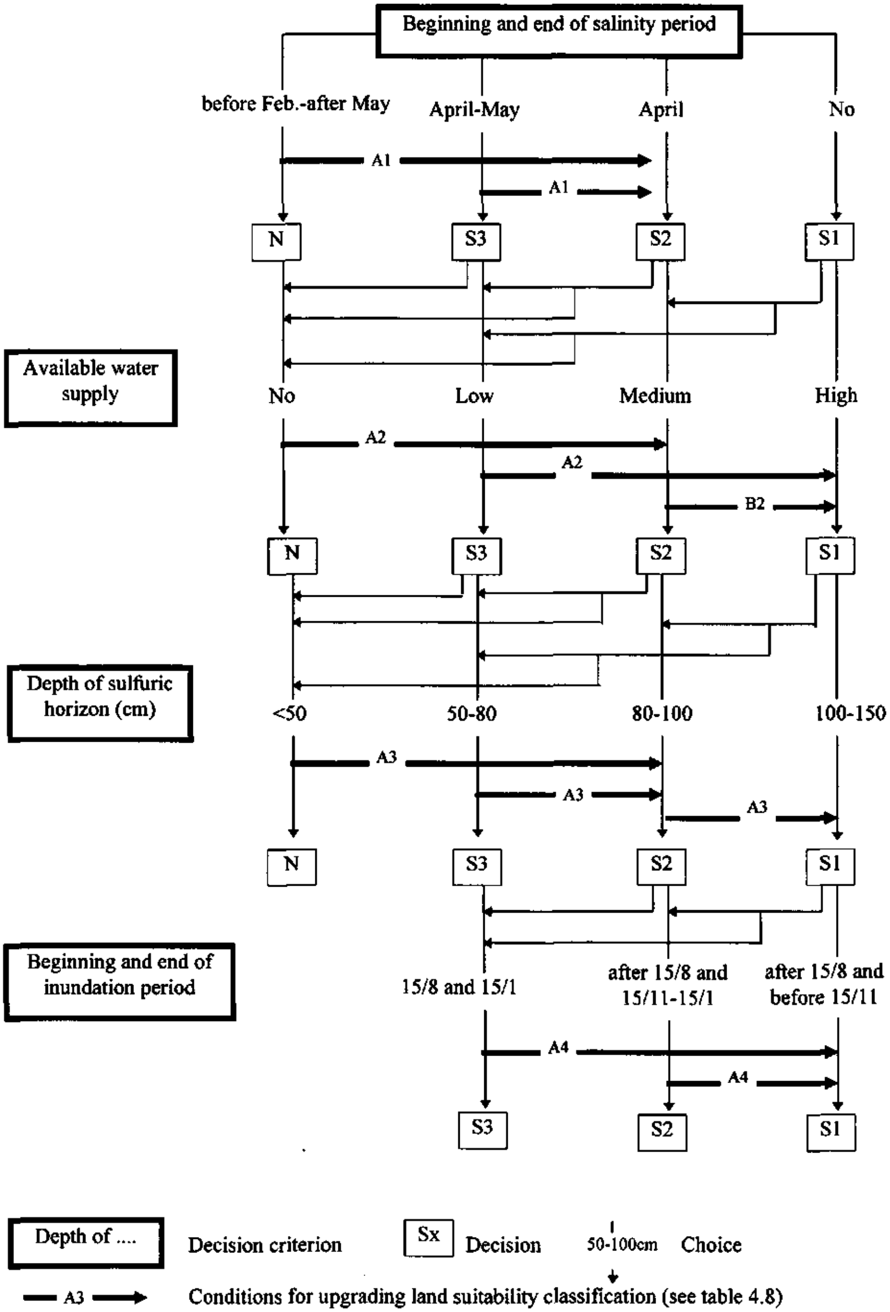


Figure 4.7: *Decision tree of single cropping of Sugarcane (LUT12) in the area 1-Tan Thanh*

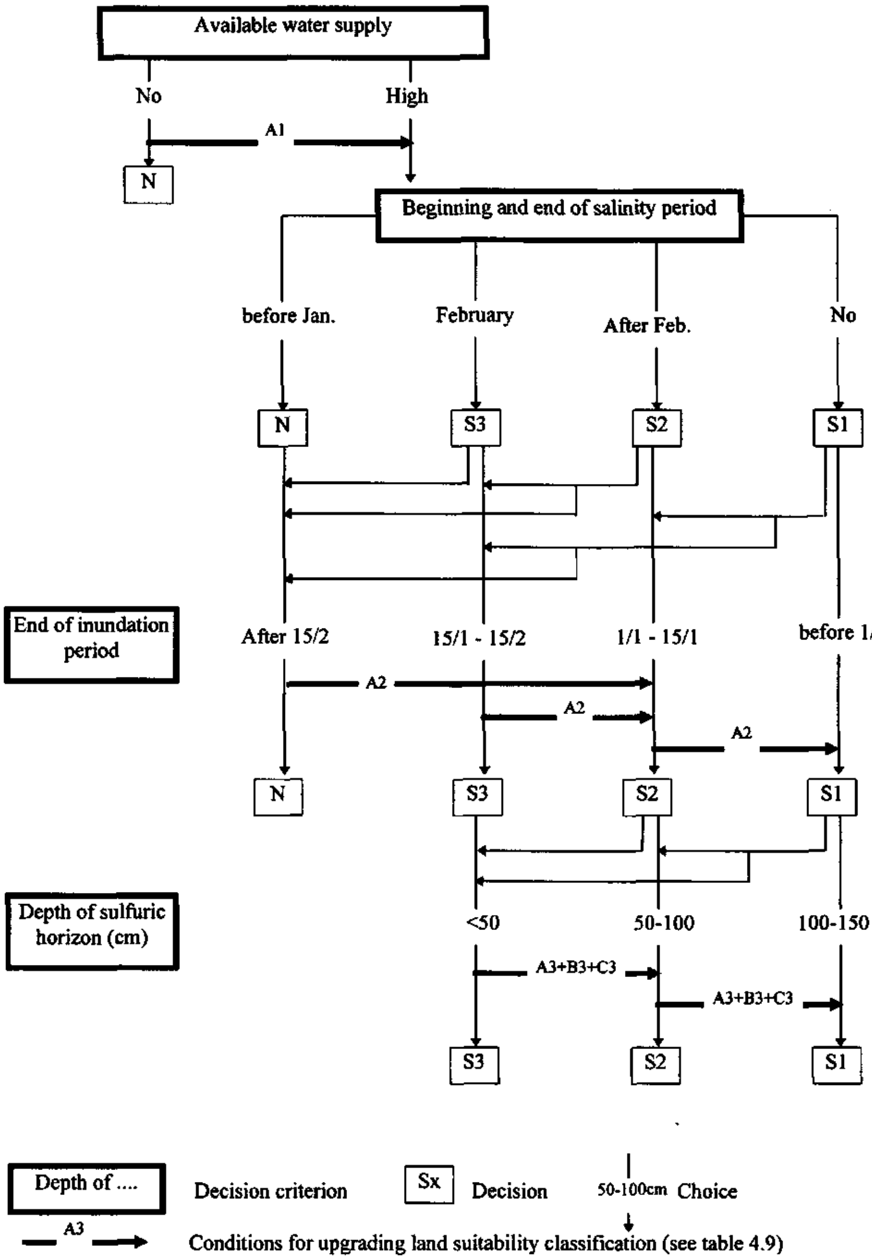


Figure 4.8: *Decision tree of single cropping of WS.HY. rice (LUT6) in the area 1-Tan Thanh*

Table 4.8: *Conditions of water and soil management practices for upgrading land suitability of single cropping of Sugarcane (LUT12) in the area No.1-Tan Thanh*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Beginning-end of salinity period: A1.Construction of dam to protect against saline water intrusion and store fresh water in the ditches and canals for water supply.	N, S3	S2	Drought hazard some time during crop growth.
2. Available water supply: A2.. Store fresh water in the ditches and surrounding canals and cover on the surface of raised beds with grass in order to reduce the evaporation in the early stage of crop growth.. B2.Construct the available canals in order to convey fresh water from main canals into the ditches	N, S3 S3, S2	S2 S1	Drought hazard some time during crop growth. No constraints
3. Depth of sulfuric horizon: A3.Place the good top soil layer on the top of raised beds when constructed	S2 N, S3	S1 S2	No constraints Acidity in the first few years
4.Beginning-end of inundation period: A4.Construction of surrounding dike of the field in order to pump water out in the early dry season.	S3, S2	S1	No constraints

Table 4.9: *Conditions of water and soil management practices for upgrading land suitability of single cropping of WS HY. Rice (LUT6) in the area No.1-Tan Thanh.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Available water supply: A1.Construction of canals and infrastructure for irrigation	N	S1	No constraints
2. End of inundation period: A2.Construction of surrounding dike of the field in order to pump water out.	N, S3, S2	S1	No constraints
3. Depth of sulfuric horizon: A3.Construction of shallow drainage systems B3. Field leveling C3. Construction of field bunds and flapgate in order to control water.	S2 S3	S1 S2	No constraints Acidity in the middle of growing period

- In the area No. 2 - Tri Ton:

Figures 4.9 and 4.12 present the decision trees of LUT1 and LUT6. These decision trees start with land quality: "fresh water availability" expressed in terms of the land characteristic: " available water supply". The land suitability classification will be N (non suitable) if there is no infrastructure for irrigation. However, it will be S1 (highly suitable) if canals for irrigation are constructed. It is obviously impossible to grow irrigated modern short-duration rice, if there is no irrigation. "Flooding hazard" is the next land quality of this decision tree. It is expressed in terms of the "number of inundated months" for LUT1 and the time of the "end of the inundation period" for LUT6. The land is highly suitable when inundation period is less than 4 months, and is not suitable if this period is longer than 5 months for LUT1. Improvement of this land characteristic and upgrading of land suitability is possible by construction of dikes surrounding the rice field in order to pump water out in the early rainy season (for LUT1 and LUT6) and application of minimum-tillage practices (for LUT1).

Figure 4.10 presents the decision tree of LUT5. The decision tree of this land use type starts with an analysis of the land quality "fresh water availability" expressed in terms of the land characteristic: "available water supply". The land suitability classification will be N (non suitable) if there is no supplementary irrigation systems. However, it will be S1 (highly suitable) if canals for irrigation are constructed. It is impossible to grow upland crops such as sesame, mungbean, maize, if there is no supplementary irrigation in the middle and end of the growing period. The possibilities for improvement of this land characteristic are to construct canals for supplementary irrigation. Land quality: "drought hazard" expressed in terms of the land characteristic: "rainy season drought", is next analyzed for this land us type. The classification of land for this land quality varies from marginally suitable (S3 with early and middle rainy season) to highly suitable (S1 with no drought spell). Upgrading land suitability of this land use type can be achieved by digging canals for supplementary irrigation during the drought period.

Figure 4.11 present the decision tree of LUT13 (upland crops: yam/cassava). This LUT was transferred from the area No.1 Tan Thanh and was applied under experimental conditions during last three years. The first land quality that also play a key role, is "fresh water availability" expressed in terms of the land characteristic "available water supply". The upland crops require supplementary irrigation sometime during the dry season. If not, the land is considered to be unsuitable (class N) because crops cannot survive in a long dry season. The possibilities for improvement of this land characteristic are to store water in the ditches and surrounding canals or to construct the available canals in order to convey fresh water from main canals into the ditches. The application of these practices for upgrading land suitability classification is imperative. "Flooding hazard" is next land quality of this decision tree. It is expressed in terms of the land characteristic: "beginning and end of inundation period". It is very high suitable (S1) with this period being after August, 15 and before November, 15 and marginally suitable (S3) with this period being before August, 15 and after January, 15. Upgrading land suitability can be achieved by construction of a dike surrounding the field so as to achieve protection against water inundation.

The land quality: " soil acidity" as expressed in terms of the land characteristic: the "depth of the sulfuric horizon" is being considered for all land use types. The depth of sulfuric horizon within 50cm from the soil surface is considered to be crucial for growing double-rainfed floating rice followed by upland crops (LUT5) . The classification of land in terms of this land quality varies from marginally suitable (< 50cm) to highly suitable (> 100cm) for the rest of the selected land use types. To upgrade the land suitability, there are many possibilities such as shallow drainage systems, and applying various technique of raised bed construction.

The actual suitability for four promising land use types is determined, and also the conditional suitability after the most important constraints have been removed (Figures 4.9, 4,10, 4.11, and 4.12). These conditions for upgrading the land suitability classification are shown in table 4.10, 4.11, 4.12, and 4.13.

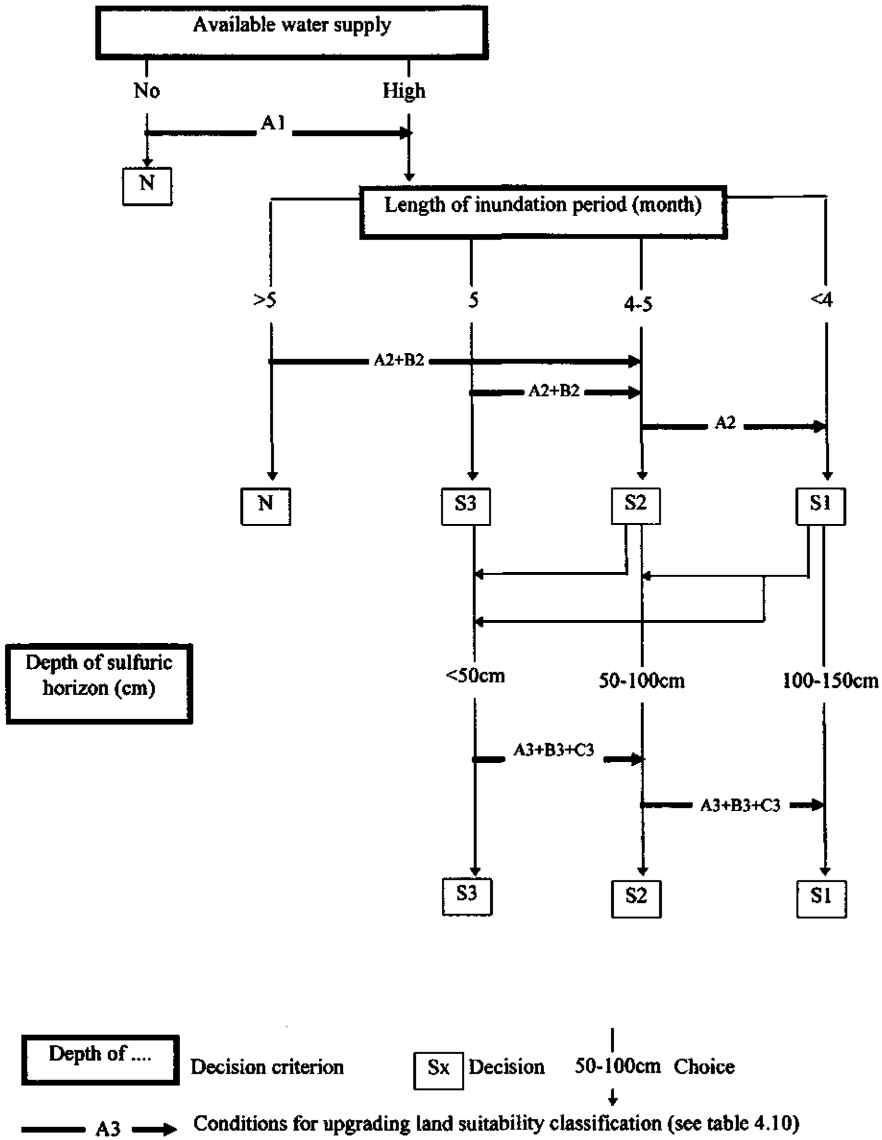


Figure 4.9: *Decision tree of Double cropping of Summer-Autumn and Winter-Spring HY. rice (LUT1) in area No.2 - Tri Ton.*

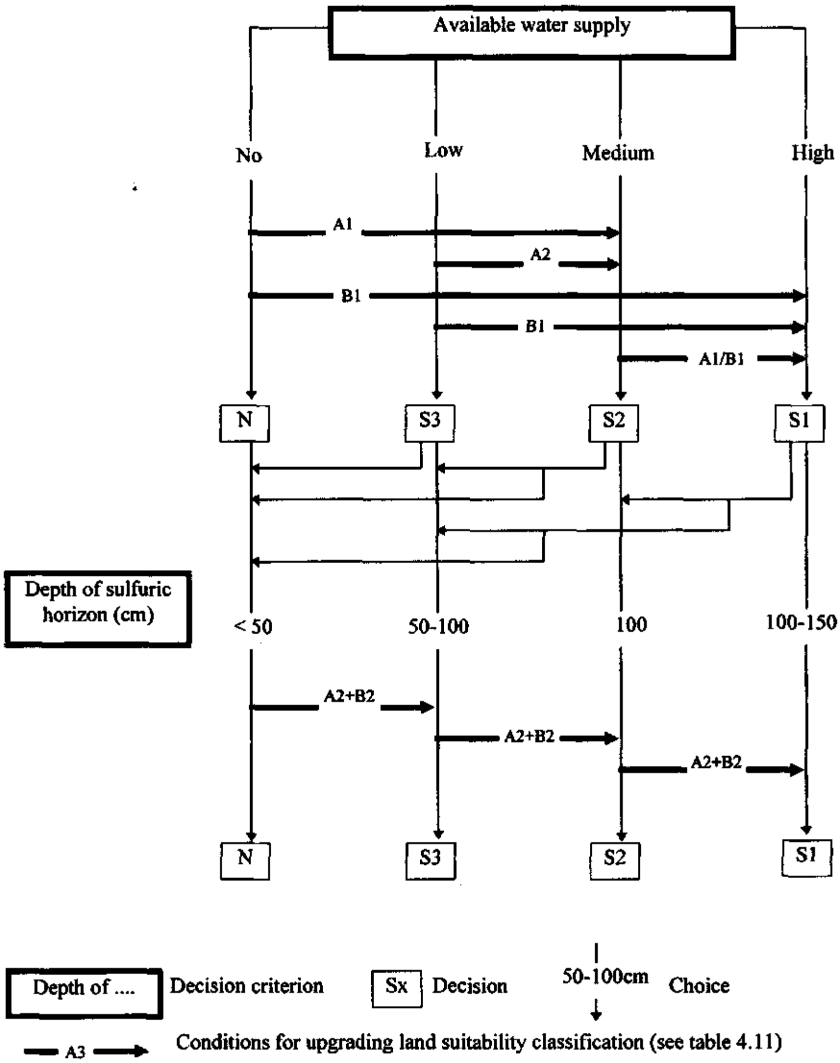


Figure 4.10: *Decision tree of double cropping of floating rice followed by upland crops (LUT5) (maize, beans, water melon grown on temporary raised beds) in the area No 2 - Tri Ton.*

Table 4.10: *Conditions of water and soil management practices for upgrading land suitability of double cropping of SA-WS HY. Rice (LUT1) in the area No.2 - Tri Ton.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. <u>Available water supply:</u> A1.Construction of canals and infrastructure for irrigation	N	S1	No constraints
2. <u>Length of inundation period:</u> A2. Construction of surrounding dike of the field in order to pump water out.	S2	S1	No constraints
B2 . Zero-tillage practices	N, S3	S2	Flooding in the end of SA crop
3. <u>Depth of sulfuric horizon:</u> A3. Construction of shallow drainage systems	S2	S1	No constraints
B3. Field leveling C3. Construction of field bunds and flapgate in order to control water.	S3	S2	Acidity in the beginning of SA crop

Table 4.11: *Conditions of water and soil management practices for upgrading land suitability of double cropping of floating rice followed by upland crops (LUT5) in the area No.2 - Tri Ton.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. <u>Available water supply</u>: A1.. Store fresh water in the ditches and surrounding canals and cover on the surface of raised beds with straw or Eleocharis in order to reduce the evaporation in the early stage of crop growth..	N, S3	S2	Drought hazard some time during crop growth.
B1 . Construct the available canals in order to convey fresh water from main canals into the ditches	N,S3, S2	S1	No constraints
2. <u>Depth of sulfuric horizon:</u> A2. Place the good top soil layer on the top of raised beds when constructed B2. Construction of shallow drainage systems in order to leach out the acidity in the early rainy season (for rice)	S2 S3 N	S1 S2 S3	No constraints Acidity in the first few years Acidity in the beginning of floating rice crop.

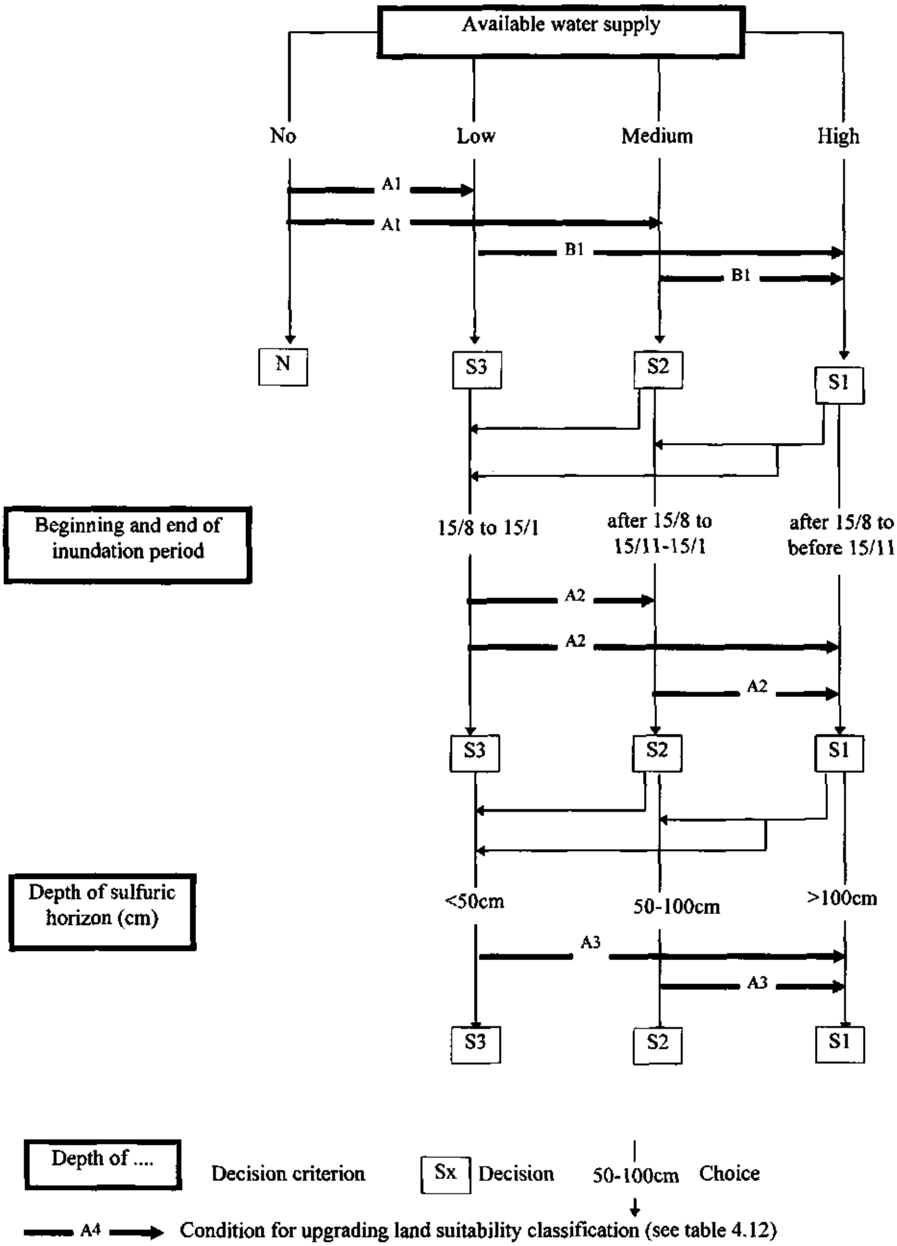


Figure 4.11: *Decision tree of single cropping of Yam/Cassava LUT13) in the area No.2 - Tri Ton*

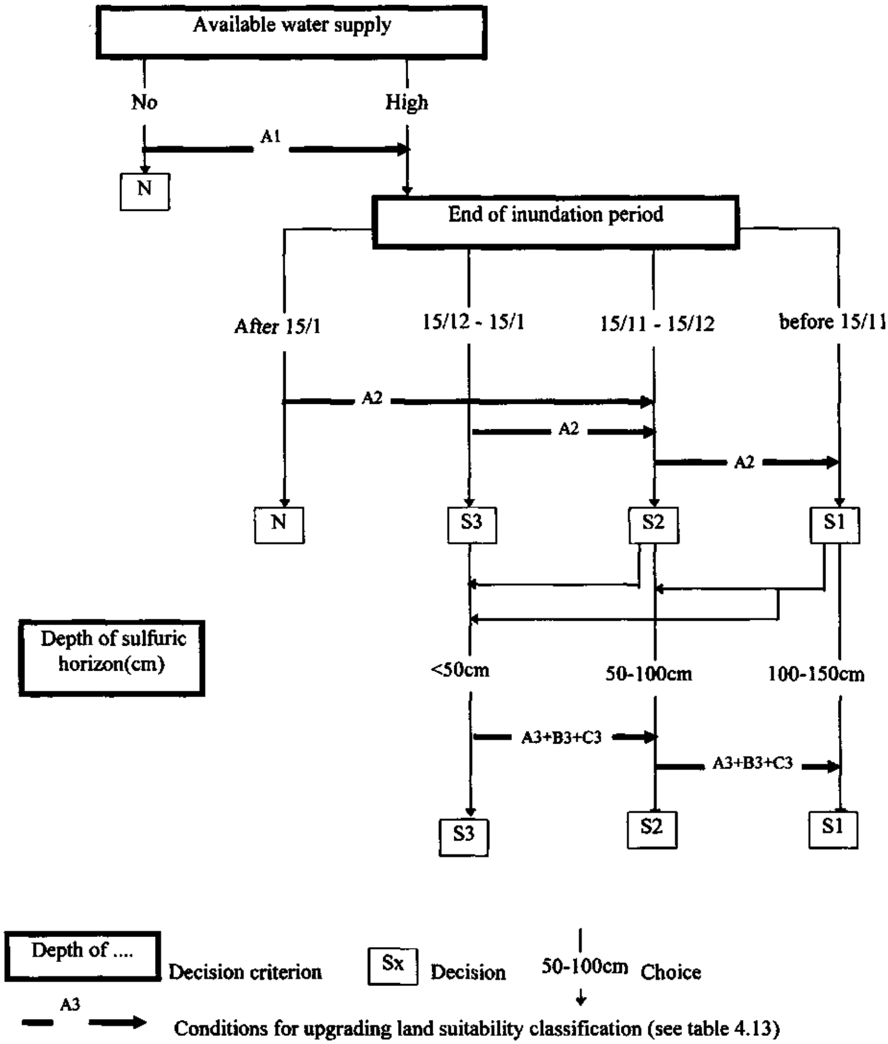


Figure 4.12: *Decision tree of single cropping of WS.HY. rice (LUT6) in the area No.2 - Tri Ton*

Table 4.12: *Conditions of water and soil management practices for upgrading land suitability of single cropping of Yam/Cassava (LUT13) in the area No.2 - Tri Ton.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Available water supply:			
A1.. Store fresh water in the ditches and surrounding canals and cover on the surface of raised beds with straw or Eleocharis in order to reduce the evaporation in the early stage of crop growth..	N, S3	S2	Drought hazard some time during crop growth.
B1 . Construct the available canals in order to convey fresh water from main canals into the ditches	S3, S2	S1	No constraints
2.Beginning-end of inundation period:			
A2.Construction of surrounding dike of the field in order to pump water out in the early dry season.	S3, S2	S1	No constraints
3. Depth of sulfuric horizon:			
A3. Place the good top soil layer on the top of raised beds when constructed	S2 S3	S1 S2	No constraints Acidity in the first few years

Table 4.13: *Conditions of water and soil management practices for upgrading land suitability of single cropping of WS HY. Rice (LUT6) in the area No.2 - Tri Ton.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Available water supply:			
A1.Construction of canals and infrastructure for irrigation	N	S1	No constraints
2. End of inundation period:			
A2.Construction of surrounding dike of the field in order to pump water out.	N, S3, S2	S1	No constraints
3. Depth of sulfuric horizon:			
A3. Construction of shallow drainage systems	S2	S1	No constraints
B3. Field leveling C3. Construction of field bunds and flapgate in order to control water.	S3	S2	Acidity in the middle of growing period.

- In the area number 3: Phung Hiep

Figures 4.13, and 4.14 present the decision trees of LUT1, and LUT2. These decision trees start with the land quality “fresh water availability” as expressed in terms of the land characteristic: “available water supply” . The land suitability classification will be N (non suitable) for both two LUTs if there is no infrastructure for irrigation. However, it will be S1 (highly suitable) if available canals for irrigation are already constructed, that means, this land characteristic plays a key role for these LUTs. It is impossible to grow double irrigated modern short duration rice without irrigation. “Flooding hazard” is the next land quality considered. It is expressed in terms of the land characteristic: “maximum inundation depth” for LUT2. Land is highly suitable for LUT2 with a maximum inundation depth less than 30cm deep. It is unacceptable if flooding is deeper than 100cm. Improvement of this land characteristic is possible by construction of a dike surrounding the rice field in order to pump water out. This technique can be used to protect against the inundation for LUT2, but it is not economically attractive because very strong dikes should be constructed.

Figure 4.16 presents the decision tree of LUT7. These decision trees start with the land quality: “potential for tidal irrigation and drainage” expressed in terms of the land characteristic: "high and low tide in relation to the soil surface". The land suitability classification will be N (non suitable) if the high tide is under the soil surface. However, it will be S1 (highly suitable) if the soil is irrigated and drained by daily tide. This land characteristic plays a key role for LUT7 because, it is not possible to raise prawn if there is no daily irrigation and drainage by the tides during the growing period. It is impossible to improve this land characteristic in order to upgrade land suitability, because it depends on the topography of the soil and the tidal regime of the rivers.

Figures 4.15, 4.17, 4.18, 4.19 and 4.20 present the decision trees of LUT4, LUT9, LUT11, LUT12 and LUT14, respectively. “Maximum inundation depth” is used to express the land quality: “flooding hazard”. The decision trees of these LUTs start with an analysis of this land characteristic. For LUT3, this land characteristic is similar to LUT2 above. The maximum inundation depth of 60cm and 100cm are distinguished as being crucial for growing upland crops on high raised beds (LUT9, LUT12, and LUT14) and for sugarcane followed by traditional rice (LUT11). Lower flooding values are associated with significantly higher potential yields and are therefore highly suitable (flooding depth < 30cm). It is very difficult to improve this characteristic. A way for improvement is to construct high strong dikes surrounding the field to protect against the flooding period. The second land quality that also play a key role, is "fresh water availability" as expressed in terms of the land characteristic "available water supply" for upland crops (LUT9, LUT11, LUT12, and LUT14) and "length of rainfed period" for double rainfed rice (LUT4). Upland crops require supplementary irrigation during the dry season. If not, the land is considered to be unsuitable (class N) because crops cannot survive in the long dry season. Double rainfed rice (LUT4) can only result in acceptable production levels if the rainfed period lasts longer than 5 months in the period May to late October. A shorter period will result in significantly lower yields. This land characteristic can be improved for upland crops by storing water in the ditches and surrounding canals or to construct canals in order to convey fresh water from main canals.

Land quality: " soil acidity" as expressed in terms of the land characteristic: the "depth of the sulfuric horizon" plays a role in all land use types. The depth of the sulfuric horizon shallower 50cm and 100 from soil surface is distinguished as being crucial for growing double rainfed rice (LUT4), sugarcane (LUT12) and ginger (LUT9), double rice combined with prawn (LUT7), respectively. The land varies from marginally suitable (< 50cm) to highly suitable (> 100cm) for the other land use types. To upgrade land suitability, shallow drainage systems, and good techniques of raised bed construction can be applied.

The actual suitability for 8 promising land use types is determined, and also the conditional suitability after the most important constraints have been removed (see figure 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19 and 4.20). These conditions for upgrading the land suitability classification are showed in table 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20 and 4.21.

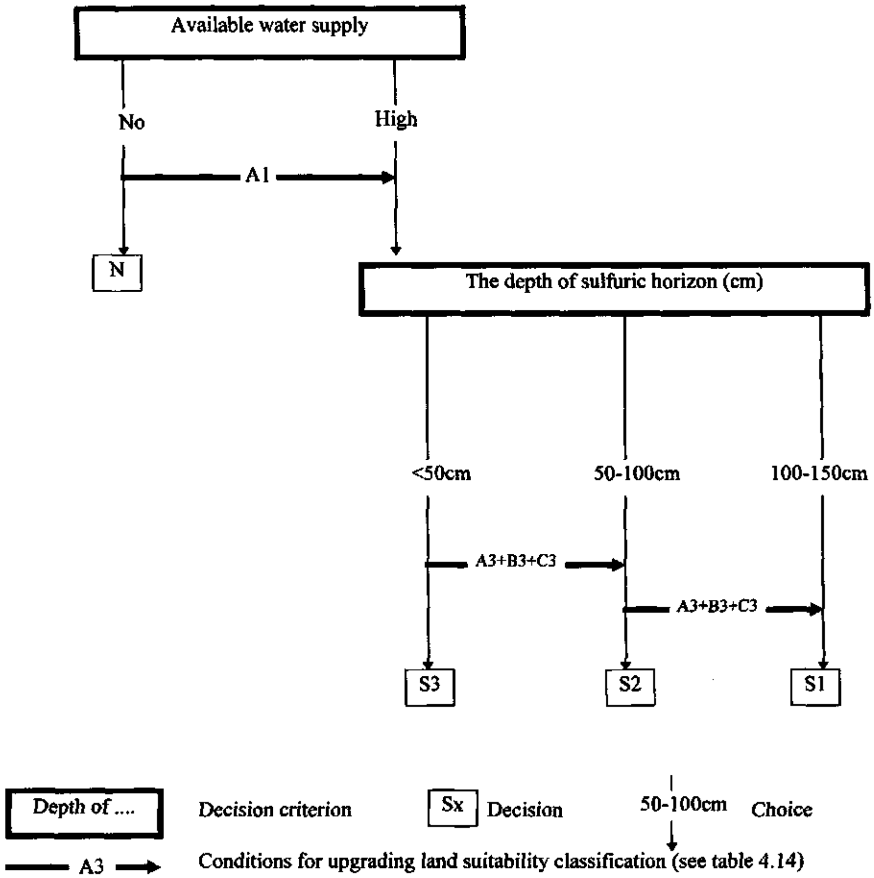


Figure 4.13: *Decision tree of Double cropping of Irrigated Summer-Autumn and Winter-Spring HY. Rice (LUT1) in area No.3 - Phung Hiep.*

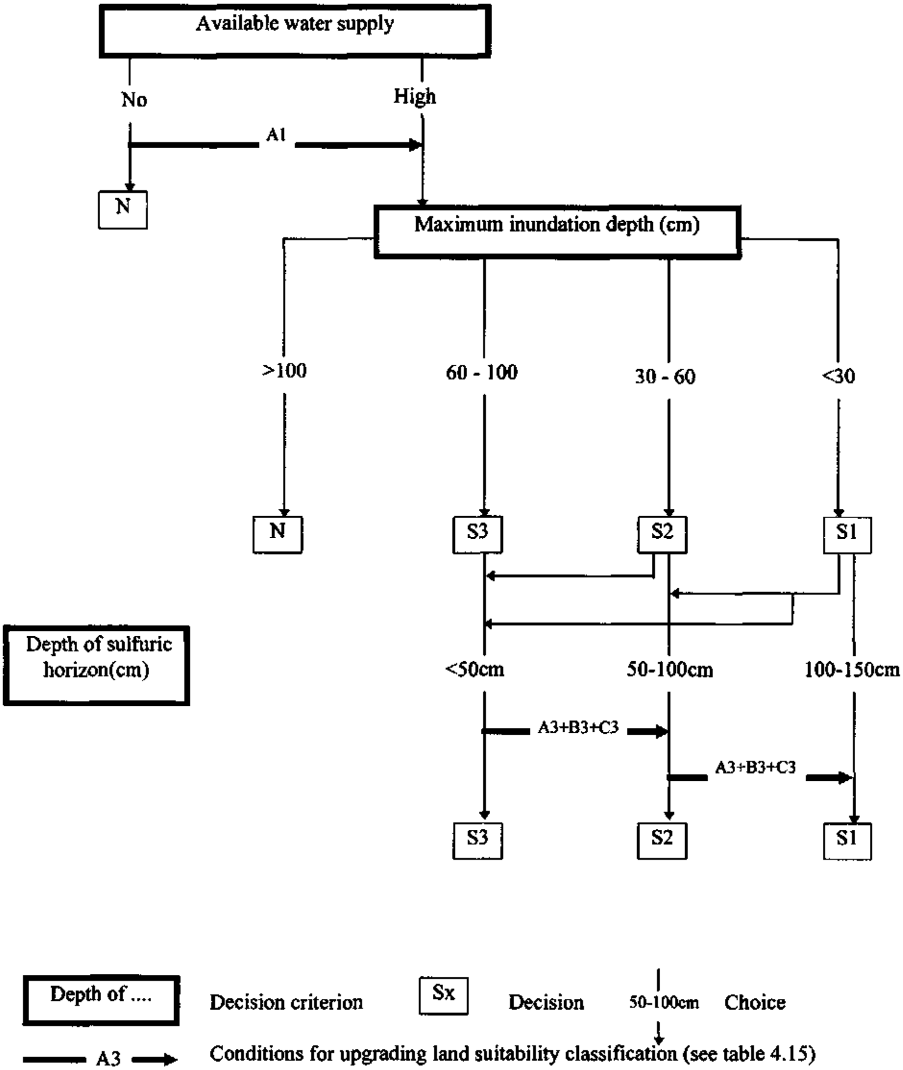


Figure 4.14: *Decision tree of Double cropping of Irrigated Summer-Autumn and traditional rice (LUT2) in area No.3 - Phung Hiep.*

Table 4.14: *Conditions of water and soil management practices for upgrading land suitability of double cropping of Irrigated SA.HY rice-WS HY. Rice (LUT!) in the area No.3 - Phung Hiep.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. <u>Available water supply:</u> A1.Construction of canals and infrastructure for irrigation	N	S1	No constraints
2. <u>Depth of sulfuric horizon:</u> A2. Construction of shallow drainage systems B2. Field leveling C2. Construction of field bunds and flapgate in order to control water.	S2 S3	S1 S2	No constraints Acidity in the beginning of SA crop

Table 4.15: *Conditions of water and soil management practices for upgrading land suitability classification of double cropping of Irrigated SA.HY. rice followed by traditional rice (LUT2) in the area No.3 - Phung Hiep.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. <u>Available water supply:</u> A1.Construction of available canals for irrigation	N	S1	No constraints
2. <u>Depth of sulfuric horizon:</u> A2.Construction of shallow drainage systems B2. Field leveling C2. Construction of field bunds and flapgate in order to control water.	S2 S3	S1 S2	No constraints Acidity in the beginning of SA crop

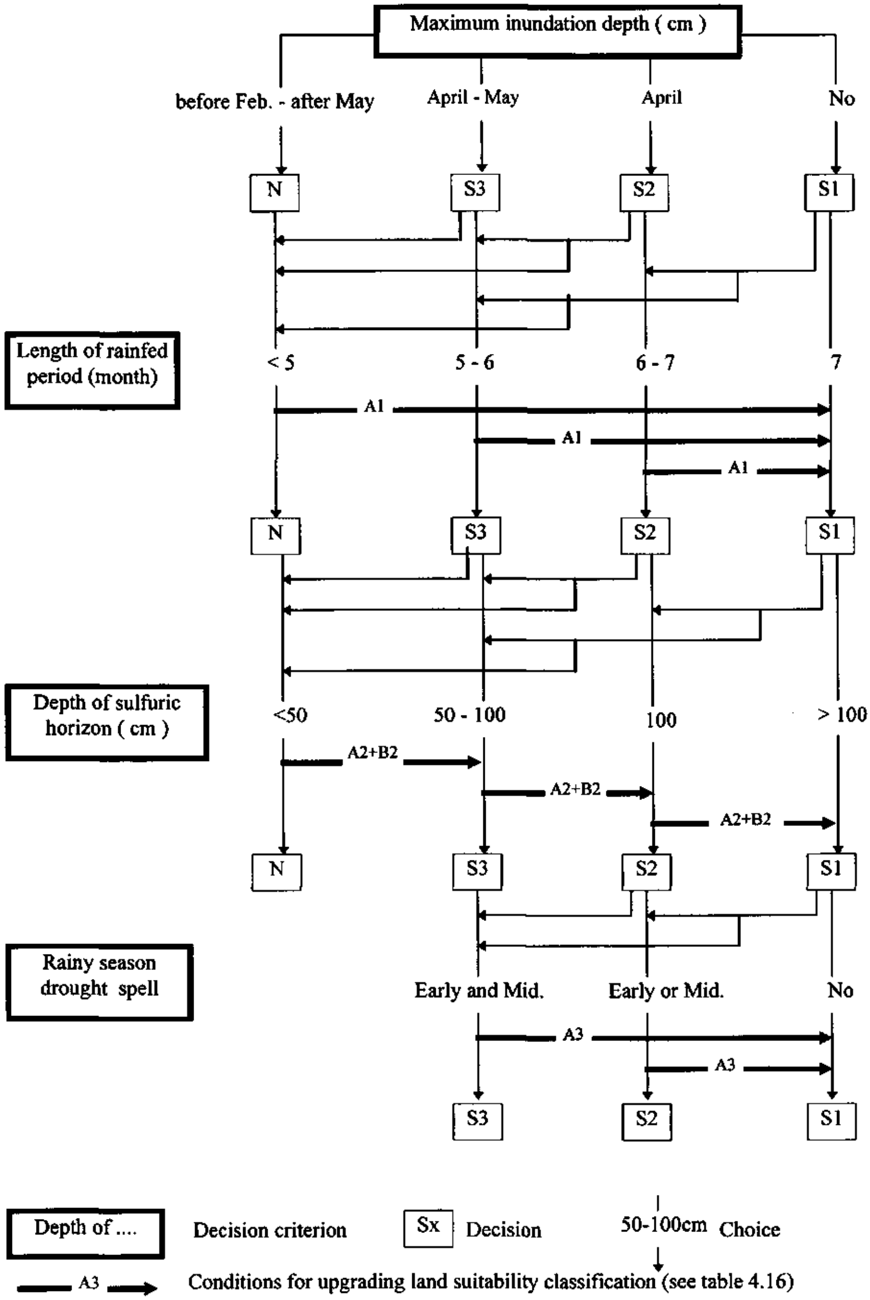


Figure 4.15: *Decision tree of double cropping of Rainfed SA- HY. rice and traditional rice (LUT4) in the area No.3 - Phung Hiep*

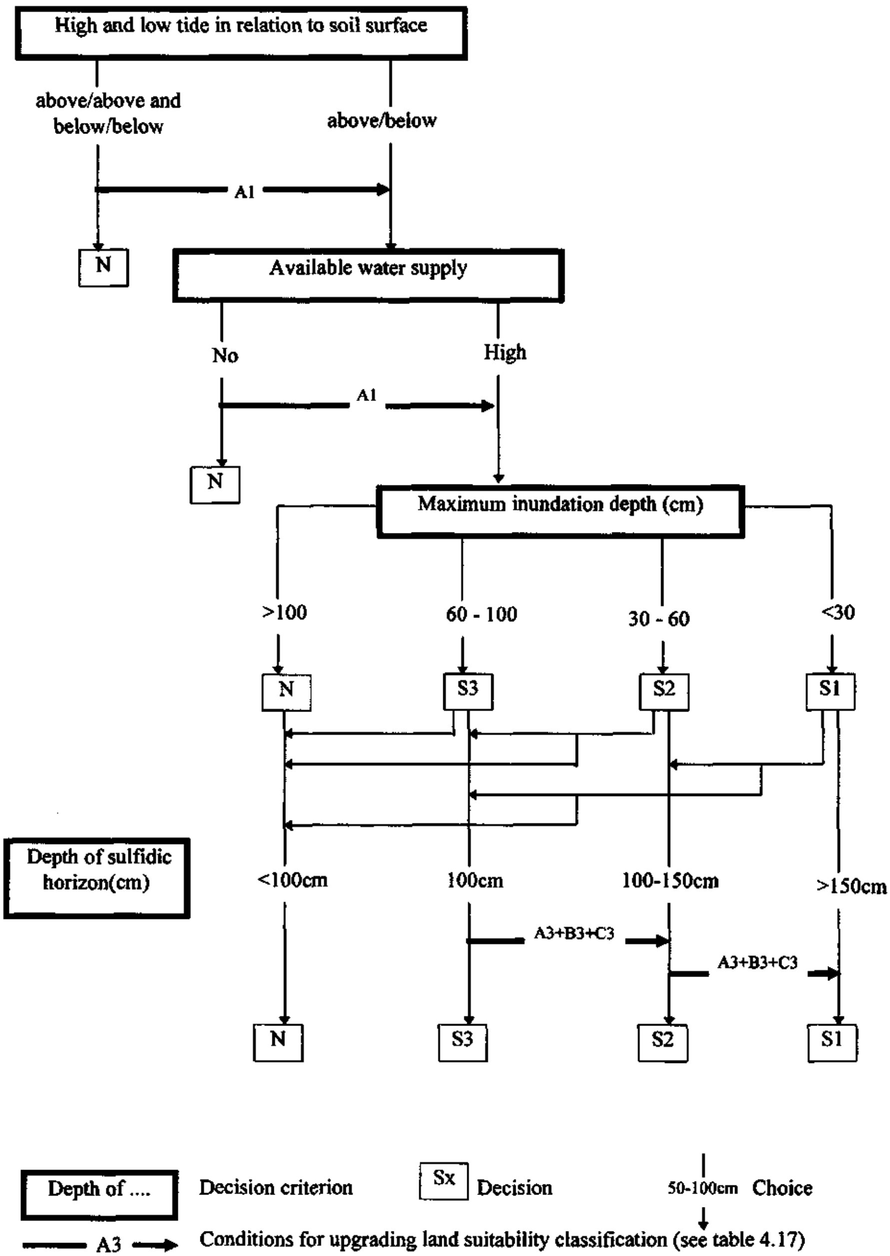


Figure 4.16: *Decision tree of Double cropping of Irrigated Summer-Autumn and traditional rice combined with prawn cultivation (LUT7) in area No.3 - Phung Hiep.*

Table 4.16: *Conditions of water and soil management practices for upgrading land suitability of double cropping of Rainfed SA.HY. rice followed by traditional rice(LUT4) in the area No.3 - Phung Hiep.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Length of rainfed period: A1.Construction of available canals for supplementary irrigation	N, S3, S2	S1	No constraints
2. Depth of sulfuric horizon: A2. Construction of shallow drainage systems B2. Field leveling C2. Construction of field bunds and flapgate in order to control water.	S2 S3 N	S1 S2 S3	No constraints Acidity in the beginning of SA crop Acidity in the beginning of SA crop
3. Rainy season drought spell: A3. Available fresh water for supplementary irrigation during the drought period.	S3, S2	S1	No constraints

Table 4.17: *Conditions of water and soil management practices for upgrading land suitability classification of double cropping of Irrigated SA.HY. rice followed by traditional rice combined with Prawn cultivation (LUT7) in the area No.3 - Phung Hiep.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Available water supply: A1.Construction of available canals for irrigation	N	S1	No constraints
2. Depth of sulfidic horizon: A2. Keep the sulfidic layer under wet condition.	S2 S3	S1 S2	No constraints Hazard by oxidation of pyritic layer in the dry season

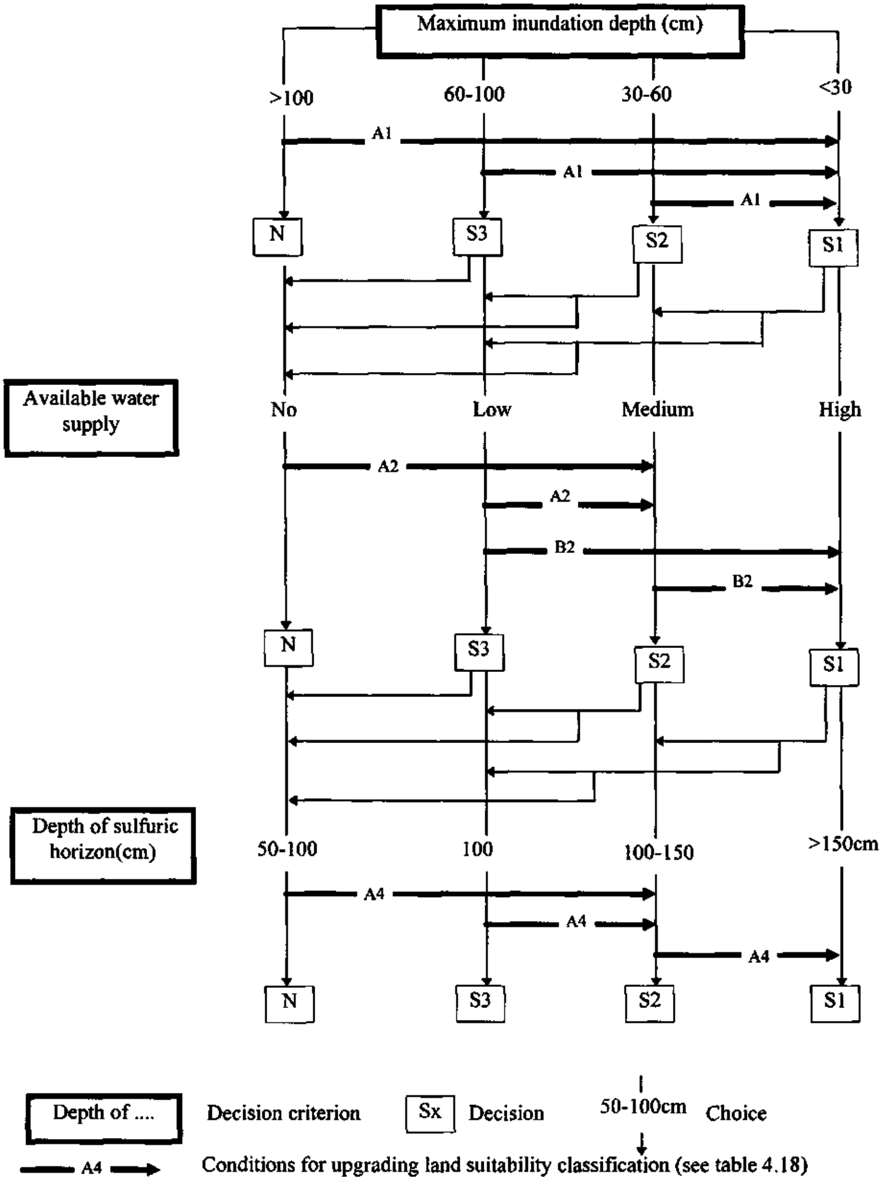


Figure 4.17: *Decision tree of Ginger intercropped with Mungbean and traditional rice (LUT9) in the area No.3 - Phung Hiep.*

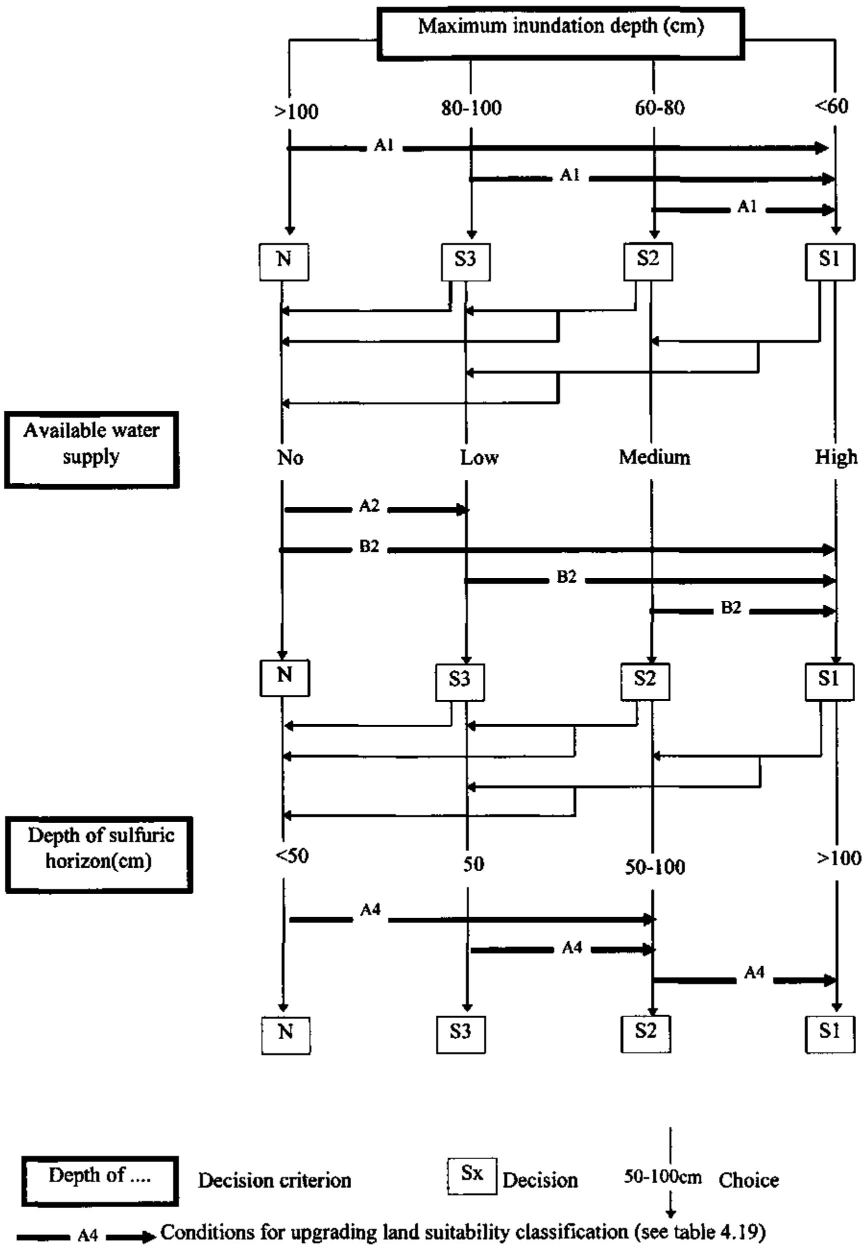


Figure 4.18: *Decision tree of double cropping of Sugarcane followed by traditional rice (LUT11) in the area No.3 - Phung Hiep.*

Table 4.18: *Conditions of water and soil management practices for upgrading land suitability of Ginger intercropped with Mungbean followed by traditional rice (LUT9) in the area No.3 - Phung Hiep.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Maximum inundation depth: A1.Construction of dike to protect against flooding.	N, S3, S2	S1	No constraint.
2. Available water supply: A2.. Store fresh water in the ditches and surrounding canals for supplementary irrigation.	N, S3	S2	Drought stress end of crop season .
B2 . Construct the available canals in order to convey fresh water from main canals into the ditches	S3, S2	S1	No constraints
3. Depth of sulfuric horizon: A3. Place the good top soil layer on the top of raised beds when constructed	S2 N, S3	S1 S2	No constraints Acidity in the first few years

Table 4.19: *Conditions of water and soil management practices for upgrading land suitability of double cropping of Sugarcane followed by traditional rice LUT11) in the area number No.3 - Phung Hiep.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Maximum inundation depth: A1.Construction of dike to protect against flooding.	N, S3, S2	S1	No constraint.
2. Available water supply: A2.. Store fresh water in the ditches and surrounding canals for supplementary irrigation.	N	S3	Drought stress end of crop season .
B2 . Construct the available canals in order to convey fresh water from main canals into the ditches	N, S3, S2	S1	No constraints
3. Depth of sulfuric horizon: A3. Place the good top soil layer on the top of raised beds when constructed	S2 N, S3	S1 S2	No constraints Acidity in the first few years

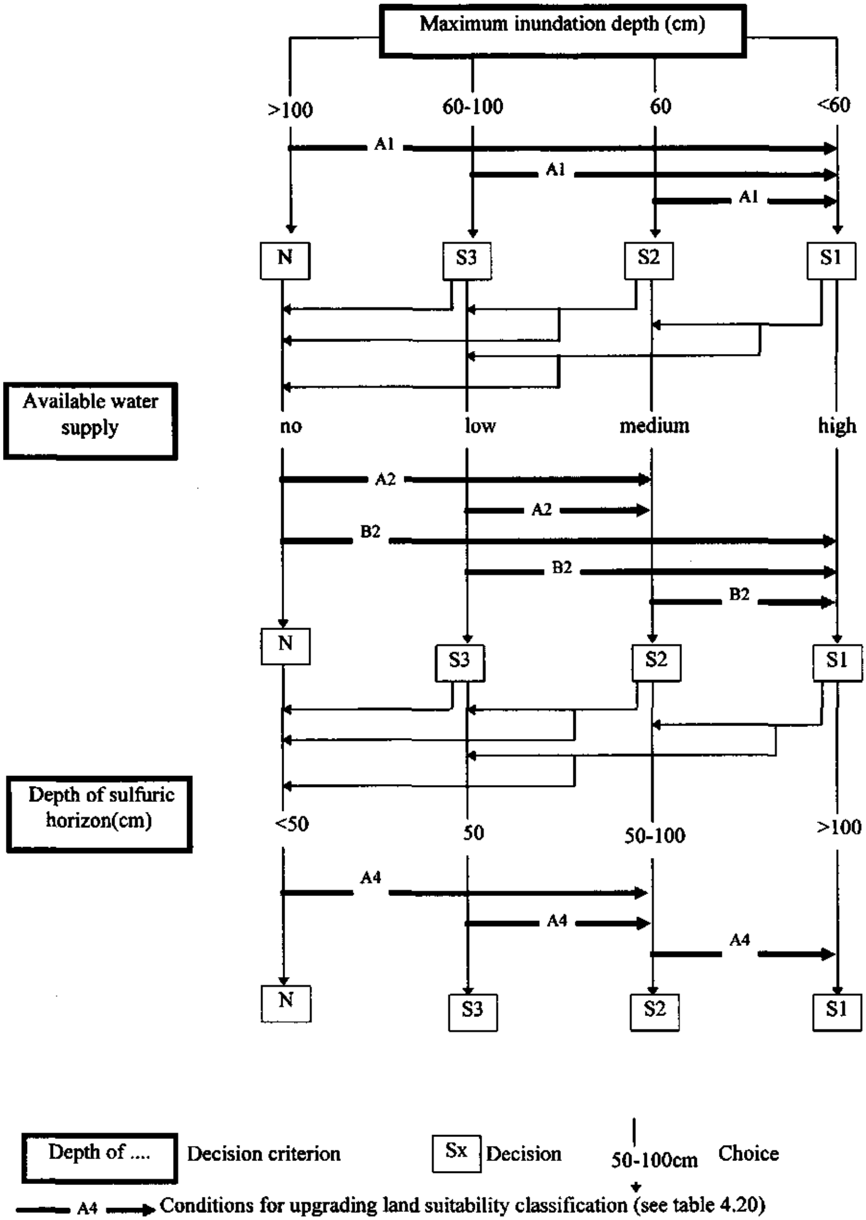


Figure 4.19: *Decision tree of Ratoon cropping of Sugarcane (LUT12) in the area No.3 - Phung Hiep.*

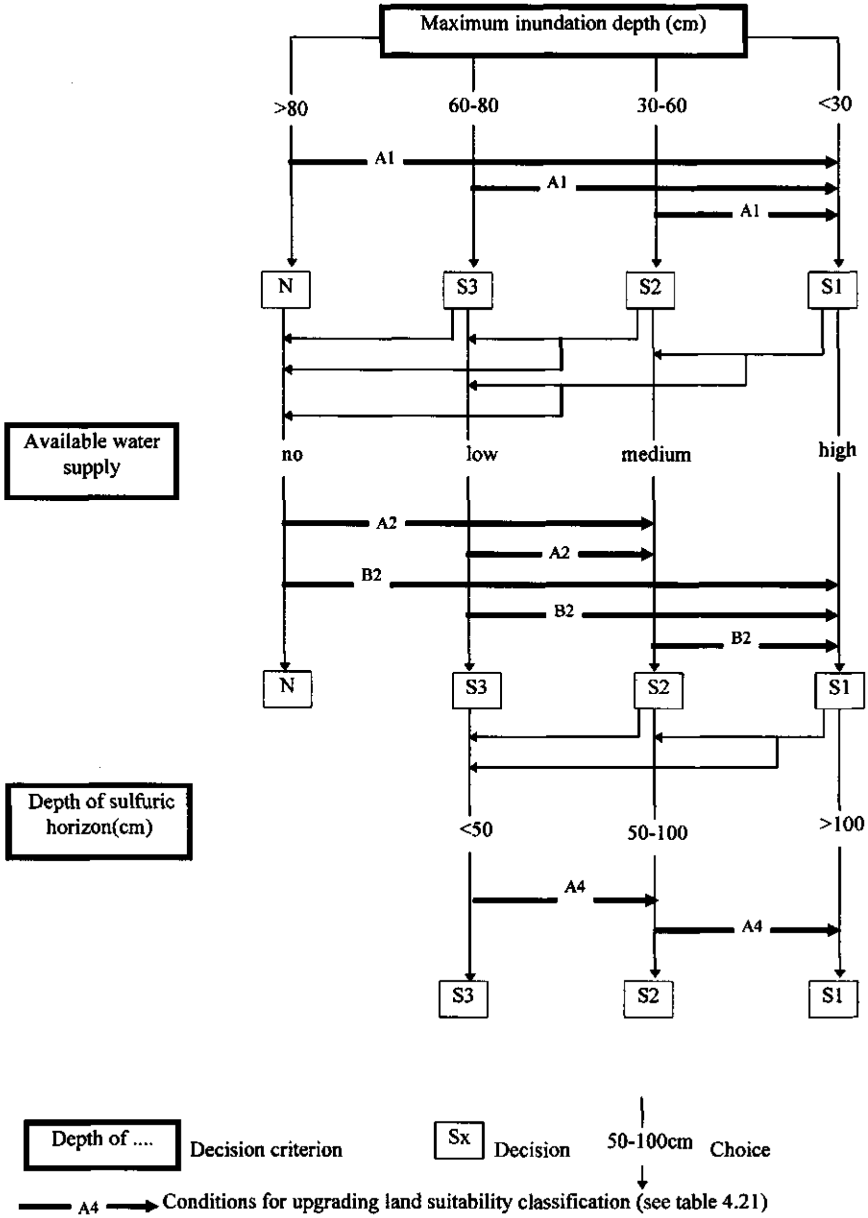


Figure 4.20: *Decision tree of single cropping of Pineapple (LUT14) in the area No.3-Phung Hiep.*

Table 4.20: *Conditions of water and soil management practices for upgrading land suitability of Ratoon cropping of Sugarcane (LUT12) in the area No.3 - Phung Hiep.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Maximum inundation depth: A1.Construction of dike to protect against flooding.	N, S3, S2	S1	No constraint.
2. Available water supply: A2. Store fresh water in the ditches and surrounding canals for supplementary irrigation. B2 . Construct the available canals in order to convey fresh water from main canals into the ditches	N, S3 N, S3, S2	S2 S1	Drought stress end of crop season . No constraints
3. Depth of sulfuric horizon: A3. Place the good top soil layer on the top of raised beds when constructed	S2 N, S3	S1 S2	No constraints Acidity in the first few years

Table 4.21: *Conditions of water and soil management practices for upgrading land suitability of single cropping of Pineapple (LUT14) in the area No.3 - Phung Hiep.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Maximum inundation depth: A1.Construction of dike to protect against flooding.	N, S3, S2	S1	No constraint.
2. Available water supply: A2. Store fresh water in the ditches and surrounding canals for supplementary irrigation. B2 . Construct the available canals in order to convey fresh water from main canals into the ditches	N, S3 N, S3, S2	S2 S1	Drought stress end of crop season . No constraints
3. Depth of sulfuric horizon: A3. Place the good top soil layer on the top of raised beds when constructed	S2 N, S3	S1 S2	No constraints Acidity in the first few years

- In the area number 4 : Hong Dan

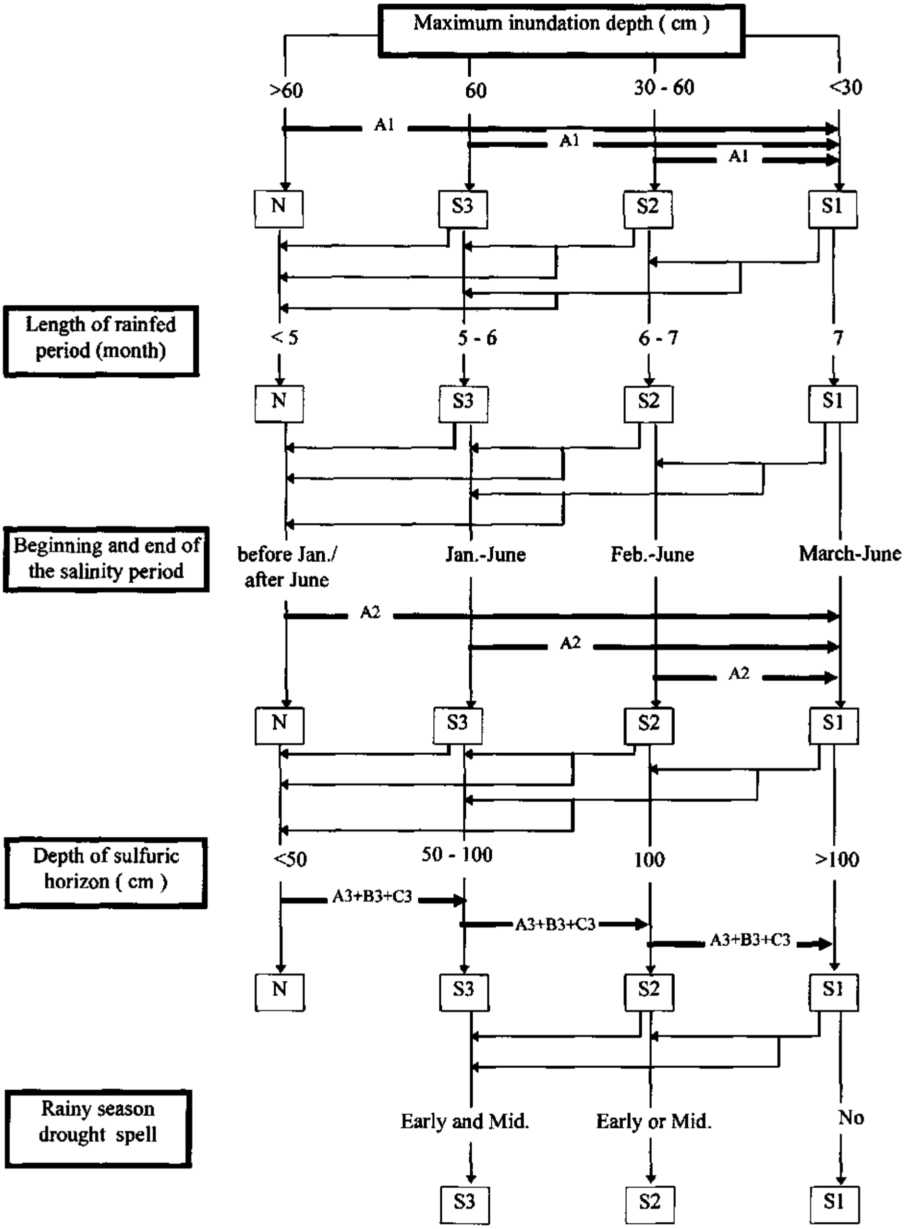
Figures 4.21, 4.22, 4.25, and 4.26 present the decision trees of LUT3, LUT4, LUT12, and LUT14. The land characteristic: "maximum inundation depth" is used to express the land quality: "flooding hazard". The decision trees of these LUTs start with an analysis of this land characteristic. A maximum inundation depth less than 60cm is thought to be crucial for growing double crops of short duration rice (LUT3) and upland crops on high raised beds (LUT12 and LUT14) and also for traditional rice (LUT4). Lower floods are associated with significantly higher potential yields and are therefore high suitable (flooding depth < 30cm for double cropping of short duration rice, upland crops and traditional rice). It is very difficult to improve this characteristic. A way for improvement is to construct high strong dikes surrounding the field to protect against the flood. The second land quality that also plays a key role, is the "fresh water availability" as expressed in terms of the land characteristic: "length of rainfed period". It is crucial for double rainfed rice (LUT3 and LUT4) and upland crops (LUT12 and LUT14). Double rainfed rice and upland crops can only result in acceptable production levels if more than 5 months (in period May to late October) and 4 months (in period June to late October) of rainfed periods, respectively. Lower values are associated with significantly lower potential yields and are therefore unacceptable. The land characteristic: "available water supply" is also used to express the land quality: "fresh water availability", and is taken into account in the decision trees for upland crops (LUT12,and LUT14). The upland crops sometimes require supplementary irrigation during the dry season, especially pineapple. A possibility for improvement of this land characteristic for upland crops is to store fresh water in the ditches and surrounding canals at the end of the rainy season. The land characteristic: the "beginning and end of the saline surface water period" is used to express the next land quality "salt water intrusion". Beginning and end of the salinity period before January and after June is thought to be crucial for growing double rice and upland crops (LUT3, LUT4, LUT12 and LUT14). A way for improvement of this land quality is to construct a dike and a dam or a sluice gate to protect against saline water intrusion and store fresh water in the ditches and canals for water supply (for LUT12 and LUT14). Land quality: "drought hazard" as expressed in terms of the land characteristic:

"early and mid rainy season drought" is also analyzed for the land use types of rainfed double rice (LUT3 and LUT4). However, the classification of land for this land quality varies only from marginally suitable (S3 with early and mid-rainy season drought) to highly suitable (S1 with no drought spell). It is impossible to improve this land characteristic.

Figures 4.23 and 4.24 present the decision trees of LUT8 and LUT10. These decision trees start with the land quality: " potential for daily tidal flood" expressed by the land characteristic: "high and low tide in relation to the soil surface". The land suitability classification will be N (non suitable) if the high tide is under the soil surface. However, it will be S1 (highly suitable) if the soil is flooded by daily tide. This land characteristic plays a key role for LUT8 and LUT10, because it is not possible to raise shrimp if there is no daily saline water flood caused by the tides during the dry season. It is impossible to improve this land characteristic in order to upgrade the land suitability, because it depends on the topography of the soil and the tidal regime of the rivers. The land characteristic: "beginning and end of the salinity period" is used to express the land quality "salt water intrusion". Beginning and end of the salinity period after February and before June is distinguished as being crucial for raising shrimp (LUT8, and LUT10) in these decision trees. Longer salinity periods are associated with significantly higher potential yields of shrimp and are therefore highly suitable S1 (before January and after June). It is also impossible to improve this characteristic because it depends on the location of each area: how far it occurs away from the sea and on the intricacy of the network of rivers or canals in the area. There is a conflict of interest between raising shrimp and cultivation of rice in this land use type (LUT8). While rice cultivation requires short salinity periods, it should be longer for shrimp cultivation. Therefore, the land use requirements of the rice-shrimp system are very strict in terms of the land qualities: "salt water intrusion" and "fresh water availability" (see Figure 4.23). Flood hazard expressed by the land characteristic "maximum inundation depth" is next in the decision tree of LUT8 (rice-shrimp system). It is highly suitable when the maximum inundation depth is less than 30cm. It is unacceptable if this is more than 60cm. Improvement of this land characteristic in order to upgrade land suitability is possible by construction of a high dike surrounding the field in order to protect against inundation, but it is not economically attractive because a very strong, costly dike should be constructed.

Land quality: " soil acidity" expressed by the land characteristic: "depth of the sulfuric horizon" is identified for all land use types. The depth of the sulfuric horizon at a depth shallower than 50cm from the soil surface is distinguished as being crucial for growing double rainfed rice (LUT3, LUT4), shrimp (LUT8 and LUT10) and sugarcane (LUT12). The classification of land varies from marginally suitable (depth < 50cm) to highly suitable (depth > 100cm) for the remainder of the selected land use types. Upgrading suitability can follow from shallow drainage systems, raised bed construction, or keeping the soil wet throughout the dry season, if feasible.

The actual suitability for promising land use types is determined, and also the conditional suitability after the most important constraints have been removed. These conditions for upgrading the land suitability are showed in table 4.22, 4.23, 4.24, 4.25, 4.26 and 4.27.



Depth of .... Decision criterion   Sx Decision   50-100cm Choice

A3 Conditions for upgrading land suitability classification (see table 4.22)

Figure 4.21: *Decision tree of double cropping of Rainfed SA- HY. rice and AW-HY rice (LUT3) in the area No.4 - Hong Dan.*

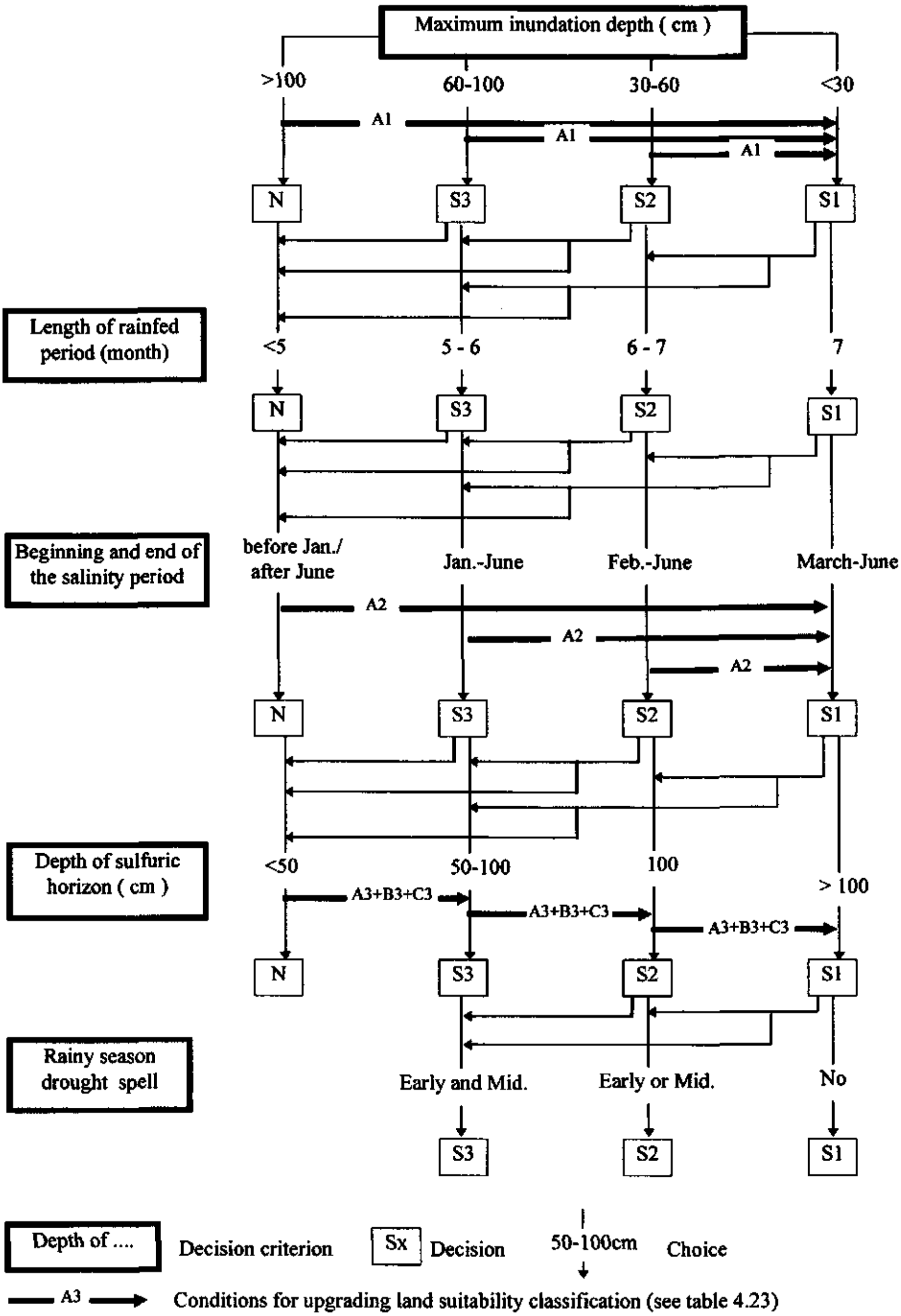


Figure 4.22: *Decision tree of double cropping of Rainfed SA- HY. rice and traditional rice (LUT4) in the area No.4 - Hong Dan.*

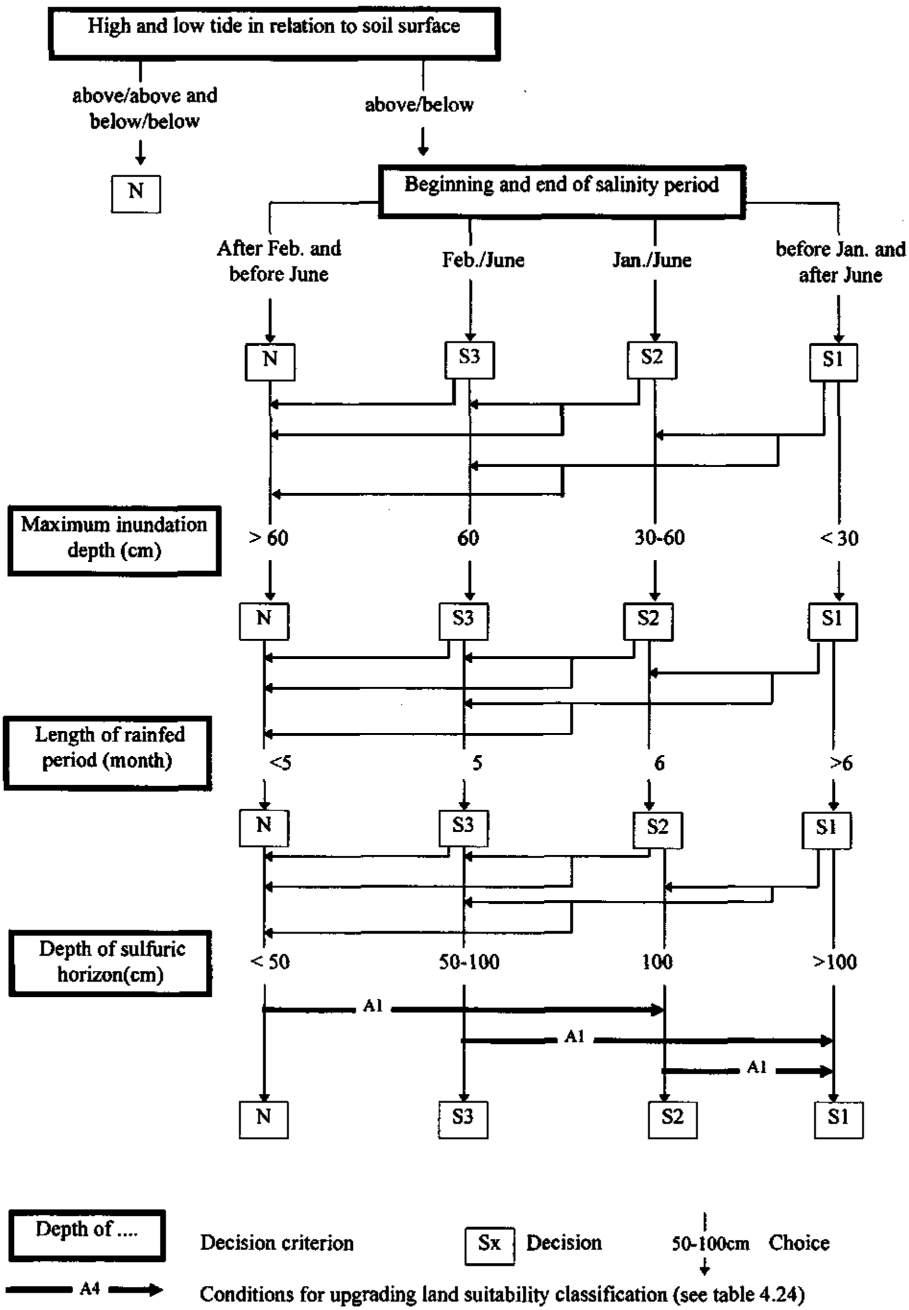


Figure 4.23: *Decision tree of extensive shrimp followed by traditional rice (LUT8) in the area No.4 - Hong Dan.*

Table 4.22: *Conditions of water and soil management practices for upgrading land suitability of double rainfed SA.HY-AW.HY. rice (LUT3) in the area No.4 - Hong Dan.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Maximum inundation period: A1.Construction of dike to protect against deep flooding.	N, S3, S2	S1	No constraints
2. Beginning - end of salinity period: A2.Construction of dike and dam to protect against salt water intrusion during the dry season	N,S3,S2	S1	No constraints
3. Depth of sulfuric horizon: A3. Construction of drainage systems	S2	S1	No constraints
B3. Field leveling	S3	S2	Acidity in beginning of SA crop
C3. Construction of field bunds and flapgate in order to control water.	N	S3	Acidity in the beginning of SA crop

Table 4.23: *Conditions of water and soil management practices for upgrading land suitability of double rainfed SA.HY.- traditional rice (LUT4) in the area No.4-Hong Dan.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Maximum inundation period: A1.Construction of dike to protect against deep flooding.	N, S3, S2	S1	No constraints
2. Beginning - end of salinity period: A2.Construction of dike and dam to protect against salt water intrusion during the dry season	N,S3,S2	S1	No constraints
3. Depth of sulfuric horizon: A3. Construction of drainage systems	S2	S1	No constraints
B3. Field leveling	S3	S2	Acidity in beginning of SA crop
C3. Construction of field bunds and flapgate in order to control water.	N	S3	Acidity in the beginning of SA crop

Table 4.24: *Conditions of water and soil management practices for upgrading land suitability of extensive Shrimp and traditional rice (LUT8) in the area No.4-Hong Dan.*

Land characteristics (land quality)	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Depth of sulfidic horizon: A1. Keep the sulfidic/sulfuric layer under wet condition.	S3, S2	S1	No constraints
	N	S2	Acidity leaching in to the ditches and acidity during ditch preparation.

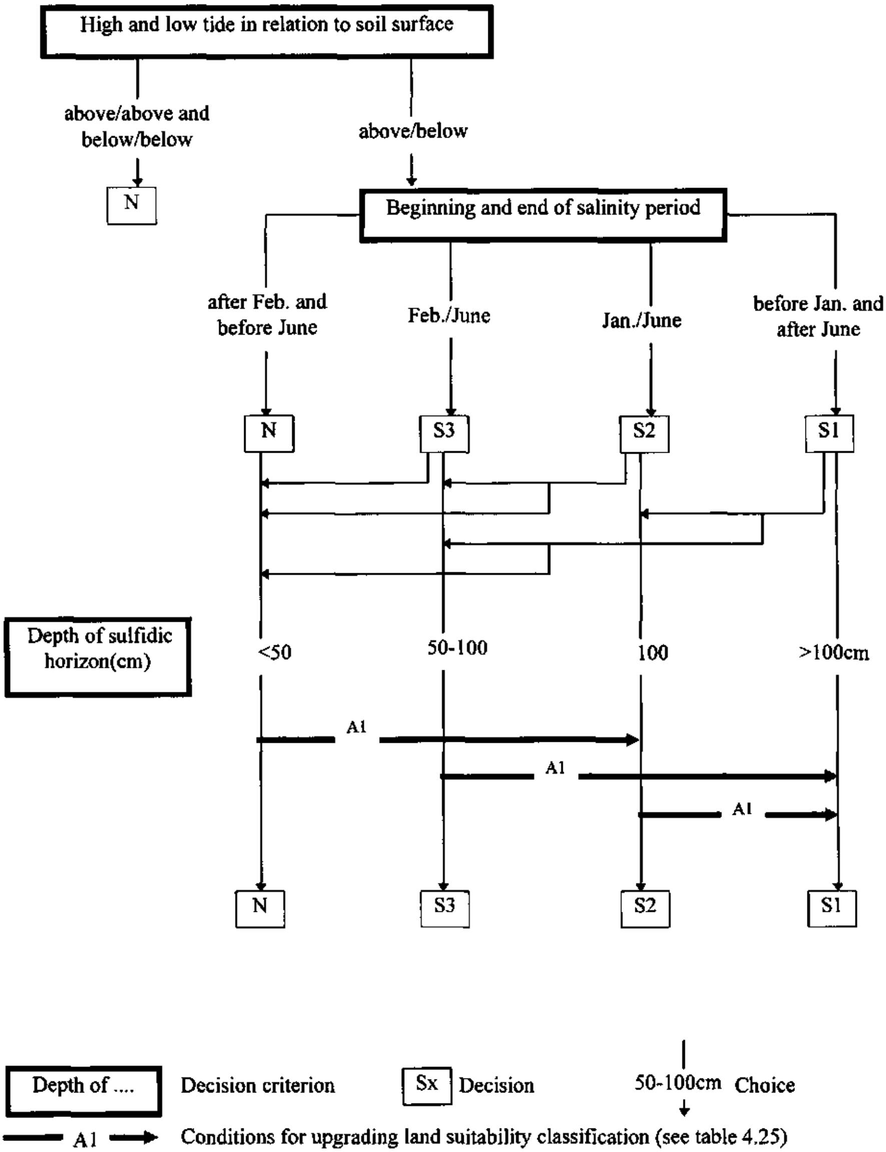


Figure 4.24: *Decision tree of extensive Shrimp cultivation (LUT10) in area No.4 - Hong Dan.*

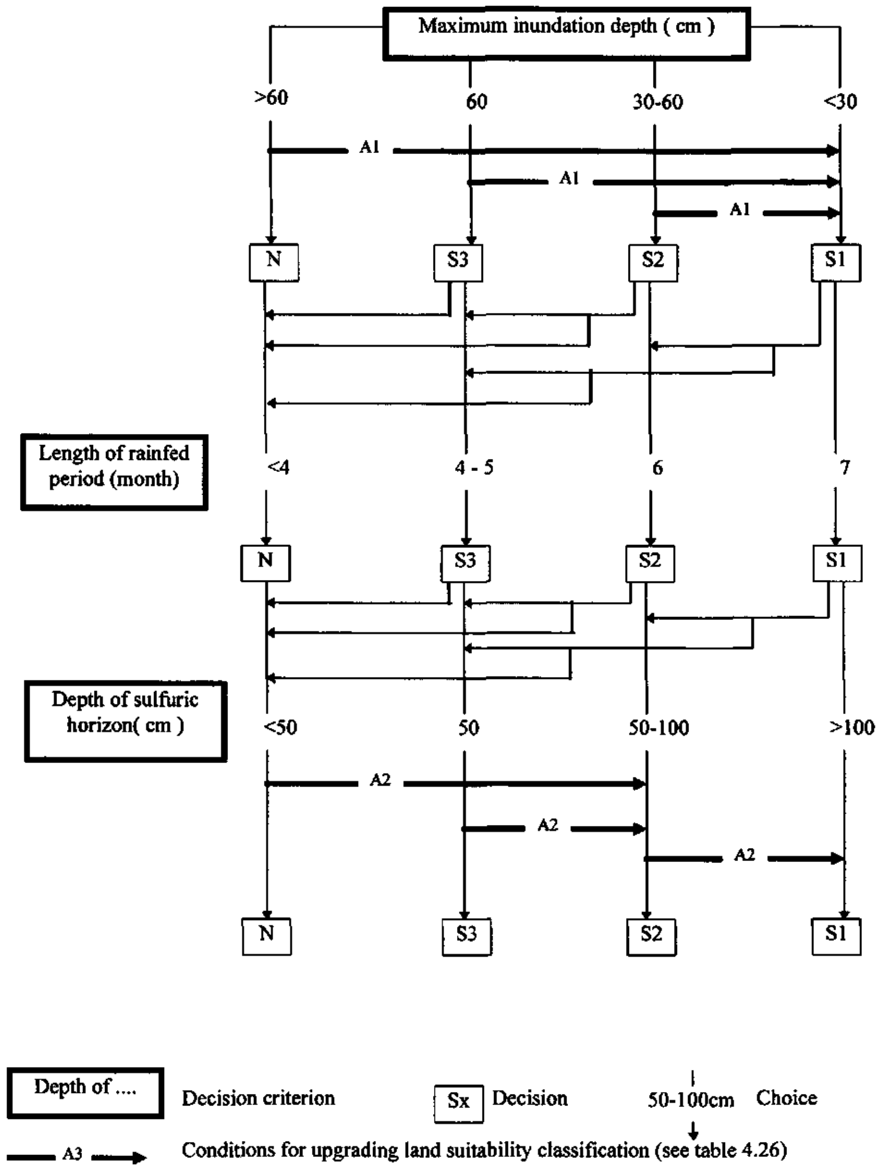


Figure 4.25: *Decision tree of Ratoon cropping of Sugarcane (LUT12) in the area No.4-Hong Dan*

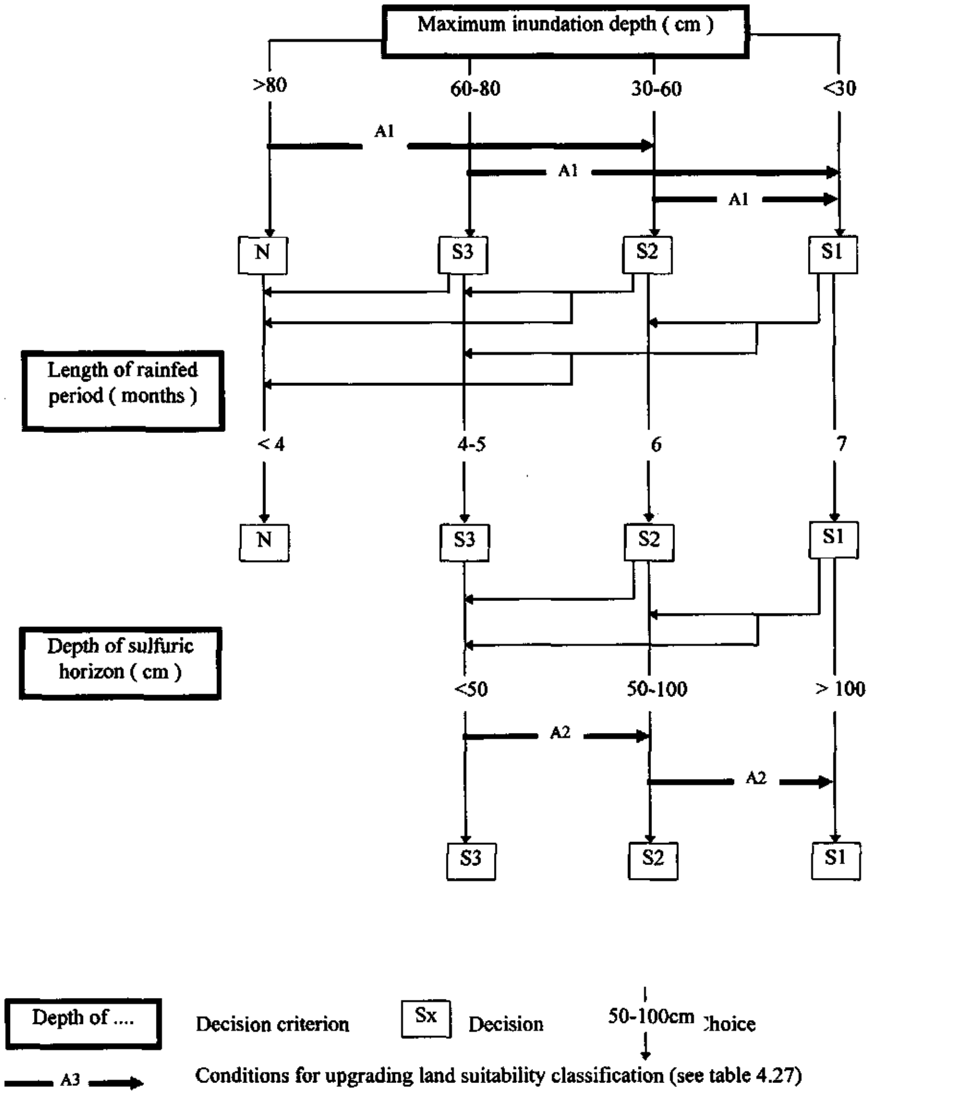


Figure 4.26: *Decision tree of single cropping of Pineapple(LUT14) in the area No.4 - Hong Dan.*

Table 4.25: *Conditions of water and soil management practices for upgrading land suitability of extensive Shrimp cultivation (LUT10) in the area No.4 - Hong Dan.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Depth of sulfidic horizon: A1. Keep the sulfidic/sulfuric layer under wet condition.	S3, S2 N	S1 S2	No constraints Acidity during ditch preparation.

Table 4.26: *Conditions of water and soil management practices for upgrading land suitability of Ratoon cropping of Sugarcane (LUT12) in the area No.4 - Hong Dan.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Maximum inundation period: A1.Construction of dike to protect against deep flooding.	N, S3, S2	S1	No constraints
2. Depth of sulfuric horizon: A2. To place good top soil layer on the top of raised beds when constructed.	S2 N,S3	S1 S2	No constraints Acidity in the first few year

Table 4.27: *Conditions of water and soil management practices for upgrading land suitability of single cropping of Pineapple (LUT14) in the area No.4 - Hong Dan.*

Land characteristics	Upgrading land suitable classification		Remaining constraints
Conditions of soil and water management practices	Present	Final	
1. Maximum inundation period: A1.Construction of dike to protect against deep flooding.	N, S3, S2	S1	No constraints
2. Depth of sulfuric horizon: A2. To place good top soil layer on the top of raised beds when constructed.	S2 S3	S1 S2	No constraints Acidity in the first few year

Chapter 5

Field experimentation

5.1 General introduction:

Land evaluation at farm level was studied in chapter 4. To make a land suitability classification of the four study areas for the different improved and/or relevant land use types, decision trees were developed and used as decision support systems. For making these decision trees, different land qualities were defined and expressed in term of land characteristics relevant for acid sulphate soils in the Mekong Delta. While developing such schemes, insufficient data on land use requirement/land qualities of relevant land use types were noted. Field experiments, to be discussed in this chapter, were therefore initiated to fill these gaps in knowledge.

- One of the promising land use types in the severely acid sulphate soil area with high flooding during the rainy season, is cultivation of yam on raised beds (Areas 1 and 2). Land qualities/land use requirements of "fresh water availability" and "soil acidity" expressed in terms of land characteristics: "available water supply" and "depth of sulfuric horizon", respectively, of this land use type were not clear. Water management practices by farmers such as storage of fresh water in ditches, irrigation frequency, mulching practices and selection of irrigation periods were more important problems in Tan Thanh and Tri ton areas. A field study on yam cultivation on the acid sulphate soils was therefore initiated. (Section 5.1)
- Pineapple cultivated on high raised beds is a promising land use type in the acid sulphate soil areas with salt water intrusion during the dry season (Area 4). Land qualities/land use requirements of "fresh water availability" and "soil acidity" expressed in terms of land characteristics: "available water supply" and "depth of sulfuric horizon", respectively, of this land use type were not clear. Is it possible to use rainwater, stored in ditches after the rainy season, as a potential source of supplementary irrigation in the early dry season in this area to improve the pineapple production? This question was unanswered. The cultural practices for pineapple cultivation also play a important role in the Hong Dan area. A study into the possibilities of pineapple cultivation in areas with salt water intrusion during the dry season is therefore necessary to complete the picture of pineapple cultivation and supply data for crop requirements in land evaluation studies on the acid sulphate soils. (Section 5.2)

- Double cropping of Winter-Spring high yielding rice followed by Summer-Autumn high yielding rice is a potentially successful land use type being practised in the acid sulphate soils with deep flooding areas. The land quality/land use requirement of "flooding hazard" expressed in terms of land characteristic: "length of inundation period" was also not clear (Areas 1 and 2). Zero-tillage technique, applied during the late Winter-Spring crop, is becoming popular for this land use type allowing reduction of the length of the cropping season. Zero-tillage has given the best method of stand establishment. But when this information is extrapolated to bigger and wider production complexes, other environmental factors interact. Many questions on effects of zero-tillage on soil conditions are still unanswered. A field experiment was therefore initiated to investigate which tillage practice is most favourable to allow growing a second Summer-Autumn rice crop in areas with a long inundation period. (Section 5.3)

5.2 Field experimentation:

5.2.1 Cultivation of Yam on an acid sulphate soil in the Mekong Delta, Viet Nam:

5.2.1.1 Introduction:

In the Mekong Delta of Viet Nam, an estimated 1.6 million ha consists of potential or actual acid sulphate soils (Xuan, 1993; Mensvoort 1993; Hefting, 1994) which pose major constraints to agriculture. Waterlogging, which occurs on many (potential) acid sulphate soils, while attractive for wetland rice cultivation, is obviously not desirable for the cultivation of upland crops. Acid sulphate soils, however, can be made productive for upland crops such as yam (Tri, 1989; Sen, 1987; Xuan , 1993; and Tri , 1993).

Yam is cultivated on a large scale as a food crop in West Africa, South East Asia and the Caribbean. *Dioscorea alata* and *Dioscorea esculenta* are the most important yam species cultivated in Viet Nam. Cultivation of yam in acid sulphate soil areas, however, requires high investments. Most capital is needed for planting material and construction of raised beds, which are needed to avoid flooding. Use of raised beds is, therefore, recommended as a practical method to reclaim and improve acid sulphate soils (Xuan *et al.*, 1982; Sen, 1987; Tri, 1989).

Yams require soils of high fertility in order to grow well. Sen *et al.* (1987) recommended levels of 160 kg P_2O_5/ha, 100 kg K_2O/ha and 80 kg N/ha for yam on acid sulphate soils. When grown during the dry season, irrigation is necessary. By means of mulching, moisture losses by evaporation and runoff can be reduced, and infiltration is increased (Sen *et al.*, 1987; Budelman, 1991). The tolerance of yam to hydrological constraints such as waterlogging and poor drainage is low (Onwueme, 1978). High water levels at the beginning and end of the yam growing season will reduce the length of the growing period and adversely affect yields.

Until now, little attention has been paid to improving yam farmer's cultivation practices on acid sulphate soils which is unfortunate because of the economic potential of the crop. Water management practices by farmers such as storage of fresh water in ditches, irrigation frequency, mulching practices, and selection of irrigation periods have not received more attention in the past. The objectives of this study are, therefore to: (i) investigate agricultural practices such as types of raised beds used, staking, planting density, and fertilization practices, and (ii) determine the effects of irrigation during the dry season on growth and tuber yields of yam.

5.2.1.2 Materials and methods:

Six experiments were carried out on acid sulphate soils with a sulfuric horizon within 50cm below the soil surface in Tan Thanh district and Tri Ton district, Mekong Delta, Viet Nam. Soil profiles were described and classified as Hydraquentic Sulfaquepts (Soil Survey Staff, 1975). Results of chemical analyses (Table 5.1) show that the soils have low pH (2.1-3.3), high total acidity and Al (17.4-25.3 meq/100g and 10.7-18.3 meq/100, respectively) in the sulfuric horizon (20-60cm deep) and in the reduced pyritic subsoils (>60 cm deep). Organic matter and total Nitrogen content are high (> 10% and >0.2% respectively) throughout the whole profile. Available phosphorus is very low (<5mg/100gsoil).

Questions regarding the proper construction of raised beds, required cultural practices and irrigation are still unanswered and have been addressed in this research which consists of six experiments : (i) construction methods of raised beds; (ii) fertilization; (iii) staking; (iv) planting density, and (v) irrigation and mulching (two experiments).

Table 5.1: *Some chemical analyses of two soil pedons in the experimental sites, Tan Thanh and Tri Ton districts.(* : H_2O (1:5) ; ** : extracted by 1M KCl (1:5))*

Horizon	Depth	pH	EC	O.M.	Tot. N	P-avail.	Al^{+++}	Tot.acid
	(cm)	(*)	(*)	(%)	(%)	mg/100g	(meq/100gsoil **)	
Tan Thanh								
Ah	0 - 25	3.29	2.00	14.62	1.020	5.00	1.55	17.45
B	25 - 60	3.30	1.27	07.94	0.242	1.25	10.70	12.40
Cr1	60 - 100	1.98	9.00	10.97	0.242	0.63	-	-
Cr2	> 100	2.30	6.40	10.56	0.223	1.25	18.30	25.30
Tri Ton								
Aph	0 - 13	3.26	-	20.62	0.523	3.70	15.10	17.45
BCj	13 - 50	2.91	-	13.67	0.242	0.62	12.95	15.45
Cr	> 50	2.17	-	12.98	0.123	1.23	32.15	-

- ***Types of raised beds***: An experiment testing two types of raised beds was carried out using a completely randomized design in the Tri Ton district, 1994-1995. The experiment has one factor (the type of raised beds) with three replications. Two types of raised bed were constructed as follows:

 * RB : first the surface soil is excavated and kept apart, and later placed on top of the bed (so-called: Rolled carpet raised beds). The size of raised beds is 3.0m wide and 0.5m high.

 * MB : simply turning the soil profile around, thus bringing the bad part of the soil profile to the surface of the bed (so-called: Mixed raised beds). The size of raised beds is 3.0m wide and 0.5m high.

- ***Fertilizer experiment***: A fertilizer experiment was laid out in the Tan Thanh district, 1993-1994. The experiment was a completely randomize block with four treatments and three replication as follows:

F1 : N_0 - P_0 - K_0 : no fertilizer

F2 : N_{120} - P_{60} - K_{60} : farmers level fartilization

F3 : N_{180} - P_{120} - K_{120} : high fertilization

F4 : N_{80} - P_{160} - K_{100} : highest fertilizer application as Sen *et al.*, 1987.

The following fertilizers were used: (i) DAP (18% N, 46% P2O5); (ii) Urea (46% N); (iii) 16-16-8 mixed fartilizer (16% N, 16% P2O5, 8% K2O); and (iv) KCL(60% K2O). Fertilizers were applied three times. The first time was 26 days after planting (DAP). The second application 55 DAP and the third application 75 DAP . The size of each experimental plots is 3 x 10m.

- ***Staking experiment***: Yam are climbers hence supplying the vines with stakes for better display of leaves seems a good practice. In this experiment, staking pyramid method was practised in the form of a pole for each plant. A staking experiment was laid out in Tan Thanh district, 1993-1994. The experiment was a completely randomized design. The two treatments were replicated three times. The staked treatments are 'ST1' and un-staked 'ST0'. The size of each experimental raised-bed plot is 3.0 x 15.0 m.

- ***Planting density experiment***: A planting density experiment was laid out in the Tri Ton district, 1994-1995. The experiment was a completely randomized design with one factor (density of plants) including three treatments and three replication. Three treatments were as follows:

D1 : 30 cm * 40 cm : dense planting

D2 : 40 cm * 50 cm : farmer's practice

D3 : 50 cm * 60 cm : so-called: "opened" planting

- ***Irrigation and mulching experiments:***

* *Experiment 1*: Irrigation and mulching experiment was a completely randomized design in Tan Thanh district, 1993-1994. Eight combinations of treatments were replicated three times. The treatments were i) 10mm irrigation every 10 days (I10), 10 mm irrigation every 15 days (I15), ii) no mulch layer applied (M0) and mulch layer applied (M1), iii) incomplete irrigation, i.e. only part of the dry season (W0) and complete irrigation, i.e. throughout the dry season (W1).

* *Experiment 2*: An experiment into optimum frequency of irrigation and irrigation timing was made as completely randomized design in Tri Ton district, 1994-1995. Four combinations of treatments were replicated three times. The treatments were: i) 10mm irrigation every 10 days (I10), 10 mm irrigation every 20 days (I20),iii) incomplete irrigation, i.e. only part of the dry season (W0) and complete irrigation, i.e. throughout the dry season (W1).

* *Measurements:* To estimate the moisture content of different soil layers. Soil samples were collected during the irrigation period at two depths, 5 - 10 cm and 20 - 25 cm below the surface of the raised bed. Monitoring of ground water levels below the surface of the raised beds was done with piezometers. Tensiometer measurements in the beds were made in the experiment 1 only.

+ ***Cultural practices:*** The size of the experimental raised bed plots is $36m^2$ and $27m^2$ (in Tan Thanh and Tri Ton, respectively). Adjacent plots were spaced 2.0 m apart. All the yam tuber sets (variety *D.Alata*) were planted at the same time for the different combinations of treatments. Yam sets were planted in rows, spaced 0.5 m apart, while the in-row distance between yam plants was 0.4 m (except in the planting density experiment). Irrigation applications were of 10mm (except in the irrigation experiments). Fertilizer application is $120N\text{-}60P_2O_5\text{-}60K_2O$ and $100N\text{-}160P_2O_5\text{-}120K_2O$ (Tan Thanh and Tri Ton, respectively), except in the fertilizer experiment.

+ ***Growth monitoring***: In each plot three plants were randomly selected monitoring the crop performance .Total number of leaves of the plant and the length of the main branch (cm) was measured one month after planting. At harvest time, tuber yield and yield components were measured in all experiments.

+ ***Methods of chemical analysis:*** ***The*** soil samples were analysed for pH (in a 1:5 extract) using a pH meter. For exchangeable aluminium, SO_4 and total acidity methods by Begheijn (1980) were used, EC was measured in a 1:5 extract. Total carbon was analysed according to Walkey and Black (1965), and total Nitrogen as Kjeldahl (Black *et al.*, 1965). The soil moisture content was expressed as percentage by volume (θ). These values can be determined as a percentage as follows:

$$\theta = \frac{100 * (Mm - M)}{M} * BD$$

Where Mm = mass of the moist soil, M = mass of the dry soil at 105^0C. BD = bulk density ($kg.m^{-3}$).

5.2.1.3 Results and discussion:

a. Effect of two types of raised bed:

Table 5.2 shows that most chemical and physical properties of the two types of raised-beds differ somewhat. The clay content in the top soil (0-10cm) and rooting zone (20-25cm) of mixed-raised beds is higher than in the Rolled-carpet raised beds, while organic matter content is relatively low. These differences are due to placement of subsoil with high clay and low organic matter content on the top of the beds (Bouma *et al.*, 1993). The higher clay content in the soils of the raised-beds might adversely affected development of yam tubers, because yams demands a loose, free draining and fertile soil (FAO, 1989; Messiaen, 1994).

Table 5.2: *Some physical and chemical characteristics of soils at two depths in two types of raised beds being study, Tri Ton, 1994-1995. (* : Extracted by H_2O (1:5))*

Soil characteristics	Rolled-raised beds		Mixed-raised beds	
	0 - 10 cm	20 - 25 cm	0 - 10 cm	20 - 25 cm
pH (H_2O 1:5 extraction)	4.41	4.15	4.20	4.03
EC (mS/cm 1:5 extraction)	0.24	0.28	0.27	0.30
O.M. (%)	14.67	14.83	12.09	13.57
SO_4 (%)	0.042	0.052	0.052	0.052
Total acidity (meq/100g)*	0.104	0.201	0.176	0.302
Al^{3+} (meq/100g)*	0.050	0.135	0.095	0.215
Particle size:				
% Sand	8.42	8.90	11.42	6.90
% Silt	47.39	47.51	41.28	43.80
% Clay	44.19	43.59	47.30	49.30

Weight and length of individual tubers tended to be higher in Rolled-carpet raised beds but differences were not significant (Table 5.3). The circumference of tubers was significantly bigger in the rolled-carpet raised beds. Yields of yam (14.4 tons/ha) obtained at the rolled raised beds were significantly higher as those in the mixed raised beds (10.4 tons/ha). Such yields are low compared to yields obtained in good soils in West Africa where 25-35 tons/ha is harvested (Messiaen, 1994).

Table 5.3: *Total yield and weight of yam on two types of raised beds in Tri Ton district, 1994-1995. In each column, means followed by a common letter are not significantly different at 5% level by LSD.*

Treatments	Weight of tuber (gram)	Length of tuber (cm)	Circumference of tuber width(cm)	Yields (tons/ha)
Rolled-beds	447.4	17.0	21.3 b	14.40 b
Mixed-beds	396.3	15.4	19.2 a	10.40 a

b. Effect of different fertilizer rates:

Crop performance on the un-fertilized treatments was very poor as compared to the fertilized treatments. Plants remained small, and leaves covered the soil for only 30 to 40% at harvest. At the high fertilization level (level F3), the total number of leaves remained low at the beginning of the experiment (Table 5.4). At 81 DAP, levels F2, F3 and F4 showed a similar number of leaves, significantly higher than level F1 (the unfertilized treatment).

Table 5.4: *Number of leaves per plant at different periods after planting (DAP) for the fertilizer experiment in Tan Thanh district, 1993-1994. Means followed by a common letter are not significantly different at 5% level by LSD. (DAP : Day After Planting).*

Treatments	19 DAP	35 DAP	50 DAP	67 DAP	81DAP
F1 : N_0- P_0-K_0	9.9 a	16.4 b	49.9 a	91.9 a	121.8 a
F2 : N_{120}- P_{60}-K_{60}	11.7 b	16.6 b	67.6 b	166.9 c	267.8 b
F3 : N_{180}- P_{120}-K_{120}	8.8 a	12.6 a	45.6 a	127.3 b	262.9 b
F4 : N_{80}- P_{160}-K_{100}	10.8 b	20.8 c	78.0 b	167.3 c	245.6 b

Table 5.5: *Yield component and tuber yields of Yam for fertilizer experiment in Tan Thanh district, 1993-1994. In each column, means followed by a common letter are not significantly different at 5% level by LSD.*

Treatments	Weight of tuber (gram)	Length of tuber (cm)	Circumference of tuber (cm)	Yields (tons/ha)
F1 : N_0- P_0-K_0	205.0	12.0	18.6 a	9.6 a
F2 : N_{120}- P_{60}-K_{60}	346.7	11.9	23.6 b	15.9 b
F3 : N_{180}- P_{120}-K_{120}	340.0	14.9	23.1 b	16.5 b
F4 : N_{80}- P_{160}-K_{100}	278.9	12.2	22.6 b	15.3 b

To increase tuber yield of yams in acid sulphate soil, P and K fertilizers should be applied in addition to N (Sen *et al.*, 1987). Table 5.5 shows that tuber yields at farmers' level (F2: N_{120}-P_{60}-K_{60}) of *D. alata* variety were 42 percent higher compared with the unfertilized treatment (F1). On acid sulphate soils nutrient deficiencies are a major factor limiting crop development and tuber yield. Phosphate availability, in particular, is restricted (Dent, 1986; Verburg, 1994). However, yields did not increase significantly when fertilizer application were raised to F3 and F4. This means that in these soils with high organic matter contents of 10-14%, high chemical fertilization is not effective, as was earlier suggested by Messiaen (1994). We, therefore, recommend fertilization at N_{120}-P_{60}-K_{60} which can significantly increase yields as compared with no fertilization (Table 5.5).

c. Effect of staking the vines:

Measurements on the leaves (Table 5.6) were taken during the initial part of the growing season. No significant differences are found in number of leaves per plant from 19 DAP to 81 DAP between staked and unstaked plants, but the overall performance of the staked yam plant seems to be very good.

Table 5.6: *Number of leaves per plant at different periods after planting (DAP) for the staking experiment in Tan Thanh, 1993-1994. (DAP : Day After Planting).*

Treatments	19 DAP	35 DAP	50 DAP	67 DAP	81DAP
Staking	6.8	10.9	47.7	104.5	166.4
No staking	6.3	12.6	42.7	111.6	193.5

Results show that staking treatment tends to increase tuber yield but not significantly (Table 5.7). Trials elsewhere showed a clear advantage in staking. However, provided the soil is healthy, weed control is good and adequate manuring is carried out, very good crops of *D. alata* can also be achieved without stakes as also reported by Messiaen (1994).

Table 5.7: *Yield component and tuber yields of Yam for staking experiment in Tan Thanh district, 1993-1994. Means followed by a common letter are not significantly different at 5% level by LSD.(ns : not significantly)*

Treatments	Weight of tuber (gram)	Length of tuber (cm)	Circumference of tuber (cm)	Yields (tons/ha)
Staking	421.1	14.8	23.7	16.9 ns
No staking	345.6	13.1	23.9	16.5 ns

d. Effect of planting density:

Density of planting had an effect on tuber yields of yam (Table 5.8). The tuber yields of treatments D1 and D2 (30x40cm and 40x50cm, respectively) were significantly higher as compared with treatment D3 (50x60cm). Yields increase with increasing planting density as also reported by Messiaen (1994). Low yields in treatment D3 can be explained by the lower number of tubers per ha, because tuber weight as well as length and circumference were not different from the other treatments.

Table 5.8: *Yield component and tuber yields of Yam for planting density experiment in Tri Ton district, 1994-1995. Means followed by a common letter are not significantly different at 5% level by LSD.*

Treatments	Weight of tuber (gram)	Length of tuber (cm)	Circumference of tuber (cm)	Yields (tons/ha)
D1 : 30 x 40 cm	351.8	16.7	20.7	12.90 b
D2 : 40 x 50 cm	396.3	15.4	19.2	10.40 b
D3 : 50 x 60 cm	338.5	16.7	20.7	7.07 a

e. Effect of frequency of irrigation, mulching and irrigation period:

In Tan Thanh district, yam grown on mulched plots developed well and leaves covered the soil surface for 60 to 90 %. Number of leaves were significantly higher than in non-mulched plots (Table 5.9). The frequency and timing of irrigation had no significant effect on yield (Table 5.10). Expected rainfall at mid-dry season supplied an adequate amount of water and caused high soil moisture contents in all treatments with mulching. Therefore, attention was focused on the effects of the presence or absence of a mulch layer on tuber yield. Table 5.10 shows that tuber weight , length, and circumference were significantly higher in the mulched treatments as compared with the non-mulched treatments. Tuber yields of *D. alata* are 46 percent higher for the mulched plots. Mulching promotes the early development of yam plants and reduces excessive weed growth (Sen *et al.*, 1987; Messiaen, 1994). Young tuber setts are protected against high radiation and destructive impact of raindrops. The presence of a mulch layer also increases the capacity of the soil to absorb water (Budelman, 1991; Hefting 1994). Influences on soil temperature and soil moisture content were of minor importance under wet soil conditions encountered in these

Table 5.9 : *Number of leaves per plant at different period after planting for the mulching and irrigation experiment in Tan Thanh district, 1993-1994. Means followed by a common letter are not significantly different at 5% level by LSD. (I10 : irrigation every 10 days ; I15 : irrigation every 15 days ; M1 : mulching ; M0 : no mulching ; DAP : Day After Planting).*

Treatments	36 DAP	51 DAP	66 DAP	81 DAP	97 DAP
I10 M1	20.5 b	54.8 b	129.3 b	242.5 b	316.6 b
I15 M1	18.0 b	46.0 b	122.2 b	236.9 b	310.6 b
I10 M0	12.7 a	24.8 a	64.7 a	125.6 a	216.3 a
I15 M0	15.8 a	33.3 a	72.6 a	146.3 a	222.6 a

Table 5.10: *Total yield and weight of Yam on the mulch - irrigation experiment in Tan Thanh district, 1993-1994. Means followed by a common letter are not significantly different at 5% level by LSD. (I10: irrigation every 10 days; I15: irrigation every 15 days; M1: mulching; M0: no mulching)*

Treatments	Weight of tuber (gram)	Length of tuber (cm)	Circumference of tuber (cm)	Yields (tons/ha)
I10 M1	283.3 b	12.1 b	18.8 b	15.0 b
I15 M1	352.2 b	12.6 b	20.2 b	14.8 b
I10 M0	131.1 a	8.4 a	15.7 a	7.9 a
I15 M0	182.2 a	10.6 a	16.8 a	8.0 a

Table 5.11: *Yield component and tuber yields of Yam for the irrigation period experiment in Tri Ton district, 1994-1995. Means followed by a common letter are not significantly different at 5% (for weight, circumference of tuber) and 1% (for yield) level by LSD. (I10: irrigation every 10days ; I20 : irrigation every 20days ; W1: complete irrigation; W0: incomplete irrigation)*

Treatments	Weight of tuber (gram)	Length of tuber (cm)	Circumference of tuber (cm)	Yields (tons/ha)
I10 W1	409.60 b	15.8	21.17 b	13.67 b
I20 W1	458.50 b	17.0	21.30 b	14.37 b
I10 W0	278.13 a	14.7	17.87 a	9.90 a
I20 W0	248.53 a	13.6	17.80 a	9.57 a

experiments, but may be very important under dryer conditions. This can be demonstrated with results from the Tri Ton area, where the experiments showed that irrigation had a positive effect on yield, because of a long dry period (Table 11). Positive effects of irrigation on yields were also reported by Coursey (1967); and Onwueme (1978). Higher soil moisture contents as a result of irrigation are documented in Figure 5.1.

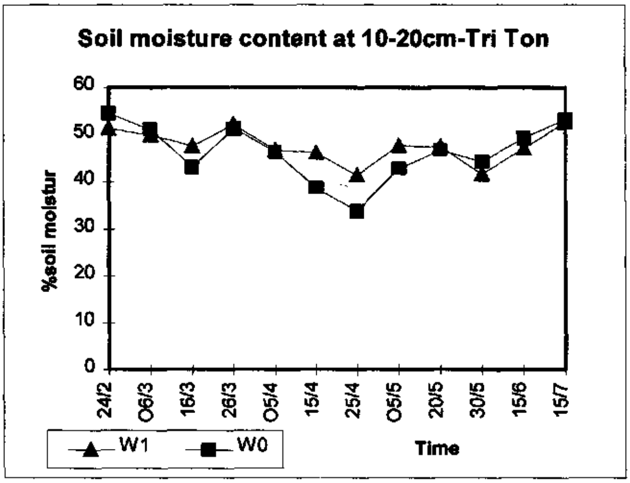


Figure 5.1: *Soil moisture contents at 10-20 cm depth for complete irrigation and incomplete irrigation during the growing season in Tri Ton, 1994-1995. (W1: complete irrigation, W0: incomplete irrigation)*

5.2.1.4 Conclusions :

1. Cultivation of yam on acid sulphate soils is quite difficult. Farmers are aware of this and deal with the problems related to soil acidity and flooding by cultivating yam on raised beds. Yam grows well and gives high yields on high raised beds. The method of construction of these raised beds has influence on tuber yield. Rolled carpet raised bed with less clay and more organic matter in the rooting zone had a significant positive effect on yam yield as compared with mixed raised bed.

2. Yam responds strongly to fertilization. A high yield can be obtained by an application of N_{120}-P_{60}-K_{60} which is already applied by farmers in the area or N_{80}-

P_{160}-K_{100}. Higher levels of chemical fertilizer do not increase tuber yield in acid sulphate soils with relatively high organic matter contents.

3. Staking practices in the area appear to be of limited importance and do not increase yam production. Yields have increased by increasing planting density but then also seed cost increased. A planting density of 40 cm x 50 cm space is proposed for yam cultivation in the acid sulphate soils.

4. Mulching results in significantly higher yields compared to unmulched plots. Mulching lowers average soil temperatures, and evaporation and positively affects the conservation of water in the soil, reducing excessive weed growth. Young tuber setts and plants are also protected against high radiation and the mulch layer reduces the destructive impact of raindrops

5. Appropriate water management is of major importance for successful cultivation of yams in acid sulphate soils. Sufficient fresh water should be available during the dry period of the cropping season. An irrigation frequency of 20 days during the dry season is recommended for yam cultivation in areas with long dry periods.

5.2.2 Cultivation of pineapple on an acid sulphate soil with salt water intrusion during the dry season in the Mekong Delta - Viet Nam:

5.2.2.1 Introduction:

In the Mekong Delta of Viet Nam are an estimated 1.6 million hectares of acid sulphate soils, of which about 400.000 ha are also hampered by salt water intrusion during the dry season (Nga *et al.*, 1994). Waterlogging is a frequently occurring phenomenon on (potential) acid sulphate soils. This is desirable in wetland rice cultivation, but obviously not for the cultivation of upland crops. Acid sulphate soils, however, can be made productive for upland crops (Tri, 1990; Xuan, 1993). Pineapple is relatively tolerant to low soil pH and aluminium toxicity (Tri, 1989). Pineapple is also tolerant to drought, and can be cultivated in areas with a wide range of rainfall from 635 - 2500mm per year. Raised beds are a prerequisite for growing pineapple in the Mekong Delta. The height of the raised beds is 50-60 cm, the top soil should have preferably been put aside and placed on the top of the raised bed (van Mensvoort *et al.*, 1983; Tri, 1990). Nga *et al.* (1994) showed that different ways of raised beds construction resulted in different concentrations of Al^{3+} and SO_4^{--} in the soil and significantly different yields. Because of the extended dry season, plants often suffer from water stress in soil already characterized by Al toxicity and low fertility resulting in low yields (Sen, 1987; Tri, 1990; Nga *et al.*, 1994; Guong, 1995). Phosphorus plays an important role in plant nutrition on acid sulphate soils. Smooth Cayenne variety showed a positive response to 1 ton of lime combined with 7g P_2O_5/plant while the Queen variety did not respond to lime application (Guong *et al.*, 1995). Earlier, Sen (1987) reported a 20% increase pineapple yield when P-application was increased from 50 to 100 kg P_2O_5/ha. The production of pineapple on acid sulphate soils with salt water intrusion during the dry season depends on surface soil management. The beneficial effect of mulch with grasses is outstanding because of better soil moisture conservation. A much better plant performance and yield (about 40% and 70% yield increase) was obtained by mulched plots with and without water control in the ditches, respectively.

Most previous studies have paid attention to pineapple cultivation in fresh water acid sulphate soils with the exception of Sen *et al.* (1987) who did initial research in a salt water intruded area. A study into the possibilities of pineapple cultivation on acid sulphate soils in areas with salt water intrusion during the dry season is useful to complete the picture of pineapple cultivation and supply data for crop requirements in land evaluation studies on the acid sulphate soils in the Mekong Delta, Viet Nam. Rainwater, as a potential source of irrigation water, is stored in ditches after the rainy season and small dams are used to avoid salt water intrusion. The objectives of this study are:(i) investigation of the cultural practices such as types of raised bed and fertilization practices for pineapple cultivation in the acid sulphate soil areas with salt water intrusion during the dry season, and (ii) determination of the effects of supplementary irrigation during the early dry season on growth and yields of pineapple.

5.2.2.2 Materials and methods:

Four experiments on pineapple cultivation were carried out on an acid sulphate soil with a sulfuric horizon within 50 cm from the soil surface and salt water intrusion during the dry season in Hong Dan district, Minh Hai province, Mekong Delta, Viet Nam. The soil was described and classified as a Typic Sulfaquept, salic phase (Soil Survey Staff, 1975). Results of chemical analysis (Table 5.12) showed that the soil has a low pH (2.5 - 3.3), high total acidity and

Al (7.4-42.3meq/100gsoil and 5.8-35.1 meq/100gsoil, respectively) in the sulfuric horizon (25-100cm deep) and subsoils (>100cm deep); high Organic matter and Nitrogen content in the top soil (8.2% and 0.27%, respectively). Available phosphorus is low for the whole profile (1.2-2.4 mg/100g).

Table 5.12: *Some chemical analysis of soil pedon in the experimental site, Hong Dan district.* *(* : H_2O (1:5) ; ** : extracted by 1M KCl (1:5))*

Horizon	Depth (cm)	pH (*)	EC (*)	O.M. (%)	Tot. N (%)	P-avail. mg/100g	Al^{+++} (meq/100gsoil **)	Tot.acid (meq/100gsoil **)
Ap	0 - 25	4.08	3.10	8.72	0.274	2.455	2.50	3.479
Bgj	25 - 65	3.37	3.31	4.53	0.118	1.473	5.80	7.472
Bj	65 - 100	3.15	4.08	2.06	0.085	1.227	7.75	9.359
Cr	> 100	2.58	6.04	3.75	0.111	4.930	35.13	42.32

In the study area, perennial small-stem bamboo is traditionally grown on low raised beds. In order to improve financial returns, a system was recently introduced growing pineapple as an intercrop for a three year period. However, yields are erratic and a new production system is, therefore, being developed in close interaction with the farmers. This system consists of high-raised beds focusing exclusively on growing pineapple. Many questions relating to construction details of high raised beds, required fertilization and irrigation are still unanswered and have been addressed in this research which consists of four experiments:

- ***Experiment 1***: Effects of the traditional low-raised beds and newly developed high-raised beds on pineapple yields, 1992-1994. Experiments were made with and without small-stem bamboo intercropping. A completely randomized design was used with two factors (types of raised bed, small-stem bamboo intercropping) in three replications. The two factors can be described as follows:

  * LB: simply turning the soil profile around, bringing the sulfuric horizon of the profile to the surface of the beds. The size of the raised beds is 5.0 m wide and 0.25m high. The raised beds for the experiment were already constructed 5 years ago.

  * HB: the raised bed construction is similar as LB, but the height is 0.5m and the bed was constructed one year earlier.

* B: Pineapple intercropped with small stem bamboo for a three years period.

* NB: Pineapple without bamboo

Chemical measurement: pH, EC, SO_4 , Al and total acidity of the raised bed soils were measured before planting.

- ***Experiment 2***: Effects of three different types of high-raised beds on the growth and yields of pineapple, 1993-1995. The experiment was done in a completely randomized design, one factor (type of raised bed) in three replications. Three types of raised bed were constructed:

* RB-93: the surface soil is excavated and kept apart, and later placed on top of the bed in 1993 (so-called: Rolled carpet beds-93).

* MB-93: simply turning the soil profile around, thus bringing the most acid part of the profile to the surface of the bed in 1993 (so-called: mixed beds-93).

* MB-92: the method for raised bed construction is similar as MB-93, but the beds were fallowed for a year before planting in 1992 (so-called: mixed beds-92).

Chemical measurement: pH, EC, SO_4 , Al and total acidity of raised-bed soils were measured just before planting, mid-rainy season, end of rainy season, mid-dry season, and after harvest using mixed samples from a depth of 0-10 cm.

- ***Experiment 3***: The effects of P and K on growth and yields of pineapple were studied in high-raised beds in a randomized complete block design with two factors and three replications, 1993-1995. P and K application rates tested were similar to Guong *et al.* (1995) :

* Phosphorus fertilizer was applied at two levels (5g and 7g P_2O_5 per plant) just before planting.

* Potassium was applied at 8, 10, and 12g K_2O per plant.

N was applied as a basal dressing of 10g N per plant. Soil sampling at planting took place and pH, EC, O.M., Available P, and Exchangeable K were analysed in mixed samples taken at 0-20cm deep from the top of beds.

- ***Experiment 4***: The effect of supplementary irrigation during the early dry season on growth and yields of pineapple was studied in high-raised beds, 1993-1995. The experiment was of a randomized complete block design with one factor (irrigation) and three replications. The frequency of irrigation was as follows:

* I-0 : no supplementary irrigation.
* I-7 : supplementary irrigation (5mm water) every 7 days.
* I-14 : supplementary irrigation (5mm water) every 14 days.

Water for irrigation was stored in the ditches between raised beds at the end of rainy season. Irrigation started in December 1993 and ended in March 1994 when the stored water in the ditches was exhausted. The depth of ground water table and soil moisture content were measured during the dry season.

+ ***Cultural practices***: The size of the raised-bed plots is 5.0m wide, 9.0m long, and 0.5m high. Queen variety is planted, density 45,000 plants/ha (for experiment 2, 3, and 4) and 35,000 plants/ha (for experiment 1: intercropping). Fertilizer application is 10gN-5gP_2O_5-12gK_2O per plant (as urea, superphosphate and KCl, respectively). Phosphorus was applied just before planting, N and K fertilization were split and applied in 10 times and completed 2 months before floral induction (Guong *et al.*, 1995). Pineapple was planted at the beginning of the rainy season (July) and harvested after 19 months. There was no irrigation during the dry season (December to April), except in the irrigation experiment.

+ ***Growth monitoring***: Crop performance was monitored through the number of leaves per plant. D-leaves are young, but fully developed leaves, standing at an angle of about 45^0. These leaves are generally taken for leaf analysis and measurement. Their weight is closely related to yield (Samson, 1986). D-leaf weight and crop yield were recorded for statistical analysis.

+ ***Analytical methods***: The soil samples were analysed for pH using pH meter (in a 1:5 extract), exchangeable aluminium, SO_4 and total acidity using methods as by Begheijn (1980), EC using EC meter (in a 1:5 extract). Total carbon was analysed according to Walkey and Black (1965), total Nitrogen as Kjeldahl (Black *et al.*, 1965). Soil moisture content was expressed as a percentage by volume (θ). These values can be determined as a percentage as follows:

$$\theta = \frac{100 * (Mm - M)}{M} * BD$$

Where Mm = mass of the moist soil, M = mass of the dry soil at 105 C. BD: bulk density(kg.m^{-3})

5.2.2.3 Results and discussion:

a. Effects of traditional low-raised beds and the newly developed high raised beds:

At the first harvest, significantly higher yields were obtained in the high raised-beds with and without small-stem bamboo, compared with the low raised-beds with and without small-stem bamboo (Table 5.13). In the second harvest, most plants on the low raised-beds died by water logging during the rainy season. The highest yield was obtained in the high raised-beds without small-stem bamboo. Yields were significantly different from yields on high beds with small-stem bamboo and low beds without small-stem bamboo. The low raised beds gave low yield, because the pineapple root is very sensitive to water logging (Samson, 1986). Pineapple intercropped with perennial trees such as small-stem bamboo has significantly lower yields in the second harvest. The explanation is probably competition between pineapple and small-stem bamboo starting at the third year after planting when small-stem bamboo overshadows pineapple. Construction of high raised beds is necessary for pineapple cultivation because of water logging.

Table 5.13: *Yield of pineapple of low and high raised beds with and without bamboo intercropping in the first harvest and second harvest, Hong Dan, 1992-1994. In each column, means followed by a common letter are not significantly different at 1% level by DMRT.*

Treatments	First harvest 1993 (tons/ha)	Second harvest 1994 (tons/ha)
Low beds + Bamboo	14.89 a	-
Low beds + No Bamboo	21.33 b	4.88 a
High beds + Bamboo	35.11 c	11.11 b
High beds + No Bamboo	31.95 c	33.11 c

Table 5.14 shows that pH and EC values, and total Acidity and Al^{3+} concentrations are not much different among different treatments. pH value is low in all raised beds and ranges from 3.46 to 3.85. Concentration of total acidity and Al^{3+} (commonly used indicators in ASS) in high beds is rather high

Table 5.14: *Some chemical analysis of traditionally low and high-raised beds with and without small-stem bamboo intercropping, Hong Dan, 1992-1994. (* : H_2O (1:5) ; ** : extracted by 1M KCl (1:5)).*

Treatments	pH	EC (mS/cm)	Total acidity ** (meq/100gsoil)	Al^{+++} ** (meq/100gsoil)
Low beds + Bamboo	3.85	1.27	5.85	4.00
Low beds + No Bamboo	3.68	1.62	4.95	2.50
High beds + Bamboo	3.46	1.03	7.20	5.00
High beds + No Bamboo	3.64	1.00	6.75	4.50

compared to the low-beds. This might be due to high acidity in the first year of bed construction (Sterk, 1993). Acidity of soil was not a major limiting factor in crop growth as compared with waterlogging. The effects of acidity may be evident when comparing different construction methods for the high raised beds (Mensvoort, 1994), as discussed in the next section.

b. Effect of three types of high-raised beds on:

- Chemical properties of the soil:

Table 5.15 shows that chemical properties of the three types of raised beds differ strongly. Conditions for plant growth are most favourable in the mixed-bed 92. Even though the surface soil was not displaced separately, as was the case in the rolled-bed 93, leaching during one year by rainfall had resulted in a higher pH and lower EC, SO_4^{--} values. Differences in total acidity (extracted by 1M KCl) were minor among the beds, but soluble acidity values obtained by water extraction were again clearly lower for the mixed-bed 92. Apparently, one year of leaching is quite effective in improving conditions for plant growth in a turned-around profile even though separate placement of the surface soil on top of the bed was considered superior to simply turning the profile around. However, the rolled-bed 93, where surface soil was treated separately, was used immediately to grow pineapples without a year of leaching. We may, however, it is expected that the rolled-raised bed 93 will perform better in future after leaching during several years. The total acidity in the top soil of the raised beds remains high, even after seven years of leaching. About 70% of this acidity is due to Al^{3+} , which is mainly adsorbed at the exchange complex, and seems not directly toxic to plants (Sterk, 1993). This result may partly be used to explain the significant difference of fruit yield of pineapple between different types of raised beds.

Table 5.15: *Some chemical analyses of three types of raised bed during growing period of pineapple on an saline acid sulphate soil, Hong Dan district, 1993-1995. ((+): H_2O (1:5) ; * : Extracted by 1M KCl (1:5) ; ** : Extracted by H_2O (1:5)).*

Period	Type of raised bed	pH (+)	EC (mS/cm)	SO_4^{2-} (%)	Total acidity	Al^{+++}	Total acidity	Al^{+++}
					(meq/100g soil)			
Planting date	Rolled bed-93	3.50	4.48	0.395	7.26	5.55	0.73	0.38
	Mixed bed-92	3.68	1.60	0.112	7.44	5.80	0.15	0.03
	Mixed bed-93	3.42	4.52	0.101	4.05	2.70	0.21	0.04
Mid-rainy season	Rolled bed-93	3.90	2.30	0.223	5.28	4.45	0.12	0.03
	Mixed bed-92	4.02	0.65	0.051	6.95	5.76	0.05	0.01
	Mixed bed-93	3.75	1.10	0.122	8.05	4.60	0.14	0.03
End rainy season	Rolled bed-93	4.75	0.34	0.102	4.82	4.20	0.09	0.08
	Mixed bed-92	4.89	0.18	0.085	6.22	5.75	0.09	0.08
	Mixed bed-93	4.08	0.35	0.085	6.10	5.20	0.03	0.03
Mid-dry season	Rolled bed-93	4.08	4.10	0.203	5.08	3.94	0.22	0.10
	Mixed bed-92	3.69	3.34	0.142	6.56	6.17	0.23	0.08
	Mixed bed-93	3.33	7.37	0.441	4.91	3.32	0.70	0.30
Harvest date	Rolled bed-93	4.16	0.80	0.240	6.23	5.55	0.04	0.03
	Mixed bed-92	4.04	1.38	0.188	4.92	3.80	0.06	0.05
	Mixed bed-93	3.52	2.16	0.343	5.02	3.70	0.26	0.14

- Crop performance and fruit yields:

The different types of raised bed had no effects on the development of the crop as indicated by formation of leaves. Table 5.16 shows that the number of leaves is highest in mixed beds-92 throughout the growth period, but not significantly so. The different types of raised-beds showed no significant differences in length, width and weight of D-leaves (Table 5.17). The highest yield was obtained from the mixed beds-92, which was significantly higher (at 1%) as compared with newly raised-beds of 1993. This result can be explained by the relatively high pH value, low total acidity and Al^{+++} concentration of mixed beds-92 after two years of natural leaching, as explained before. The raised-beds constructed in 1993 have relatively high acidity in the first year of bed construction (Sterk, 1993).

Table 5.16: *The number of leaves per pineapple plant on three types of raised beds during the dry season period, 1994.(RP-93:Rolled bed-93; MB-92 Mixed bed-92; MB-93:Mixed bed-93)*

Time	Number of leaf per plant		
	RB-93	MB-92	MB-93
December - 93	29.53	32.20	27.83
January - 94	34.00	37.11	31.67
February	38.67	41.90	36.00
March	43.47	46.77	39.33
April	46.27	51.23	42.47
May	49.87	55.77	45.67
June	54.93	61.10	49.63

Table 5.17: *Yield component and yield of pineapple on three types of raised bed, Hong Dan. Means followed by a common letter are not significantly different at 1% level by DMRT.*

Treatments	Length of D-leaf (cm)	Width of D-leaf (cm)	Weight of D-leaf (gram)	Yield (tons/ha)
Rolled bed-93	53.13	6.3	25.73	43.00 a
Mixed bed-92	52.10	6.2	23.60	56.75 b
Mixed bed-93	42.27	4.6	23.73	41.87 a

c. Effect of Phosphorus and Potassium rates:

The highest P and K applications (7g P_2O_5/plant and 12g K_2O/plant) resulted in the highest yield (50.4 tons/ha) (Table 5.18). At low P application rates (5g P_2O_5/plant), the yield was not significantly different when increasing K application rates from 8g K_2O/plant to 12g K_2O/plant. However, at higher P application rates (7g P_2O_5/plant), yield increased significantly when increasing the K rates from 8g to 10g and 12g. This means that phosphorus is required to stimulate uptake of potassium (Allemann, 1965; Guong *et al.*, 1995). This result also shows that at low K application rates (8g K_2O/plant), yield of pineapple is significantly lower because uptake of nitrate and phosphorus of the pineapple plant is reduced by a potassium deficiency (Allemann, 1965). The increase of potassium fertilization will greatly influence plant growth and quality (Collins J.L., 1960). But increasing the K application from 10g K_2O/plant to 12g K_2O/plant in this study did not increase the pineapple yield significantly for high P treatments. Fertilization of 7g P_2O_5/plant and 10g K_2O/plant is recommended which can increase yields by 20% as compared with the low rates for P and K indicated in table 5.18.

Table 5.18: *Yield of pineapple at different P and K rates, Hong Dan, 1993-1995. Means followed by a common letter are not significantly different at 1% level by DMRT. (* : gram of N-P-K per plant).*

Treatments (*)	Weight of D-leaf (gram)	Yield (tons/ha)
10 - 05 - 08	25.0	38.2 a
10 - 05 - 10	28.4	40.3 a
10 - 05 - 12	24.7	41.9 a
10 - 07 - 08	26.8	41.3 a
10 - 07 - 10	32.9	48.4 b
10 - 07 - 12	33.4	50.4 b

d. Effects of supplementary irrigation at the early dry season:

Farmers in the salt water intruded areas, traditionally plant pineapple without irrigation because there is no fresh water in the dry season. Supplementary irrigation in the early dry season by using the stored fresh water in the ditches was expected to be effective in increasing yields of pineapple. The results of the study show that the supplementary irrigation in the early dry season does not clearly affect pineapple yield. The irrigation treatments (every 7 days and 14 days) tended to increase yield

Table 5.19: *Yield component and yield of pineapple between no supplementary irrigation (I-0) and irrigation of every 7 days (I-7) and 14 days (I-14), Hong Dan, 1993-1995.*

Treatments	Dry weight of root(gram)	Length of D-leaf (cm)	Width of D-leaf (cm)	Weight of D-leaf (gram)	Yields (tons/ha)
T-7	16.34	55.7	6.6	35.2	48.88
T-14	16.63	58.8	6.4	42.9	47.81
T-0	14.26	53.1	6.3	25.7	43.00

but not significantly so (Table 5.19). The explanation for this result can be that the soil was wet enough in the beginning of the dry season to adequately supply water to the crop (Figure 5.2). Saving rainwater behind a dam to be used later in the dry season does not work because water will evaporate. In general, the soil moisture content in the rooting zone remains sufficiently high during the dry season. Pineapple plants can, therefore, survive in the dry period without supplementary irrigation.

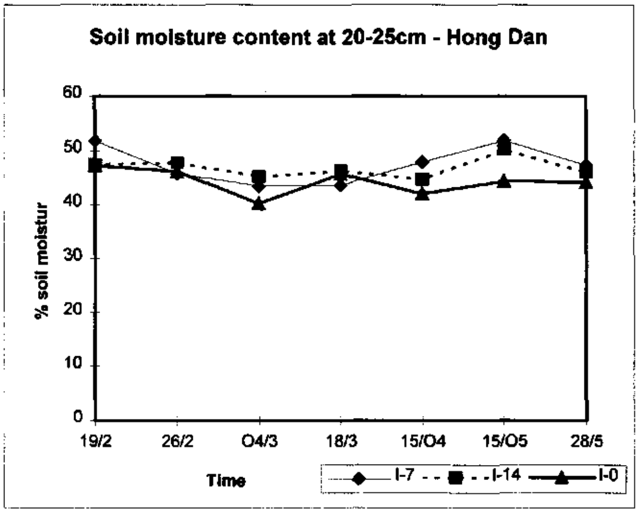


Figure 5.2: *Soil moisture content at the depth of 20-25cm during the dry season 1994, Hong Dan. (I-7: irrigation of every 7 days; I-14: irrigation of every 14 days; I-0: no irrigation)*

5.2.2.4 Conclusions:

1. Pineapple grows better and gives higher yields on high raised beds as compared with traditional low-raised beds because water logging negatively influences crop growth in the rainy season.
2. Pineapple can tolerate high acidity levels in different types of raised beds in acid sulphate soil with salt water intrusion during the dry season. The method of constructing raised beds has no influence on the yield of pineapple in the same year. High mixed-raised beds (constructed by simply turning the soil profile around), fallowed for one year and subjected to natural leaching by rain, gave a significantly higher yield of pineapple as compared with fresh raised beds, even

when the surface soil was saved and placed on top of the beds.

3. Pineapple responds fertilization. A yield increase of about 20% can be obtained by a combination of high P and K fertilization. ($10N-7P_2O_5-10K_20$ gram/plant is proposed for conditions encountered in the Hong Dan area).

4. Supplementary irrigation in the early dry season has no effect on yield, because the natural moisture content of the soil remains sufficiently high.

5.2.3 The role of the zero-tillage technique in rice cultivation on an acid sulphate soil in the Mekong Delta Viet Nam

5.2.3.1 Introduction:

About 40% of the Mekong Delta (an estimated 1.6 million ha) consists of potential or actual acid sulphate soils which pose major constraints to agriculture. Double cropping of Winter-Spring (W-S) high yielding (H.Y.) rice followed by Summer-Autumn (S-A) H.Y. rice has been practised in large areas when the canals for irrigation and drainage were available in the acid sulphate soils with deep flooded areas (see Figure 1 with a cropping calendar). In recent years the zero-tillage technique, applied during the late W-S rice crop, is becoming popular for double rice cropping in the acid sulphate soil areas with a long inundation period. This method was developed by farmers, and passed on from one to another (Xuan *et al.*, 1991). Xuan *et al.* (1991) reported that the zero-tillage technique was more profitable compared with conventional ploughing and wet broadcast on well developed acid sulphate soils because of lower cost for land preparation and irrigation. Also sowing of the second crop could proceed more rapidly as compared with ploughing after the first crop which could only be done after waiting 10-14 days after the harvest (Figure 5.3). Because available time is small, this could present the difference between having or not having a second crop. For clearing new acid sulphate land, Vinh *et al.* (1991) also suggested that zero-tillage (or minimum tillage) practices would help to prevent capillary rise of acid water from the subsoil to the soil surface and reduction of the length of the cropping season. This suggestion is difficult to understand because conditions are generally wet leaving little opportunity for capillary rise. Moreover, regular tillage is more likely to result in interruption of upward flow patterns than zero-tillage. Also regular tillage forms clods which can more efficiently be leached than a rather compact zero-tillage soil surface with exposed macro-pores that can result in by bypass flow and poor leaching (Bouma *et al.*, 1990). Many questions on effects of zero-tillage on soil conditions are thus still unanswered. This study investigates, therefore, which tillage practice is most favourable to allow growing a second S-A. rice crop in areas with a long inundation period by comparing effects of regular and zero-tillage on soil conditions and crop growth.

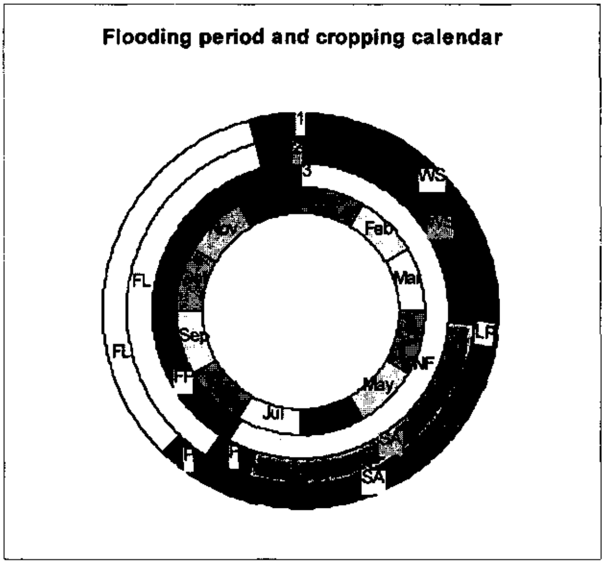


Figure 5.3: *Diagram of activities of zero-tillage and regular tillage practices for double rice cropping (Winter-Spring + Summer-Autumn) of the farmers in the acid sulphate soil areas with long flooding period. (Cycle 1: Double rice cropping with regular tillage practice; Cycle 2: Double rice cropping with zero-tillage practice; Cycle 3: Flooding period during a year; WS: Winter-Spring rice cropping; SA : Summer-Autumn rice cropping; LP : Land preparation; FP : Flooding period; P : Ploughing; NF : No flooding; FL : Fallow land period)*

5.2.3.2 Materials and methods:

The experiment was set up on recently reclaimed acid sulphate soils with a sulfuric horizon within 50 cm below the soil surface in Tan Thanh district, Mekong Delta, Viet Nam, where only two single rice crops had been grown in the previous two years. Soil profiles were described and classified as Hydraquentic Sulfaquepts (Soil Survey Staff, 1975). Results of chemical analyses (Table 5.20) show that the soils have low pH (2.1-3.3), high total acidity and Al (17.4-25.3 meq/100g and 10.7-18.3 meq/100, respectively) in the sulfuric horizon (20-60cm deep) and in the reduced pyritic subsoils (> 60 cm deep). Organic matter and total Nitrogen content are high (> 10% and >0.2%, respectively) throughout the whole profile. Available phosphorus is very low (<5 mg/100gsoil).

* *Experimental design:* This experiment was carried out using a completely randomized block design in the Tan Thanh district, 1994. The design considered the one factor tillage with three replication. Zero-tillage and regular tillage techniques are explained as follows. The diagram in figure 5.3 is included to illustrate the activities during the year.

> ***ZT*** : Zero-tillage practice: Before the W-S rice crop is harvested, the rice field was drained for 7-10 days. The stubble and straw were spread evenly over the field and left to dry 3-4 days. Next, it was burnt. Immediately after straw burning, pre-germinated rice seeds were broadcast directly onto the ash. Then irrigation water was rushed onto the field to soak the soil for 24 hours at a water depth of 3-4 cm and then drained. The soil was next kept in saturated condition for 7 days. After that, the field water levels were gradually increased to reach the 5 cm level at 10 days after sowing. After harvesting the fields were ploughed and left fallow during the flooding period.

> ***T*** : Regular tillage practice: After the harvest of the W-S rice crop, the threshed straw and weeds were removed from the field. Ploughing followed after waiting about 7-10 days for the soil to dry out, turning a soil layer of 15 to 20cm, including the stubble remains on the field. After ploughing, the soil was dried under the sun for at least one to two weeks. After harrowing, the field was flushed and flooded again before puddling. The rice is sown on the puddled fields after the fields were drained. About one week after sowing, the fields were flooded continuously. After harvesting the fields were ploughed and left fallow during the flooding period.

* ***Measurements:*** Soil samples were taken before burning, at sowing date, and 6, 30, 80 days after sowing, and after harvesting. Chemical analysis included pH. EC, Soluble acidity, Al, Fe, and SO_4 . Record variable costs.

* ***Cultural practices:*** The size of the experimental plots was 250 m^2. Rice variety of MTL119 (IR 53936-97-2-3-3) was directly sown at a quantity of 200 kg/ha.

Fertilizer application was 150kg Urea + 150kg compound fertilizer 12-12-5 per hectare.

* ***Growth monitoring**:* In each plot three frames of 0.25 m^2 were randomly selected to monitor crop performance. At harvest time, grain yield and yield components were measured.

* ***Methods of chemical analysis**:* The soil samples were analyzed for pH (in a 1:5 extract) using a pH meter. For exchangeable aluminium, SO_4 and total acidity methods by Begheijn (1980) were used, EC was measured in a 1:5 extract. Total carbon was analyzed according to Walkey and Black (1965), and total Nitrogen as Kjeldahl (Black *et al.*, 1965).

Table 5.20: *Some chemical analyses of two soil pedons in the experimental sites, Tan Thanh districts. (* : H_2O (1:5) ; ** : extracted by 1M KCl (1:5))*

Horizon	Depth (cm)	pH (*)	EC (*)	O.M. (%)	Tot. N (%)	P-avail. mg/100g	Al^{+++} (meq/100gsoil **)	Tot.acid (meq/100gsoil **)
Tan Thanh								
Ah	0 - 25	3.29	2.00	14.62	1.020	5.00	1.55	17.45
B	25 - 60	3.30	1.27	07.94	0.242	1.25	10.70	12.40
Cr1	60 - 100	1.98	9.00	10.97	0.242	0.63	-	-
Cr2	> 100	2.30	6.40	10.56	0.223	1.25	18.30	25.30

5.2.3.3 Results and discussion:

a. Chemical properties of the soil:

Table 5.21 shows that chemical properties of the zero-tillage and the regularly tilled soils are not significantly different. However, soil that was regularly tilled had slightly low EC, Al^{+++}, total acidity values which might suggest somewhat more efficient leaching in the regularly tilled soil due to better contact between clods and water (see introduction part). At the sowing date, the soil was very acid. When the soil was saturated for an increasingly longer period during the growing season, pH relatively increased and Al^{3+} , total acidity, EC and SO_4 decreased. Changes during the growing season were, however, not as large as might be expected. This result shows that improvement of acid soil by leaching with fresh water was not effective and not significantly different for both tillage practices.

b. Crop performance and yield component:

Because of rice cultivation practices, the sowing date in the regular tillage practice was at least 10 days later as compared with zero-tillage because land preparation took time (Figure 5.3). Both plant growth and tillering of plants developed poorly as compared to growth of rice plants on good soil. Yield components of the rice crop are presented in table 3. Zero-tillage and tillage practices had no significant effect on yields (Table 5.22).

Table 5.21: *Some chemical analyses of soil at 0-10cm depth (average of 0-5cm and 5-10cm) in zero-tillage and tillage practices during the growing season of SA.HY. rice in Tan Thanh district 1994. (* : date of first crop harvest; **: sowing date of zero-tillage and tillage, respectively; + : extracted by H_2O (1:5)).*

Analyses	Technique	Time					
		25/3	27/3&2/4	1/4&7/4	23/4	10/6	Harvest
pH (H_2O) (1:2.5)	Zero-tillage	3.66	3.37	3.40	3.46	3.61	3.62
	Tillage	3.65	3.39	3.41	3.51	3.63	3.61
EC (1:2.5)	Zero-tillage	1.25	1.45	1.60	0.90	0.96	1.52
	Tillage	1.32	1.36	1.30	1.00	0.90	1.40
Al^{3+} + (meq/100g)	Zero-tillage	0.84	0.86	1.40	0.70	0.78	1.23
	Tillage	1.12	1.29	0.91	0.67	0.69	1.20
Total acidity (meq/100g) +	Zero-tillage	1.27	1.54	1.77	0.87	0.93	1.42
	Tillage	1.27	1.70	1.33	0.81	0.86	1.25
SO_4 (%)	Zero-tillage	0.16	0.18	0.18	0.08	0.10	0.22
	Tillage	0.16	0.16	0.15	0.10	0.10	0.20

Table 5.22 shows grain yield of the Summer-Autumn rice crop was obviously low (0.8 ton/ha) as compared to yields obtained in well developed acid soils in the Plain of Reeds where 5.5 tons/ha is harvested (Xuan *et al.*, 1991). The

low yields are due to high acidity in the soil (Table 5.21) and poor water control during the growing season. The poor water control was due to conditions in the newly reclaimed acid sulphate soil that can not retain water because the organic matter content in this relatively permeable soil is relatively high and there is as yet no hardpan under the top soil layer. The relatively high acidity also has the implication that double rice cropping, especially Summer-Autumn rice crop, is poorly to grow in the first few years after reclamation of acid sulphate soils. However, improvements of soil physical and chemical characteristics after leaching have the effect that a second rice crop can give better yield after three to five growing seasons of double rice cropping. This experiment on double cropping was made after only two years of single cropping of Winter-Spring modern rice following reclamation.

Table 5.22: *Yield component and yield of SA.HY.rice between zero-tillage and tillage practices in Tan Thanh district, 1994.(ns : not significant).*

Treatments	Panicles (No./m^2)	Filled grain (No./panicle)	%filled grain per panicle	1000 grain weight (g)	Yields (tons/ha)
Zero-tillage	443.9	11.1	36.1	24.65	0.80
Tillage	446.7	10.0	34.1	24.65	0.77
LSD	ns	ns	ns	ns	ns

c. Comparison of variable costs between zero-tillage and regular tillage practices:

Variable cost including land preparation, water management, production materials and harvesting and threshing was computed for second rice crop (Summer-Autumn). This cost did not include family labour. Table 5.23 shows that variable cost for regular tillage practice is high as compared with variable cost of zero-tillage practice. This higher variable cost is mainly due to the cost of land preparation (Xuan *et al.*, 1991).

Table 5.23: *Variable costs of Summer-Autumn modern rice crop in 1994, Tan Thanh district.*
*(* : 1$US dollar = 10,500 VN dong)*

Activities/Materials	Costs (VN dong/ha)	
	Zero-tillage	Regular tillage
Land preparation	-	200,000
Hire of tractor/buffaloes	-	250,000
Seeds	220,000	220,000
Water management	100,000	100,000
Pesticides	25,000	25,000
Fertilizers	480,000	480,000
Harvesting and threshing	340,000	340,000
Total variable costs	1,165,000	1,615,000

d. Effects of zero-tillage practices:

The major impact of the zero-tillage practice is to save time and allow sowing of the second rice crop at all times while yields do not decrease. Application of conventional tillage after the first crop takes at least two precious weeks, and may result in a poor second crop under adverse conditions (see Figure 5.3). The zero-tillage technique also reduces costs. Even though less efficient leaching and lower yields might be expected after zero-tillage, our experiments do not indicate this to be the case. Of course, regular tillage is always applied after the harvest of the second crop and this will help to improve soil leaching also in the zero-tillage experiment.

5.2.3.4 Conclusions:

1. Zero-tillage and regular tillage techniques had no significant effects on improving soil characteristics or rice yields of the second crop of newly reclaimed acid sulphate soils during the first growing season of the double rice cropping. But the regular tillage technique had a tendency to improve soil leaching due to better contact between clods and water.
2. The zero-tillage technique is more economically profitable compared to conventional wet broadcasting because of lower cost of land preparation.

3. The zero-tillage technique reduced the length of the growing season of double rice cropping in acid sulphate soils with a long inundation period, thereby making the system more feasible by reducing risks.
4. The second, Summer-Autumn rice crop grows poorly on newly reclaimed acid sulphate land because of the high acidity and poor water control during the growing season. After three to five years this is likely to change due to soil improvement by leaching.
5. The long term effects of the zero-tillage and regular tillage techniques on soil chemical and physical characteristics should be further studied on acid sulphate soils. Grain yields should be also monitored.

Chapter 6

Optimal farm management packages based on farmer/expert knowledge and field experiments

In the four study areas, soil acidity and hydrology are major physical constraints. Although there are still problems to be solved, it appears that existing technologies for the development of the various acid sulphate soils can bring higher income for farmers (Xuan, 1993). However, the essential component of land use systems on acid sulphate soils is appropriate water management (Tuong *et al.*, 1991). Agronomic practices and expected yields were based on the results of field experiments, field observations, knowledge of expert, and farmer's interview. Based on the farmer's present land use and soil and water management practices and results of the land evaluation study using decision trees, optimal farm management packages can be presented as follows:

6. 1 Area No. 1: Tan Thanh

6.1.1 If present:

(i) Having available water supply with canals and infrastructure for irrigation;

(ii) No salinity in dry season;

(iii) Length of inundation period less than 5 months;

(iv) Depth of sulfuric horizon between 50-100 cm and deeper than 100 cm.

- Optimal land use type: " ***Double cropping of irrigated Winter-Spring High Yielding rice followed by Summer-Autumn High Yielding rice.***"

- This land use type requires the following land and water management practices: (i) construction of shallow drainage systems to leach the acidity out in the beginning of rainy season; (ii) building sluice gates and field bunds (or small dikes) for water control during the growing season; (iii) field leveling for modern rice cultivation in order to control water in the field; (iv) zero tillage to shorten the duration of double rice cultivation and to ensure harvest before the beginning of the long flooded period.

- Agronomic practices and expected yields are as follows:

+ *Winter-Spring HY rice crop*: The growing period starts from November when water is receding to the harvest in January/February. Rice is directly sown at 200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 100 kgN and 90 kgP_2O_5 and 30 kgK_2O per ha per crop. Expected yield : 5.0 to 5.8 tons/ha.

+ *Summer-Autumn HY rice crop*: The growing period starts from March after harvesting of Winter-Spring crop to the harvest in June/July. Rice is directly sown at 200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 250kgUrea and 100kgDAP and 100 kg16-16-8 per ha per crop. Expected yield: 4 tons/ha.

6.1.2 If present:

(i) Having available water supply with canals and infrastructure for irrigation;

(ii) Beginning of salinity period occurs after February;

(iii) End of inundation period is before January 15;

(iv) Depth of sulfuric horizon between 50-100 cm and deeper than 100 cm.

- Optimal land use type: " ***Single cropping of irrigated Winter-Spring High Yielding rice .***"
- This land use type requires the following land and water management practices: (i) construction of the shallow drainage systems in order to leach the acidity out in the beginning of rainy season; (ii) building sluice gates and field bunds (or small dikes) for water control during the growing season; (iii) field leveling for modern rice cultivation in order to control water in the field.
- Agronomic practices and expected yields are as follows:

+ *Winter-Spring HY rice crop*: The growing period starts from November when water is receding to the harvest in January/February. Rice is directly sown at 200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and 75% during the growing season. Amount of fertilizer is 250kgUrea and 100kgDAP and 40 kg16-16-8 per ha per crop. Expected yield: 3.5 to 4.0 tons/ha.

6.1.3 If present:

(i) No salinity in dry season or salinity in April;

(ii) Having available water supply;

(iii) Beginning and end of inundation period is after August 15 and before January 15;

(iv) Depth of sulfuric horizon between 50cm or more;

- Optimal land use type: ***- Single cropping of yam.***
  - Double cropping of yam followed by cassava
  - Ratoon cropping of sugarcane (*).
  - Single cropping of cassava.

- These land use types require the following land and water management practices: (i) construction of raised beds: Raised beds are constructed in dry season, top soil without acidity is placed on the top of raised beds. Size of raised beds having a width of 2.5 to 3.0m, height of 0.3 to 0.4m and length of 10 to 20m; (ii) the ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season; and (iii) mulching with grasses or straw after planting.

- Agronomic practices and expected yields are as follows:

  + *Yam cropping*: The growing period starts from November when water is receding to the harvest in May /June before the water level reaches the surface of the raised beds. Planting density is 15.000-18.000 sets/ha. The fertilizers are applied for 30% in 20 days after planting and 70% during the rest of the growing season. Amount of fertilizer is 80kgN + 160kgP2O5 + 100kgK2O per ha per crop. Expected yield: 40 to 47 tons/ha for white varieties and 20 to 30 tons/ha for purple varieties.

  + *Yam - cassava cropping*: The cultural practices of the first crop (yam) are described above. After harvesting yam in May, cassava is planted afterwards. The varieties of cassava have short growing period about 3 months (*Mi ke*). Cassava should be harvested before the water level reaches the surface of the raised beds. The growing period starts from May to the harvest in August. Planting density is 30.000 cuttings/ha. The fertilizers are applied 20 day after planting. Amount of fertilizer is 100 kg Urea per ha per crop. Expected yield: 3-5 tons/ha

  + *Cassava cropping*: The growing period starts from November when water is receding to the harvest in May/June before the water level reaches the surface of the raised beds. Planting density is 30.000 cuttings/ha. The fertilizers are applied 20 day after planting. Amount of fertilizer is 125 kg Urea per ha per crop. Expected yield: 25-30 tons/ha

  + *Sugarcane cropping*: Sugarcane is planted on the raised beds that had

Yam or Cassava before and surrounding by strong dike in order to protect against flood during the inundation period. Ratoon of sugarcane is 3 to 4 years. Sugarcane is planted from November up to one year later for first crop and continued. Amount of fertilizer is 250kg Urea + 250kg DAP per ha per year. Expected yield: first crop: 60-70 tons/ha of beds and 80-90 tons/ha of beds for ratoon crop.

6.1.4 If present:

(i) Depth of sulfuric horizon within 50cm from soil surface;

(ii) No available canal systems for irrigation

- Optimal land use type: "***Planted Melaleuca and Melaleuca cajuputi.***"
- This land use type requires the following land and water management practices: (i) excavation of canals among *Melaleuca* forest in order to protect against fire in the dry season; (ii) constructing stove and distillation pan for oil extraction from *Melaleuca cajuputi*; and (iii) re-forestation after harvesting *Melaleuca* for timber or for oil extraction.

**** Soil and water management conditions for land improvement in these areas:***

- **If:** (i) Construction of raised beds as described in section 6.1.3;
  (ii) Ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season.
  (iii) Mulching with grasses or straw after planting in order to reduce the evaporation in the early stage of crop growth.
  (iv) Store fresh water in the ditches and surrounding canals or construct the canal in order to convey fresh water from main canals into the ditches.
- Optimal land use types: ***Yam ; Cassava; Sugarcane***
- Agronomic practices: of Yam, Cassava and Sugarcane as described above. ***Sugarcane***: is planted in the raised beds that had Yam or Cassava before and surrounding by strong dike in order to protect against flood during the inundation period.

- **If:** (i) Construction of the canals and infrastructure for irrigation;
  (ii) Construction of shallow drainage systems;

(iii) Sluice gates and field bunds(or small dike) for water control;

(iv) Field leveling and zero-tillage practice;

- Optimal land use types:

+ Just recently reclaimed: ***" Single cropping of irrigated Winter Spring High Yielding rice."***

+ After 3 - 4 years of reclamation: ***" Double irrigated modern rice crops: Summer Autumn +Winter Spring."***

- Agronomic practices and expected yields: The land use types presented here mostly have a same agronomic practices as the land use types that were described above. But the expected yields of these land use types only are of 60 - 80% of highest expected yields when all conditions of soil and water management practices as mentioned above are met. Because, land still remain the limitations that in aggregate are moderately severe for sustained application of the defined use.

The summary of optimal management packages on acid sulphate soils in area No.1 Tan Thanh is shown in table 6.1.

6.2 Area No. 2: Tri Ton

6.2.1 If present:

(i) Having available water supply with canals and infrastructure for irrigation;

(ii) Length of inundation period less than 5 months;

(iii) Depth of sulfuric horizon between 50-100 cm and deeper than 100 cm.

- Optimal land use type:

" Double cropping of irrigated Winter-Spring High Yielding rice followed by Summer-Autumn High Yielding rice."

- This land use type requires the following land and water management practices: (i) construction of shallow drainage systems to leach the acidity out in the beginning of rainy season; (ii) building sluice gates and field bunds (or small dikes) for water control during the growing season; (iii) field leveling for modern rice cultivation in order to control water in the field; (iv) zero tillage to shorten the duration of double rice cultivation and to ensure harvest before the beginning of the long flooded period.

Table 6.1: *Optimal farm management packages based on farmer/expert knowledge and field experiments in the area 1 - Tan Thanh. The present situation is defined in terms of a series of land characteristics not land qualities, which is done for operational reasons. The corresponding land qualities were earlier defined in table 4.1 to express expert knowledge.*

Situation	Land use types	Agronomic practices and expected yields	Land and Water management practices
6.1.1. If present: - Having available water supply; - No salinity in dry season or salinity in April; - Length of inundation period: < 5 months; - Depth of sulfuric horizon : 50-100cm and >100 cm.	***Double irrigated modern rice crops: Summer-Autumn + Winter-Spring.***	- **First crop: SA.HY rice** +Growing period: March - June/July. +Seeds: directly sown at 200kg/ha. +Fertilizers:(250kgUrea+100kgDAP+100kg16-16-8)/ha; + Expected yield: 4 tons/ha. - **Second crop: WS.HY.rice crop** +Growing period: November - Jan./Feb. + Seeds: directly sown at 200kg/ha. +Fertilizers:($100N+90P_2O_5+30K_2O$)/ha + Expected yield: 5.0 - 5.8 tons/ha.	- Construction of canals and infrastructure for irrigation - Construction of shallow drainage systems; - Sluice gates and field bunds (or small dike) for water control; - Field levelling; - Zero tillage practice.
6.1.2. If present: - Having available water supply; - Beginning of salinity period: after February; - End of inundation period: before January 15; - Depth of sulfuric horizon: 50 cm or more;	***Single irrigated modern rice crop: Winter-Spring***	+ Growing period: Nov. to Jan./Feb. + Seeds: directly sown at 200kg/ha. + Fertilizers: (250kg Urea+100kgDAP+40kg16-16-8)/ha; + Expected yields: 3.5-4.0 tons/ha.	- Construction of available canal systems for irrigation; - Construction of shallow drainage systems; - Sluice gates and field bunds for water control; - Proper field levelling.
6.1.3. If present: - Salinity period: at April or no; - Having available water supply; - Beginning and end of inundation period: after August 15 and before January 15;	***- Single cropping of yam.*** ***- Double cropping of yam followed by cassava***	- **Crop: Yam** + Growing period: Nov. to May/June + Density: 15.000-18.000pieces/ha + Fertilizers: ($80kgN + 160kgP_2O_5 + 100kgK_2O$)/ha + Expected yield: 40-47 tons/ha.	+ Construction of raised beds: Raised beds are constructed in dry season, top soil without acidity is placed on the top of raised beds. Size of raised beds having a width of 2.5 to 3.0m, height of 0.3 to 0.4m and length of 10 - 20m.

- Depth of sulfuric horizon: at 50cm or more;	***- Ratoon cropping of sugarcane (*).*** ***- Single cropping of cassava.***	- **<u>Crop: Yam + cassava</u>** + Cassava: + Growing period: from May to August. + Planting density: 30.000 cutting/ha. + Fertilizers: 100kgUrea/ha + Expected yield: 3-5 tons/ha - **<u>Crop: Single cropping of cassava</u>** + Growing period: Nov. to June/July + Density: 30.000-32.000 cutting/ha + Fertilizers: 125kgUrea/ha + Expected yield: 25-30 tons/ha - **<u>Crop: Sugarcane</u>** + Growing period: from Nov. to August + Fertilizers:250kg Urea+250kgDAP/ha + Expected yields: 60-70 tons/ha of beds for first crop; 80-90tons/ha for ratoon	- Ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season. - Mulching with grasses or straw after planting. - Sugarcane is planted in the raised beds that had Yam or Cassava before and surrounding by strong dike in order to protect against flood during the innundation period.
6.1.4. If present: -Extremely acid sulphate soils: sulfuric horizon occurs within 50cm from soil surface. - No available canal systems for irrigation.	***- Planted Melaleuca*** ***- Melaleuca cajuputi***	- *Melaleuca* is transplanted at 40,000-50,000trees/ha. After three years, the *Melaleuca* forest can be thinned to have more space and to remove poorly or irregularly growing trees for fire wood usage. The sixth year, *Melaleuca* will be cut for fire wood or construction wood: 30,000 trees/ha/6 years.	- Excavation of canals among *Melaleuca* forest in order to protect against fire in the dry season. - Constructing stove and distillation pan for oil extraction from *Melaleuca cajuputi.* - Re-forestation after harvesting *Melaleuca* for timber or for oil extraction.

- Agronomic practices and expected yields are as follows:

  + *Winter-Spring HY rice crop*: The growing period starts from November when water is receding to the harvest in January/February. Rice is directly sown at 200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 100N and 90 P_2O_5 and 30 K_2O per ha per crop. Expected yield: 5.0 to 5.8 tons/ha.

  + *Summer-Autumn HY rice crop*: The growing period starts from March after harvesting of Winter-Spring crop to the harvest in June/July. Rice is directly sown at 200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 250kgUrea and 100kgDAP and 100 kg16-16-8 per ha per crop. Expected yield: 4 tons/ha.

6.2.2 If present:

(i) Having available water supply for irrigation during dry season;

(ii) Depth of sulfuric horizon occurs at deeper 100 cm.

- Optimal land use type:

"***Double cropping of floating rice followed by Maize (Sesame; Mungbean; Water melon).***"

- This land use type requires the following land and water management practices: (i) construction of the canal systems for supplementary irrigation during dry season.

- Agronomic practices and expected yields are as follows:

  + *Floating rice crop:* The growing period starts from June/July after rain coming to the harvest in December. Rice is directly sown at 120 to 150kg of rice seed per ha. The fertilizers are applied in the beginning of growing season. Amount of fertilizer is very low about 120 kg per ha per crop, mainly Urea. Expected yield: 1.5 to 2.0 tons/ha.

  + *Second cropping*: Maize/Sesame/Munbean/Water Melon: The growing period starts from December immediately after harvesting of floating rice to the harvest in February/March. Planting density or directly sown of Sesame: 10-12kg/ha; Water melon: 1000-1200 plants/ha; Maize: 30-35kg/ha; Mungbean: 35-40kg/ha. The fertilizers are applied during growing season. Amount of fertilizer (1/2 Urea + 1/2 DAP): Sesame: 240kg/ha; Water melon: 800kg/ha; Maize: 240kg/ha; Mungbean: 160kg/ha per crop. Expected yields: Sesame: 0.55 tons/ha; Maize: 3.0tons/ha; Water melon: 24 tons/ha; Mungbean: 0.9 tons/ha.

6.2.3 If present:

(i) Having available water supply with canals and infrastructure for irrigation;

(ii) End of inundation period is before December 15;

(iii) Depth of sulfuric horizon between 50-100 cm and deeper than 100 cm.

- Optimal land use type:

" ***Single cropping of irrigated Winter-Spring High Yielding rice*** ."

- This land use type requires the following land and water management practices: (i) construction of shallow drainage systems to leach the acidity out in the beginning of rainy season; (ii) building the sluice gates and field bunds (or small dikes) for water control during the growing season; (iii) field leveling is most important land management practice for modern rice cultivation in order to control water in the field.
- Agronomic practices and expected yields are as follows:

+ *Winter-Spring HY rice crop*: The growing period starts from November/December when water is receding to the harvest in February/March. Rice is directly sown at 200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during growing season. Amount of fertilizer: 250kgUrea and 100kgDAP and 40 kg16-16-8 per ha per crop. Expected yield: 3.5 to 4.0 tons/ha.

6.2.4 If present:

(i) Having available water supply for irrigation during the dry season;

(ii) Beginning and end of inundation period are after August 15 and before January 15;

(iii) Depth of sulfuric horizon with high O.M. content between 50cm and more.

- Optimal land use type is: "***Single cropping of Yam/Cassava.***"

- This land use type requires the following land and water management practices: (i) construction of raised beds: Raised beds are constructed in dry season, top soil without acidity is placed on the top of raised beds. Size of raised beds having a width of 2.5 to 3.0m, height of 0.4-0.5m and length of 10 to 20m; (ii) the ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season; and (iii) mulching with grasses or straw after planting.
- Agronomic practices and expected yields are as follows:

  + *Yam cropping*: The growing period starts from November/December when water is receding to the harvest in May/June before the water level reaches the surface of the raised beds. Planting density is 15.000-18.000 sets/ha. The fertilizers are applied for 30% in 20 days after planting and for 70% during the rest of the growing season. Amount of fertilizer is 80kgN + 160kgP2O5 + 100kgK2O per ha per crop. Expected yield: 15 to 20 tons/ha for purple varieties.

  + *Cassava cropping*: The growing period starts from November/ December when water is receding and harvest in May/June before the water level reaches the surface of the raised beds. Planting density of Cassava is 30.000 cutting/ha. The fertilizers are applied 20 day after planting. Amount of fertilizer is 125 kg Urea + 60 kg DAP + 60 kg KCl per ha per crop. Expected yield: 25-30 tons/ha.

6.2.5 If present:

(i) Depth of sulfuric horizon occurs within 50cm from soil surface;
(ii) Deep flooding during inundation period (deeper than 100cm);
(iii) No available canal systems for irrigation.

- Optimal land use type: ***"Planted Melaleuca."***

- This land use type requires the following land and water management practices: (i) excavation of canals among *Melaleuca* forest in order to protect against fire in the dry season; (ii) re-forestation after harvesting *Melaleuca* for timber or for oil extraction.

**** Soil and water management conditions for land improvement in this area:***

- **If:** (i) Construction of raised beds as described in section 6.2.4.
  (ii) Ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season.
  (iii) Mulching with grasses or straw after planting in order to reduce the evaporation in the early stage of crop growth.
  (iv) Store fresh water in the ditches and surrounding canals or construct the canal in order to convey fresh water from main canals into the ditches.
- Optimal land use types: ***Yam/ Cassava***
- Agronomic practices of Yam and Cassava as described above.

If: (i) Construction of the canals and infrastructure for irrigation;
(ii) Construction of shallow drainage systems;
(iii) Sluice gates and field bunds(or small dike) for water control;
(iv) Field leveling and zero tillage practice;

- Optimal land use types: Just recently reclaimed:

" Single cropping of irrigated Winter-Spring High Yielding rice."

- After 3 - 4 years of reclamation:

" Double irrigated modern rice crops: Summer-Autumn +Winter-Spring".

- Agronomic practices and expected yields: The land use types presented here mostly have a same agronomic practices as the land use types that were described above. But the expected yields of these land use types only are of 40 - 80% of highest expected yields when all conditions of soil and water management practices as mentioned above are met. Because, land still remain the limitations that in aggregate are moderately severe for sustained application of the defined use.

The summary of optimal management packages on acid sulphate soils in area No.2 Tri Ton is shown in table 6.2.

Table 6.2: *Optimal farm management packages based on farmer/expert knowledge and field experiments in the area 2 - Tri Ton. The present situation is defined in terms of a series of land characteristics not land qualities, which is done for operational reasons. The corresponding land qualities were earlier defined in table 4.2 to express expert knowledge.*

Situation	Land use types	Agronomic practices and expected yields	Land and Water management practices
6.2.1. If present: - Having available water supply; - Length of inundation period: < 5 months; - Depth of sulfuric horizon : 50-100cm and >100 cm.	***Double irrigated modern rice crops: Summer-Autumn + Winter-Spring.***	- **First crop: SA.HY rice** + Growing period: March to June/July. + Seeds: directly sown at 200kg/ha. + Fertilizers: (250kgUrea + 100kgDAP + 10016-16-8)/ha; + Expected yield: 4 tons/ha. - **Second crop: WS.HY.rice** + Growing period: Nov. to January/Feb. + Seeds: directly sown at 200kg/ha. + Fertilizers:100N+ 90P2O5 + 30K2O/ha; + Expected yield: 5.0 - 5.8 tons/ha.	- Construction of canals and infrastructure for irrigation; - Construction of shallow drainage systems; - Sluice gates and field bunds(or small dike) for water control; - Field levelling; - Minimum/Zero tillage practice.
6.2.2. If present: - Available water supply; - Depth of sulfuric horizon : >100 cm	***Double cropping of floating rice followed by Maize/ Sesame/ Mungbean***	- **First crop: Floating rice** + Growing period: June/July to December. + Seeds: directly sown at 120-150kg/ha. + Expected yield: 1.5 to 2.0 tons/ha. - **Second crop: Maize /Sesame /Munbean /Water Melon** + Growing period: Dec. to Feb./March. + Seeds:directly sown : Sesame:10-12kg/ha Water melon: 1000-1200 plants/ha; Maize: 30-35kg/ha; Mungbean: 35-40kg/ha. + Fertilizers: (1/2 Urea+1/2DAP): Sesame: 240kg/ha; Water melon: 800kg/ha; Maize: 240kg/ha; Mungbean: 160kg/ha.	- Construction of canal systems for supplementary irrigation during dry season; - Mulching with grasses or straw for upland crops after planting.

		+ Expected yield: Sesame: 0.55 tons/ha; Maize: 3.0tons/ha; Water melon: 24 tons/ha; Mungbean: 0.9 tons/ha.	
6.2.3.If present: - Having available water supply; - End of inundation period is before December 15; - Depth of sulfuric horizon: 50-100cm and more.	***Single irrigated modern rice crop: Winter-Spring.***	+Growing period: Nov/Dec. to Feb./March. + Seeds: directly sown at 200kg/ha. + Fertilizers: (250kg Urea + 100kg DAP + 40kg16-16-8)/ha; + Expected yields: 3.5-4.0 tons/ha.	- Construction of shallow drainage systems; - Sluice gates and field bunds for water control; - Proper field levelling.
6.2.4.If present: - Having available water; - Beginning and end of inundation period: after 15/8 and before 15/1; - Depth of sulfuric horizon:with high O.M. between 50cm or more.	***Single cropping of yam/cassava.***	- **<u>Crop: Yam</u>** + Growing period: Nov./Dec. to May/June + Planting density: 40 cm x 50 cm. + Fertilizers: (80kgN + 160kgP2O5 + 100kgK2O)/ha; + Expected yield: 15 to 20 tons/ha. - **<u>Crop: Single cropping of cassava</u>** + Growing period: Nov./Dec. to May/June +Planted density: 30.000-32.000 cutting/ha + Fertilizers: 125kgUrea + 60kgDAP + 60kgKCl/ha + Expected yield: 25-30 tons/ha.	- Containing water in canals and ditches for supplementary irrigation during dry period. - Construction of raised beds: Raised beds are constructed in dry season, top soil without acidity is placed on the top of raised beds. Size of raised beds having a width of 2.5 to 3.0m, height of 0.4 to 0.5m and length of 10 to 20m. - Ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season. - Mulching with grasses or straw after planting.
6.2.5.If present: - Depth of sulfuric horizon within 50cm from soil surface. - Deep flooding during inundation period. - No available canal systems for irrigation. Remote area from main canal.	***Planted Melaleuca***	- *Melaleuca* is transplanted at 40,000-50,000trees/ha. After three years, the Melaleuca forest can be thinned to have more space and to remove poorly or irregularly growing trees for fire wood usage. The sixth year, *Melaleuca* will be cut for fire wood or construction wood: 30,000 trees/ha/6 years.	- Excavation of canals among *Melaleuca* forest in order to protect against fire in the dry season. - Re-forestation after harvesting *Melaleuca* for timber or firewood.

6.3 Area No. 3: Phung Hiep

6.3.1 If present:

(i) High and low tide in relation to and soil surface are above and below, respectively;

(ii) Having available water supply with canals and infrastructure for irrigation;

(iii) Maximum inundation depth is less than 30cm or at 30-60cm;

(iv) Depth of sulfidic layer and sulfuric horizon are deeper than 100 cm and deeper than 150 cm, respectively.

- Optimal land use type:

"***Double irrigated SA.HY rice followed by traditional rice (or irrigated Winter-Spring High Yielding rice) combined with prawn cultivation.***"

- This land use type requires the following land and water management practices: (i) construction of ditch systems for combination of growing shrimp in ditches surrounding rice fields and rice on the same field at the same time; (ii) building sluice gates and field bunds (or small dikes) for water control during the growing season; (iii) field leveling for modern rice cultivation in order to control water in the field.

- Agronomic practices and expected yields are as follows:

+ *Summer-Autumn HY rice crop*: The growing period starts from March/April after harvesting of Winter-Spring crop (if double HY rice) to the harvest in July/August. Rice is directly sown at 250-280kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during growing season. Amount of fertilizer is 200kgUrea + 150kgDAP + 80 kg16-16-8 per ha per crop. Expected yield: 5.0-5.5 tons/ha.

- *Winter-Spring HY rice crop*: The growing period starts from November when water is receding to the harvest in January/February. Rice is directly sown at 250-280kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during growing season. Amount of fertilizer is 100kgN + 90 kgP_2O_5 + 30 kgK_2O per ha per crop. Expected yield: 5.5 to 6.0 tons/ha.

+ *Traditional rice crop*: The growing period starts from June for seed beds to the harvest in January. Rice is transplanted at 80kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during growing season. Amount of fertilizer is 30kg Urea + 100kg DAP per ha per crop. Expected yield: 4.0 to 4.5 tons/ha.

+ *Prawn*: Prawn is grown in the ditches of rice field with a width of 2.5 m to 3.0 m and a depth of 1.0 m to 1.2 m. Density of prawn is 40kg - 50kg young prawn per ha. For feeding, the 200kg of rice bran and 10kg of industrial foods and 150kg of cassava are applied. Expected yield: 0.1-0.2 tons prawn per ha per year.

6.3.2 If present:

(i) Having available water supply with canals and infrastructure for irrigation;

(ii) Depth of sulfuric horizon between 50-100 cm and deeper than 100 cm.

- Optimal land use type:

" ***Double irrigated modern rice crops: Winter-Spring + Summer-Autumn***."

- This land use type requires the following land and water management practices as follows: (i) construction of shallow drainage systems to leach the acidity out in the beginning of rainy season; (ii) to build the sluice gates and field bunds (or small dikes) for water control during the growing season; (iii) field leveling for modern rice cultivation in order to control water in the field.

- Agronomic practices and expected yields are as follows:

+ *Winter-Spring HY rice crop*: The growing period starts from November/December to the harvest in February. Rice is directly sown at 200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 100 kgN + 60 kgP_2O_5 + 30 kgK_2O per ha per crop. Expected yield: 5.0 to 6.5 tons/ha.

+ *Summer-Autumn HY rice crop*: The growing period starts from March/April after harvesting of Winter-Spring crop to the harvest in July. Rice is directly sown at 200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 150 kgUrea + 100 kgDAP + 80 kg 16-16-8 per ha per crop. Expected yield: 4.0-5.0 tons/ha.

6.3.3 If present:

(i) Having available water supply with canals and infrastructure for irrigation;

(ii) Maximum inundation depth is less than 30 or 30-60;

(iii) Depth of sulfuric horizon between 50-100 cm and deeper than 100 cm.

- Optimal land use type:

" ***Double cropping of irrigated Summer-Autumn High Yielding rice followed by traditional rice.***"

- This land use type requires the following land and water management practices: (i) construction of shallow drainage systems to leach the acidity out in the beginning of rainy season; (ii) building sluice gates and field bunds (or small dikes) for water control during the growing season; (iii) field leveling for modern rice cultivation in order to control water in the field.
- Agronomic practices and expected yields are as follows:

+ *Summer-Autumn HY rice crop*: The growing period starts from March/April to the harvest in July. Rice is directly sown at 200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 150 kgUrea + 100 kgDAP + 80 kg 16-16-8 per ha per crop. Expected yield: 4.0-5.0 tons/ha.

+ *Traditional rice crop*: The growing period starts from July/August after harvesting first crop to the harvest in January. Rice crop is transplanted at 80kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 30 kgUrea + 50 kgDAP per ha per crop. Expected yield: 3.5 to 4.0 tons/ha.

6.3.4 If present:

(i) Maximum inundation depth is less than 30 or 30-60cm;

(ii) Length of rainfed period is more than 6 months;

(iii) Depth of sulfuric horizon at 100 cm and deeper than 100 cm;

(iv) No rainy season drought.

- Optimal land use type:

" ***Double cropping of rainfed Summer-Autumn High Yielding rice followed by traditional rice.***"

- This land use type requires the following land and water management practices: (i) construction of shallow drainage systems to leach the acidity out in the beginning of rainy season; (ii) building field bunds for water control during the growing season; (iii) field leveling for modern rice cultivation in order to control water in the field.
- Agronomic practices and expected yields are as follows:
    + *Summer-Autumn HY rice crop*: The growing period starts from May/June to the harvest in August. Rice is directly sown at 200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 80 kgUrea + 150 kgDAP per ha per crop. Expected yield: 4.0-5.0 tons/ha.
    + *Traditional rice crop*: The growing period starts from August after harvesting first crop to the harvest in January. Rice crop is transplanted at 80kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during growing season. Amount of fertilizer is 30 kgUrea + 50 kgDAP per ha per crop. Expected yield: 3.0 to 4.0 tons/ha.

6.3.5 If present:

(i) Maximum inundation depth is less than 30 or 30-60 cm;
(ii) Having available water supply for irrigation during dry season;
(iii) Depth of sulfuric horizon at 100 cm or more.

- Optimal land use type:

" ***Ginger intercropped with mungbean and traditional rice.*** "

- This land use type requires the following land and water management practices: (i) construction of raised beds: Raised beds are constructed in dry season, top soil without acidity is placed on the top of raised beds. Size of raised beds having a width of 4.0 to 6.0m, height of 0.6 to 0.7m and length of 50 to 250m; (ii) the ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season.
- Agronomic practices and expected yields are as follows: Ginger is grown on permanent raised beds and mungbean is grown between rows of ginger. Rice is transplanted in the shallow ditches between the raised beds during the rainy

season. Nursery beds of rice are prepared at other places before transplanting.

+ *Ginger crop*: The growing period starts from March to the harvest in next January. Planting density is 1,200kg/ha. The fertilizers are applied 3 times at the same time with hilling up periods during the growing season. Amount of fertilizer is 50 kgN + 50 kgP2O5 per ha per crop. Expected yield: 15 tons/ha.

+ *Mungbean crop*: The growing period starts from March to the harvest in early June. Mungbean is planted at a 35cm space on the row between ginger rows. The fertilizers are applied 2 times after planting. Amount of fertilizer is 20kg Urea + 10 kg KCl per ha per crop. Expected yield: 0.3 tons/ha.

+ *Traditional rice crop*: The growing period starts from August after harvesting first crop to the harvest in January. Rice is transplanted at a 40cm x 40cm spacing. The fertilizers are applied in early period of growing season. Amount of fertilizer is 20kg Urea + 20 kgDAP per ha per crop. Expected yield: 2.0 to 2.5 tons/ha.

6.3.6 If present:

(i) Maximum inundation depth is less than 30 or 30-60cm;

(ii) Having available water supply for irrigation during dry season;

(iii) Depth of sulfuric horizon between 50-100 cm or more.

- Optimal land use type: - "***Ratoon cropping of sugarcane.***
  - Ratoon cropping of pineapple."

- These land use types require the following land and water management practices: (i) construction of raised beds: Raised beds are constructed in dry season, top soil without acidity is placed on the top of raised beds. Size of raised beds having a width of 4.0 to 6.0m, height of 0.5 to 0.6m and length of 50 to 250m.; (ii) the ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season.

- Agronomic practices and expected yields are as follows:

+ *Sugarcane cropping*: Sugarcane is planted in the raised beds and surrounding by strong dike in order to protect against flood during the inundation period. Ratoon of sugarcane is 3 to 4 years. Sugarcane is planted from December/February up to October/January for first crop and continued for 3 to 4 years. Planting density is 80,000plants/ha. Amount of fertilizer is 250 kgN + 25 kgP_2O_5 per ha per year. Expected yields: first crop: 60-80 tons/ha and 80-100 tons/ha for ratoon crop.

+ *Pineapple cropping*: Pineapple is planted in the raised beds. Ratoon of pineapple is 3 to 4 years. Pineapple is planted from May up to after 18 months for first crop and continued for 3 to 4 years. Planting density is 50,000 plants/ha for Queen variety and 44,000 plants/ha for Smooth Cayenne variety. Amount of fertilizer is 400 kgN + 250 kg P_2O_5 and 400 kg K_2O per ha per year. Expected yields: first crop: 30-50 tons/ha and 40-60 tons/ha for ratoon crop.

6.3.7 If present:

(i) Maximum inundation depth is less than 60cm or 60-80cm.

(ii) Having available water supply for irrigation during the dry season;

(iii) Depth of sulfuric horizon occurs at 50 cm or more.

- Optimal land use type: ***"Sugarcane followed by traditional rice."***

- This land use type requires the following land and water management practices: (i) construction of raised beds: Raised beds are constructed in dry season, top soil without acidity is placed on the top of raised beds. Size of raised beds having a width of 4.0 to 6.0m, height of 0.2 to 0.3m and length of 100 to 200m.; (ii) the ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season.

- Agronomic practices and expected yields are as follows: Sugarcane is planted on low raised beds during the dry season and early rainy season when the water does not yet floods the raised beds and transplanting traditional rice during the rainy season when the beds are flooded.

+ *Sugarcane cropping*: Sugarcane is planted from January/February up to August /September. Planting density is 40,000-60,000plants/ha. Amount of fertilizer is 400 - 500 kgDAP and Urea per ha per year and applied 3 times at the same time with hilling up periods. Expected yield: 60-80 tons/ha.

+ *Traditional rice crop*: The growing period starts from August/September after harvesting sugarcane crop to the harvest in January/February. Rice is transplanted at a 40cm x 40cm spacing. The fertilizers are applied in the early period of the growing season. Amount of fertilizer is 30 kg Urea + 50 kgDAP per ha per crop. Expected yield: 2.5 to 3.0 tons/ha.

6.3.8 If present:

(i) Depth of sulfuric horizon within 50cm from soil surface;

(ii) Deep flooding during inundation period (deeper than 100cm);

(iii) No available canal systems for irrigation.

- Optimal land use type: ***"Planted Melaleuca."***

- This land use type requires the following land and water management practices: (i) excavation of canals among *Melaleuca* forest in order to protect against fire in the dry season; (ii) re-forestation after harvesting *Melaleuca* for timber or for oil extraction.

- Agronomic practices and expected yields are as follows:

+ *Melaleuca* is transplanted at 40,000-50,000trees/ha. After three years, the *Melaleuca* forest can be thinned to have more space and to remove poorly or irregularly growing trees for fire wood usage. At the sixth year, *Melaleuca* will be cut for fire wood or construction wood: 30,000 trees/ha/6 years.

**** Soil and water management conditions for land improvement for this area:***

If: (i) To construct the canals and infrastructure for irrigation;

(ii) Construction of shallow drainage systems;

(iii) Sluice gates and field bunds (or small dike) for water control;

(iv) Field leveling.

- Optimal land use types:

+ Just recently reclaimed:

" Single cropping of irrigated Winter-Spring HY rice."

+ After 3 - 4 years of reclamation:

" Double irrigated modern rice crops: Summer-Autumn + Winter-Spring."

If: (i) Construction of high raised beds: Raised beds are constructed in dry season, top of the surface soil without acidity is placed on the top of raised beds and that the material from the acid soil horizon is placed at the bottom in the raised beds. Size of raised beds having a width of 4.0 to

6.0m, height of 0.2 to 0.4m and length of 100 to 200m.

(ii) Ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season.

(iii) Store fresh water in the ditches and surrounding canals or construct the canal in order to convey fresh water from main canals into the ditches.

- Optimal land use types: - ***Pineapple or Sugarcane***
- Agronomic practices and expected yields: The land use types presented here mostly have a same agronomic practices as the land use types that were described above. But the expected yields of these land use types only are of 60% - 80% of highest expected yields when all conditions of soil and water management practices as mentioned above are met. Because, land still remain the limitations that in aggregate are moderately severe for sustained application of the defined use.

The summary of optimal management packages on acid sulphate soils in area No.3 Phung Hiep is shown in table 6.3.

6.4 Area No. 4: Hong Dan

6.4.1 If present:

(i) Maximum inundation depth is less than 30 or 30-60cm;

(ii) Length of rainfed period is more than 6 months and no rainy season drought;

(iii) Beginning and end of the salinity period: February and June;

(iv) Depth of sulfuric horizon between 50-100 cm and deeper than 100 cm.

- Optimal land use type:

"***Double rainfed modern rice crops: Summer-Autumn + Autumn-Winter***"

"***Double cropping of rainfed SA. HY. rice followed by traditional rice.***"

- These land use types require the following land and water management practices: (i) construction of dikes and dams or sluice gates to prevent salt water intrusion in the dry season; (ii) construction of shallow drainage systems to leach the acidity and salinity out in the beginning of rainy season; (iii) building the field bunds for keeping rainy water during the growing season; (iv) field leveling for modern rice cultivation in order to control water in the field.

Table 6.3: *Optimal farm management packages based on farmer/expert knowledge and field experiments in the area 3 - Phung Hiep area. The present situation is defined in terms of a series of land characteristics not land qualities, which is done for operational reasons. The corresponding land qualities were earlier defined in table 4.3 to express expert knowledge.*

Situation	Land use types	Agronomic practices and expected yields	Land and Water management practices
6.3.1. If present: - High and low tide in relation to soil surface: above and below - Having available water supply for irrigation; - Maximum inundation depth: < 30cm or at 30-60cm; - Depth of sulfuric horizon : >100 cm or 150cm;	***Double irrigated SA.HY rice followed by traditional rice (or irrigated WS.HY rice) combined with prawn cultivation***	- **First crop: SA.HY. rice** +Growingperiod:March./April -July/Aug. + Seeds: directly sown at 250 - 280kg/ha. + Fertilizers: (200kgUrea + 150kgDAP + 80kg16-16-8)/ha; + Expected yield: 5.0 to 5.5 tons/ha. - **Second crop: Traditional rice** + Growing period: August to January. + Seeds: transplanting at 80kg/ha. +Fertilizers:(30kgUrea+100kg D.A.P)/ha; + Expected yield: 4.0 - 4.5 tons/ha. - **Prawn:** June/July to February + Density: 40kg-50kg young prawn/ ha. + Feed: 200kg rice bran + 10kg industrial foods + 150kg cassava per ha. + Expected yield: 0.1 - 0.2 ton/ha/ year.	- Construction of canals and infrastructure for irrigation. - Construction of a ditch systems; - Sluice gates and field bunds for water control; - Field levelling. - Prawn is grown in the ditches of rice field with a width of 2.5 m to 3.0 m and a depth of 1.0 m to 1.2 m.
6.3.2. If present: - Having available water supply for irrigation; - Depth of sulfuric horizon : 50-100cm and >100 cm.	***Double irrigated modern rice crops: Summer-Autumn + Winter-Spring.***	- **First crop: SA.HY.rice** + Growing period: March/April - July. + Seeds: directly sown at 200kg/ha. + Fertilizers: (150kgUrea + 100kgDAP + 80kg16-16-8)/ha; + Expected yield: 4.0 - 5.0 tons/ha. - **Second crop: WS.HY. rice** + Growing period: Nov./Dec.- February. + Seeds: directly sown at 180 - 200kg/ha. + Fertilizers: (100N + 60P2O5)/ha; + Expected yield: 5.0 - 6.5 tons/ha.	- Construction of canals and infrastructure for irrigation; - Construction of shallow drainage systems; - Sluice gates and field bunds(or small dike) for water control; - Field levelling;
6.3.3. If present: - Having available water supply for irrigation; - Maximum inundation depth: < 30cm or at 30-60cm; - Depth of sulfuric horizon : 50-100cm and >100 cm;	***Double cropping of irrigated SA.HY rice followed by traditional rice.***	- **First crop: irrigated SA.HY. rice** + Growing period: March/April - July. + Seeds: directly sown at 180 - 200kg/ha. + Fertilizers: (150kgUrea + 100kgDAP +	- Construction of canals and infrastructure for irrigaton; - Construction of shallow drainage systems;

		80kg16-16-8)/ha; + Expected yield: 4 to 5.5 tons/ha. - **<u>Second crop: Traditional rice</u>** + Growing period: August to January. + Seeds: transplanting at 80kg/ha. +Fertilizers: (30kg Urea + 50kg DAP)/ha; + Expected yield: 3.5 - 4.0 tons/ha.	- Sluice gates and field bunds for water control; - Field levelling.
6.3.4. If present: - Maximum inundation depth: <30cm or at 30 - 60cm; - Length of rainfed period: > 6 months - Depth of sulfuric horizon: at 100 cm or > 100 cm; - No rainy season drought.	***Double cropping of rainfed SA.HY.rice followed by traditional rice.***	- **<u>First crop: Rainfed SA.HY.rice</u>** + Growing period: May to August. + Seeds: directly sown at 200 kg/ha. +Fertilizers: (80kgUrea + 150kgDAP)/ha; + Expected yield: 4.0 - 5.0 tons/ha. - **<u>Second crop: Traditional rice</u>** + Growing period: August to January. + Seeds: transplanting at 80 kg/ha. +Fertilizers: (30kgUrea + 50kg D.AP)/ha; + Expected yield: 3.0 - 4.0 tons/ha.	- Construction of shallow drainage systems, field levelling and field bunds.
6.3.5. If present: - Maximum inundation depth: < 60cm or at 60cm; - Having available water supply for irrigation during dry season; - Depth of sulfuric horizon: > 100 cm .	***Ginger intercropped with mungbean and traditional rice.***	- **<u>Crop: Ginger</u>** + Growing period: March to next January. + Seed: 1,200 kg ginger per ha. + Fertilizers: (50 kgN+ 50kg P_2O_5) /ha; + Expected yield: 15 tons ginger per ha. - **<u>Crop: Mungbean</u>** + Growing period: March to early June. + Planting density: planted at a 35cm space on the row between ginger rows. + Fertilizers: (20kg Urea + 10kgKCl)/ha. + Expected yield: 0.3 tons per ha. - **<u>Crop: Traditional rice</u>** + Growing period: August to January. + Seeds: transplanted at a 40cm x 40cm. +Fertilizers:(20kg Urea + 20kg D.AP)/ha; + Expected yield: 2.0 - 2.5 tons per ha.	- Construction of available canals. - Construction of raised beds: top soil without acidity is placed on the top of raised beds. Size of raised beds having a width of 4.0 to 6.0m, height of 0.6 to 0.7m and length of 50 to 250m. - Ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season. - Ginger is grown on permanent raised beds and mungbean is grown between rows of ginger. Rice is transplanted in the shallow ditches between the raised beds during the rainy season. Nursery beds of rice are prepared at other places.
6.3.6. If present: - Maximum inundation depth: < 30cm or at 30 - 60cm; - Having available water supply for irrigation; - Depth of sulfuric horizon: at 50 - 100cm or more.	- ***Ratoon cropping of sugarcane.***	- **<u>Crops: Surgarcane</u>**. + Growing period: Dec./Feb. to Oct./Jan. + Ratoon: 3 - 4 crops. + Planting density: 80,000 plants/ha.	- Construction of raised beds: Raised beds are constructed in dry season, top soil without acidity is placed on the top

	- Ratoon cropping of pineapple.	+ Fertilizers: (250 kgN + 25kgP_2O_5) /ha; + Expected yield: 60-80 tons raw cane/ha. - **<u>Crops: Pineapple</u>** + Growing period:May to after 18months. + Planting density: 50.000 plants/ha for Queen variety and 44,000 plants/ha for Smooth Cayenne variety. +Fertilizers:(400kgN+250kgP_2O_5+ 400kgK_2O)/ha. + Expected yield: 30 - 50 tons/ha fir first crop and 40-60 tons/ha for ratoon crop.	of raised beds. Size of raised beds having a width of 4.0 to 6.0m, height of 0.5 to 0.6m and length of 50 to 250m. - Ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season.
6.3.7. If present: - Maximum inundation depth: 60 - 80cm; - Having available water supply for irrigation; - Depth of sulfuric horizon: > 50cm ;	***Sugarcane followed by traditional rice.***	- **<u>Crops: Surgarcane</u>** + Growing period: Jan./Feb. to Aug./Sept. +Plantingdensity: 40,000-60,000p lants/ha. + Fertilizers: 400 -500 kgDAP - Urea/ha; + Expected yield: 60 - 80 tons/ha. - **<u>Second crop: Traditional rice</u>** + Growing period: August to January. + Seeds: transplanted at 40 x 40cm(50cm). + Fertilizers: (30kg Urea + 50kg D.AP)/ha; + Expected yield: 2.5 - 3.0 tons/ha.	- Construction of low raised beds: top soil without acidity is placed on the top of raised beds. Size of raised beds having a width of 4.0 to 6.0m, height of 0.2 to 0.3m and length of 100 to 200m. - Ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season - Sugarcane is planted on low raised beds during the dry season and early rainy season when the water does not yet floods the raised beds and transplanting traditional rice during the rainy season when the beds are flooded.
6.3.8. If present: - No available canal systems for irrigation. - Extremely acid sulphate soils: sulfuric horizon occurs with 50cm from soil surface.	***- Planted Melaleuca***	- Melaleuca is transplanted at 40,000-50,000trees/ha. After three years, the Melaleuca forest can be thinned to have more space and to remove poorly or irregularly growing trees for fire wood usage. The sixth year, Melaleuca will be cut for fire wood or construction wood: 30,000 trees/ha/6 years.	- Excavation of canals among Melaleuca forest in order to protect against fire in the dry season. - Re-forestation after harvesting Melaleuca for timber.

- Agronomic practices and expected yields are as follows:

  + *Summer-Autumn HY rice crop*: The growing period starts from May/June to the harvest in August. Rice is directly sown at 180-200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 200 kgUrea + 50 kgDAP /ha/crop. Expected yield: 4.0-5.0 tons/ha.

  + *Autumn-Winter HY. rice crop*: The growing period starts from September to the harvest in December. Rice is directly sown at 180-200kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 200 kgUrea + 50 kgDAP /ha/crop. Expected yield: 4.0-5.0 tons/ha.

  + *Traditional rice crop*: The growing period starts from August after harvesting first crop to the harvest in January. Rice is transplanted at 80kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 50kg Urea + 50 kgDAP /ha/crop. Expected yield: 3.0 to 4.0 tons/ha.

6.4.2 If present:

(i) Maximum inundation depth is less than 30 or 30-60 cm;

(ii) Length of rainfed period is 6-7 months;

(iii) Depth of sulfuric horizon between 50-100 cm or more.

- Optimal land use type: - "***Ratoon cropping of sugarcane.***
  - Ratoon cropping of pineapple."

- These land use types require the following land and water management practices: (i) construction of dikes and dam or sluice gates to prevent salt water intrusion in the dry season (ii) construction of raised beds: Raised beds are constructed in dry season, top soil without acidity is placed on the top of raised beds. Size of raised beds having a width of 4.0 to 6.0m, height of 0.4 to 0.5m and length of 50 to 250m.; (iii) the ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season.

- Agronomic practices and expected yields are as follows:

  + *Sugarcane cropping*: Sugarcane is planted in the raised beds. Ratoon of sugarcane is 3 to 4 years. Sugarcane is planted from May to after 9-10 months for first crop and continued for 3 to 4 years. Planting density is 80,000plants/ha. Amount of fertilizer is 200kgUrea + 100kgDAP/ha/ year Expected yields: first crop: 40-60 tons/ha and 60-80 tons/ha(ratoon crop).

+ *Pineapple cropping*: Pineapple is planted in the raised beds. Ratoon of pineapple is 3 to 4 years. Pineapple is planted from May up to after 18 months for first crop and continued for 3 to 4 years. Planting density is 50,000 plants/ha for Queen variety and 44,000 plants/ha for Smooth Cayenne variety. Amount of fertilizer is 300 kgN + 200 kg P_2O_5 + 300kg K_2O per ha per year. Expected yields: first crop: 30-50 tons/ha and 40-60 tons/ha for ratoon crop.

6.4.3 If present:

(i) High and low tide in relation to soil surface are above and below, respectively, during the dry season; with shrimp fries;

(ii) Beginning and end of salinity period: January and June;

(iii) Maximum inundation depth at 30-60cm;

(iv) Length of rainfed period : 6-7 months;

(iii) Depth of sulfuric horizon at more 50cm.

- Optimal land use type: ***- Rice - shrimp system.***

- Shrimp/crab culture.

- These land use types require the following land and water management practices: (i) construction of a polder, size not more than 10 ha; (ii) each polder has a network of canals and ditches to serve as drainage system during the rainy season and in the dry season as refuge shrimp fries; (iii) construction of a flapgate along the main water way. It lets brackish or saline water into the polder in order to keep the soil wet at all time to prevent oxidation of pyritic material, hence suppressing acidification of the soil (Xuan, 1984).

- Agronomic practices and expected yields are as follows: Rice varieties used in the rice/shrimp system are selected to mature before the onset of the salt water intrusion (Xuan, 1992).

+ *Shrimp (in rice-shrimp system):* The growing period is from December to May with natural shrimp fries: *Penaeus merguiensis*, *Penaeus indicus*, and *Penaeus monodon*. Expected yield is about 300 - 400kg/ha/year.

+ *Traditional rice crop*: The growing period with seedlings in late May to July and transplanting in July/August to the harvest in early December. Rice is transplanted at 80kg of rice seed per ha. The fertilizers are applied during seeding preparation. Amount of fertilizer is 30 kgUrea + 200 kgDAP for seedbeds. Expected yield: 2.5 to 3.0 tons/ha.

+ *Medium term variety rice crop*: The growing period starts in July to the harvest in the end of October. Rice crop is directly sown at 180kg of rice seed per ha. The fertilizers are applied for 25% during land preparation and for 75% during the growing season. Amount of fertilizer is 100 kgUrea + 50 kgDAP per ha. Expected yield: 3.0 to 4.0 tons/ha.

+ *Shrimp cropping*: The growing period is from early November to May with natural shrimp fries: *Penaeus merguiensis*, *Penaeus indicus*, and *Penaeus monodon*. Expected yield: 350 - 500kg/ha/year.

<u>6.4.4 If present</u>:

(i) Maximum inundation depth is less than 60cm;

(ii) Length of rainfed period is 6-7 months;

(iii) Depth of sulfuric horizon within 50cm.

- Optimal land use type: ***- Pineapple***

- Small stem bamboo.

- Planted Melaleuca

- These land use types require the following land and water management practices: (i) construction of high raised beds: Raised beds are constructed in dry season, with the surface soil without acidity on the top of the bed and that the materials from the acid soil horizon placed at the bottom of the beds. Size of the raised beds: 4.0 to 6.0m wide, 0.4 to 0.5 m high and 100 to 200 m long; (ii) the ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season; store fresh water in the ditches and surrounding canals or construct the canal in order to convey fresh water from main canals into the ditches.

- Agronomic practices and expected yields are as follows:

+ *Pineapple*: mostly has a same agronomic practices as the land use type that was described above (section 6.4.2). But the expected yields only are

Table 6.4: *Optimal farm management packages based on farmer/expert knowledge and field expeiments in the area 4 - Hong Dan. The present situation is defined in terms of a series of land characteristics not land qualities, which is done for operational reasons. The corresponding land qualities were earlier defined in table 4.4 to express expert knowledge.*

Situation	Land use types	Agronomic practices and expected yields	Land and Water management practices
6.4.1. If present: - Maximum inundation depth: at 30 cm or < 60 cm; - Lenght of rainfed period: > 6 months; - Beginning and end of the salinity period: Feb. - June; - Depth of sulfuric horizon : 50-100cm or >100 cm; - No rainy season drought spell.	***- Double rainfed modern rice crops: Summer-Autumn + Autumn-Winter.*** ***- Double rainfed Summer-Autumn modern rice followed by traditional rice.***	**- First crop: Rainfed SA. HY. rice** + Growing period:early May- mid August + Seeds: directly sown at 180 - 200kg/ha. + Fertilizers: (200kgUrea +50kgDAP)/ha; + Expected yield: 4.0 - 4.5 tons/ha. **- Second crop: Rainfed AW. HY. rice** + Growing period: Sept. to December. + Seeds: directly sown at 180 - 200kg/ha. + Fertilizers: 200kg Urea+ 50kgDAP/ha; + Expected yield: 4.0 - 5.0 tons/ha. - **Second crop: Rainfed traditional rice** + Growing period: August to January. + Seeds: transplanting at 80kg/ha. + Fertilizers: 50kg Urea + 50kg D.AP/ha; + Expected yield: 3.0 - 4.0 tons/ha.	- Construction of dikes and dam or sluice gates to prevent salt water intrusion in the dry season - Shallow drainage systems; - Field bunds for keeping rain water; - Levelled field.
6.4.2. If present: - Maximum inundation depth: < 30cm or at 30-60cm; - Length of rainfed period: 6-7 months; - Depth of sulfuric horizon: > 50cm.	***- Ratoon cropping of sugarcane.*** ***- Ratoon cropping of pineapple.***	- **Crops: Surgarcane.** +Growing period:May to February. + Ratoon: 3 - 4 crops. + Planting density: 80,000 plants/ha. + Fertilizers:200kg Urea+100kgDAP/ha; + Expected yield: 40-60 tons raw cane/ha. - **Crops: Pineapple** +Growing period: May to after 18 months +Planting density:40,000-50,000plants/ha + Fertilizers: (300kg N + 200kg P_2O_5 + 300kg K_2O)/ha + Expected yield: 15 - 20 tons/ha	- Construction of dikes and dam or sluice gates to prevent salt water intrusion in the dry season; - Construction of raised beds: top soil without acidity is placed on top of the beds. Size of the beds: width 4.0 to 6.0 m, height 0.4 to 0.5m and length 50 to 250m. - Ditches between raised beds should be connected to deeper canals for leaching out acidity and salt in the early rainy season.
6.4.3. If present: - High and low tide in relation to soil surface: above and below during the dry season;	***-Rice - shrimp system.***	- **Crop: shrimp** (in rice-shrimp system) + Growing period: from December- May. + Seeds: natural shrimp fries: *Penaeus merguiensis, Penaeus indicus*, and	- Construction of a polder, size not more than 10 ha. - Each polder has a network of canals and ditches to serve as drainage system

- Beginning and end of salinity: January and June; - Maximum inundation depth: 30 - 60 cm. - Length of rainfed period: 6-7 months; - Depth of sulfuric horizon: > 50 cm; - Tidal saline water rich in shrimp fries.	***- Shrimp/crab culture.***	*Penaeus monodon.* + Expected yield: 300 - 400kg/ha/year. **- <u>Second crop: Traditional rice</u>** + Growing period: late May to early Dec. + Seeds: 60 - 80kg/ha. + Fertilizers: 30kg Urea + 20kg D.AP/ha; + Expected yield: 2.5 - 3.0 tons/ha. **-<u>Second crop:medium term rice varieties</u>** + Growing period: July to end of October. + Seeds: directly sown at 180kg/ha. + Fertilizers: 100kgUrea + 50kgDAP/ha; + Expected yield: 3.0 - 4.0 tons/ha. **- <u>Single cropping of shrimp</u>** + Growing period: early November - May + Seeds: natural shrimp fries: <u>*Penaeus merguiensis*</u>, <u>*Penaeus indicus*</u>, and <u>*Penaeus monodon*</u>. + Expected yield: 350 - 500kg/ha/year.	during the rainy season and in the dry season as refuge shrimp fries. - Construction of a flapgate along the main water way. It lets brackish or saline water into the polder in order to keep the soil wet at all time to prevent oxidation of pyritic material, hence suppressing acidification of the soil (Xuan *et al.*, 1984).
6.4.4. If present: - No canal system for drainage in early rainy season. - Extremely acid sulphate soils: sulfuric horizon occurs with 50cm from soil surface.	***- Pineapple*** ***- Small stem bamboo.*** ***- Planted Melaleuca***	**- <u>Crops: Pineapple</u>** +Growing period: May to after 18 months +Plantingdensity:40,000-50,000 plants/ha + Fertilizers: 150kg Urea + 50kg DAP/ha + Expected yield: 15 - 20 tons/ha **- <u>Small stem bamboo:</u>** + Growing period: July to after 3 years. + Planting density: 2m x 2m spacing. + Fertilizers: (50kgUrea + 50kgDAP)/ha; + Expected yield: 2000 - 2500 bushes/ha. **- <u>Planted Melaleuca:</u>** - Melaleuca is transplanted at 40,000 - 50,000trees/ha. After three years, the Melaleuca forest can be thinned and to poor trees removed for fire wood usage. In the sixth year, Melaleuca can be cut for fire wood or construction wood: 30,000 trees/ha/6 years.	- Construction of high raised beds: top soil without acidity is placed on the top of the bed and that the materials from the acid soil horizon placed at the bottom of the beds. Size of the raised beds: 4.0 to 6.0m wide, 0.4 to 0.5 m high and 100 to 200 m long. - Ditches between raised beds should be connected with deeper canals for leaching out acidity in the early rainy season. - Store fresh water in the ditches and surrounding canals or construct the canal in order to convey fresh water from main canals into the ditches. - Excavation of canals in the Melaleuca forest in order to protect against fire in the dry season.

of 60 - 80% of highest expected yields when all conditions of soil and water management practices as mentioned above are met. Because, land still remain the limitations that in aggregate are moderately severe for sustained application of the defined use.

+ *Small stem bamboo cropping*: Bamboo is planted in July and harvest after 3 years. Planting density is 2m x 2m of spacing. The fertilizers applied in the early stage of growing season with amount of 50 kgUrea + 50 kgDAP per ha per year. Expected yield: 2000 - 2500 bushes/ha of raised bed.

+ *Planted Melaleuca:* Excavation of canals in the *Melaleuca* forest in order to protect against fire in the dry season. *Melaleuca* is transplanted at 40,000-50,000trees/ha. After three years, the *Melaleuca* forest can be thinned and to poor trees removed for fire wood usage. In the sixth year, *Melaleuca* can be cut for fire wood or construction wood: 30,000 trees/ha/6 years.

The summary of optimal management packages on acid sulphate soils in area No.4 Hong Dan is shown in table 6.4.

Chapter 7

General conclusions

1. Acid sulphate soils are very unfavourable for farming. Farmers in the Mekong Delta, Viet Nam have developed various practices to overcome the constraints of their lands and these practices vary in different areas in the Delta. The history of farmers' land use and soil-water-crop management practices indicated changes of land use systems over time in the different study areas. Interaction between farmers and experts resulted in the development of innovative management systems. Double modern rice cropping, yam, prawn-rice system, ginger intercropped with others, are common in the fresh water areas. Shrimp-rice and pineapple have received more attention in areas with dry season salinity. The most important requirements for water and management practices when developing these land use systems were: (i) construction of canals and infrastructure for irrigation, (ii) construction of high raised beds for cultivation of upland crops and (iii) construction of a ditch system for the prawn/shrimp-rice systems.

2. Available knowledge on acid sulphate soils from farmers and experts may be used to identify proper land characteristics representing crucial land qualities which can define land use requirements. In this study, sixteen promising land use types are defined based on present land use systems of four study areas. Double cropping of modern rice varieties are present in all areas. Eight land qualities were identified in four study areas. Land quality of "(potential) soil acidity" is important for all land use types selected. Land qualities: "flood hazard", "drought hazard", "salt water intrusion", and "fresh water availability" are important for double cropping of modern rice varieties. Land qualities: "potential for daily tidal flooding and drainage" are critical for raising of prawn/shrimp..

3. Farmers' question are quite different from those of regional planners who are well served by the traditional land evaluation procedure. Using decision trees as a decision support system for land evaluation at farm level was shown to be helpful to identify optimal management decisions. Decision trees also indicate possibilities to improve suitability.

4. Field experimentation based on identified gaps in expert knowledge showed that: (1) For yam cultivation in acid sulphate soil areas with a high flooding depth in the wet season, application of a mulch layer on top of the raised bed resulted in

a 46% higher yield of yam as compared with unmulched plots; (2) use of fresh water in an irrigation frequency of 20 days, when available during the dry period of the cropping season, increased yields of yam by 31%. (3) Rolled-carpet raised beds gave higher yields as compared with mixed-raised beds. (4) A relatively high yield of yam can be obtained by application of N_{120}-P_{60}-K_{60} as is already being practised by farmers in the area or N_{80}-P_{160}-K_{100}. Staking yam vines is of limited importance and does not increase yam production. A planting density of 40 cm x 50 cm is proposed for yam cultivation. (5) For pineapple cultivation in areas with dry season salinity, supplementary irrigation in the early dry season had no effect on pineapple yield. (6) Production was higher on high raised beds as compared with traditional low-raised beds because of flooding of the latter in the rainy season. Old raised beds gave significantly higher yields as compared with younger raised beds because of lower acidity due to longer leaching by rain. (7) A yield increase of pineapple of about 20% can be obtained by a combination of high P and K fertilization (10N-7g P_2O_5 -10K_2O/plant). And (8) application of the zero-tillage technique was profitable as it shortened the duration of double cropping of Winter-Spring modern rice followed by Summer-Autumn rice in the areas with long duration flooding.

5. Formulation of optimal management packages can play a key role for defining new practices and for developing land use systems on acid sulphate soils. In the Mekong Delta, Viet Nam, there are many options to select suitable land use types including cultural practices and proper soil-water management for different physical conditions. Double modern rice cropping, yam, pineapple, and sugarcane, are commonly recommended for fresh water areas. In the areas with salt water intrusion by daily tide during the dry season, land use types including raising of shrimp are more profitable. *Melaleuca spp.* is mostly recommended for remote acid sulphate soil areas as a means for reforestation in order to protect natural environments.

6. Characterization of the process of interaction between farmers and experts in developing innovative soil and water management schemes and formulation of optimal management packages on acid sulphate soils provides a good start to obtain description of realistic and acceptable systems. These description can also be used to identify areas of additional research by measurement or by simulation

modelling. By linking such systems to georeferenced locations with well defined agro-ecological properties, extrapolation of results obtained to other areas in the Delta, with similar characteristics, is made possible.

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SUMMARY

Le Quang Tri, 1996. Developing management packages for acid sulphate soils based on farmers and expert knowledge. Field study in the Mekong Delta, Viet Nam. Doctoral thesis. Wageningen Agricultural University, Wageningen, The Netherlands, 200pp.

Effective interaction of farmers' expertise and expert knowledge has been a special point of attention for this study. The objectives of the study were to describe the process of interaction between farmers and experts in improving the use of acid sulphate soils and to point out difficulties encountered. Actual conditions for four major areas were described including variabilities. Four representative areas: Tan Thanh, Tri Ton, Phung Hiep, and Hong Dan in the Mekong Delta, Viet Nam were selected for this study. Physical conditions were defined in terms of soil properties, as reflected by soil classification, and hydrological conditions were defined by climate data including flooding. Methods for land improvement in different areas were first defined by describing and analyzing measures taken by farmers, and by next developing schemes for improvement, using expert knowledge. These schemes were expressed by decision trees as a part of expert systems. But many questions were left and a series of experiments was designed and executed to answer those questions that could not be answered by experts.

Four study areas were selected. Tan Thanh and Tri Ton (in the Plain of Reeds and Long Xuyen Quadrangle, respectively) have acid sulphate soils with sulphuric horizons within 50 cm from the soil surface, and deep flooding (>100cm) during the rainy season. The Phung Hiep area with moderately acid sulphate soils is not deeply flooded and is located in the fresh water area of Ca Mau peninsula. The Hong Dan area contains mainly moderately and strongly acid sulphate soils with salt water intrusion during the dry season. The main agricultural problems in these study areas, where most farmers are poor, arise from the fact that most modern practices or new cropping patterns are applied incompletely and at unequal levels. Also unfavourable soil acidity coincides with

high flooding depth or salt water intrusion, poor infrastructure for irrigation and drainage and shortage of capital for farm production. Furthermore, price fluctuations of farm products are very high, which makes economic production very difficult.

A study at farmers' level shows that the history of farmers' land use, including their soil-water-crop management practices clearly indicates changes of land use over time and the important role of expert knowledge in initiating these changes. Developments also illustrate the positive effects of the creative interaction between farmers and experts in developing innovative management systems. Ten, four, sixteen and eleven actual land use types, including land and water practices, were described for the Tan Thanh, Tri Ton, Phung Hiep, and Hong Dan areas, respectively. Water-soil-crop management practices such as construction of canals and infrastructure for irrigation, construction of high raised beds for cultivation of upland crops, and construction of a ditch system for the prawn/shrimp-rice system were essential parts of these land use systems.

Studies by experts paid more attention to the cultivation of crops, mainly rice, and the associated water management practices. Sixteen promising land use types were defined for a land suitability classification study based on present land use systems of four study areas. Double cropping of modern rice varieties is present in all study areas. Eight land qualities were identified for a farm-level land evaluation. Land quality "(potential) soil acidity" is important for all land use types selected. Land qualities: "flood hazard", "drought hazard", "salt water intrusion", and "fresh water availability" are important for double cropping of modern rice varieties. Land qualities: "potential for daily tidal flooding and drainage" are critical for raising of prawn/shrimp. For land evaluation at farm level, decision trees were developed and used as an decision support system. Decision trees were made for each promising land use type. Using decision trees as a decision support system for land evaluation study at the farm level was shown to be helpful to identify optimal management decisions. Conditions for improvement of suitability were identified and visualized in those decision trees, in terms of improved soil and water practices based on farmers' expertise and expert knowledge.

While developing these schemes, it became clear that many unanswered questions on land use requirements and water management practices were encountered. These were formulated and field experiments were carried out to answer the questions. Some conclusions were drawn from these experiments: (1) For yam cultivation in acid sulphate soil areas with a deep flood in the wet season, application of a mulch layer on top of the raised bed resulted in a 46% higher yield as compared with unmulched plots; (2) the use of fresh water in an irrigation frequency of 20 days, when available during the dry period of the cropping season, increased yields of yam by 31%. (3) Rolled-carpet raised beds gave higher yields as compared with mixed-raised beds. (4) A relatively high yield of yam can be obtained by application of N_{120}-P_{60}-K_{60} as is already being practised by farmers in the area or N_{80}-P_{160}-K_{100}. Higher fertilizer applications give no better yields. Staking yam vines is of limited importance and does not increase yam production. A planting density of 40 cm x 50 cm is proposed for yam cultivation. (5) For pineapple cultivation in areas with dry season salinity, supplementary irrigation in the early dry season had no effect on pineapple yield. (6) Production was higher on high raised beds as compared with traditional low-raised beds because excess water in the rainy season. Old raised beds gave significantly higher yields as compared with younger raised beds because of lower acidity due to longer leaching by rain. (7) A yield increase of pineapple of about 20% can be obtained by a combination of high P and K fertilization (10N-7g P_2O_5 -10K_2O/plant). And (8) application of the zero-tillage technique was profitable as it shortened the duration of double cropping of Winter-Spring modern rice followed by Summer-Autumn rice in areas with long duration flooding. These accumulated results provided quantitative data to characterize land qualities and land use requirements relating to fresh water availability, soil acidity, and flooding hazard . Also data for agronomic practices were obtained by experiments to be used for formulating optimal management packages.

Under different physical conditions, optimal management packages on acid sulphate soils were finally formulated for the four study areas in. These optimal management packages were based on the farmers' practice, expert knowledge, results of land evaluation study at farm level and accumulated results obtained by field experiments. There are many options including various cultural, soil and water management practices for the different physical conditions encountered. Double modern rice cropping, and growing yam, pineapple, and sugarcane, are suitable in areas where fresh water is available during the dry season. In areas with salt water intrusion during the dry season, land use types incorporating shrimp are more profitable. Melaleuca spp. is most suitable for remote and unfavourable areas for crop growth as a means for reforestation in order to protect natural environments. These results provides a good start to obtain description of realistic and acceptable systems. In the future, these description can also be used to identify areas of additional research by measurement or by simulation modelling.

SAMENVATTING

(Summary in Dutch)

Le Quang Tri, 1996. Developing management packages for acid sulphate soils based on farmers and expert knowledge. Field study in the Mekong Delta., Viet Nam. Proefschrift. Landbouwuniversiteit, Wageningen, Nederland, 200pp.

Effectieve interactie tussen boeren en experts heeft speciale aandacht gekregen in deze studie. Het doel van de studie was deze interactie met de daarbij behorende problemen te beschrijven, waarbij alle werkzaamheden waren gericht op het verbeteren van het gebruik van kattekleigronden. De bestaande condities in vier proefgebieden zijn beschreven, inclusief de optredende variabiliteit. Deze gebieden waren: Tan Thanh, Tri Ton, Phung Hiep and Dong Dan in de Mekong Delta. Fysische condities werden beschreven in termen van bodemeigenschappen zoals weergegeven met behulp van bodemclassificatie en de hydrologische condities werden gedefinieerd met behulp van klimaatsgegevens met inbegrip van de overstromingsfrequentie. Methoden voor het verbeteren van het land werden in eerste instantie beschreven door het analyseren van door boeren getroffen maatregelen. Vervolgens werden schema's ontwikkeld met behulp van expert kennis om tot verdergaande verbeteringen te komen. Daarbij is gebruik gemaakt van besluitbomen zoals die in expert systemen worden toegepast. Er bleven echter nog veel vragen over en er is daarom een serie veldexperimenten opgezet om deze vragen, die niet op basis van bestaande kennis konden worden beantwoord, alsnog op te lossen.

De studiegebieden Tan Thanh en Tri Ton (in de Plain of Reeds en Long Xuyen Quadrangle, respectievelijk) hebben kattekleigronden met een sulphuric horizon binnen 50 cm beneden maaiveld en een meer dan 100 cm diepe overstroming gedurende het regenseizoen. Het Phung Hiep gebied met matig zure kattekleigronden wordt minder diep overstroomd en ligt in het gebied met zoet water van het Ca Mau schiereiland. Het Dong Han gebied bevat hoofdzakelijk matig en sterk ontwikkelde kattekleigronden met zout water intrusie gedurende de droge tijd. De belangrijkste landbouwkundige problemen in deze studiegebieden, waar de meeste boeren erg arm zijn, vloeien voort uit het feit dat moderne teeltmaatregelen onvolledig en onjuist worden toegepast. Een hoge zuurgraad van de gronden valt samen met langdurige en diepe overstromingen of met intrusie van zeewater, terwijl er tevens een slechte infrastructuur bestaat voor irrigatie en drainage. Er is een chronisch gebrek aan kapitaal. Daarnaast zijn prijsfluctuaties voor landbouwkundige producten zeer groot, wat het moeilijk maakt om economisch te produceren.

Een studie op boerenniveau toonde aan dat er al veel veranderingen zijn opgetreden in de wijze van landgebruik en dat daarbij expert kennis een belangrijke rol heeft gespeeld.Tien, vier, zestien en elf bestaande landgebruikstypen zijn beschreven voor respectievelijk de Tan Thanh, Tri Ton, Phung Hiep en de Hong Dan deelgebieden. In deze landgebruikstypen speelden de constructie van kanalen,een infrastructuur voor irrigatie, constructie van "raised beds" voor het telen van gewassen en kanalen voor de garnalenteelt, een belangrijke rol.

Door experts werd in het verleden speciale aandacht geschonken aan de teelt van gewassen op de hoger gelegen gronden met name rijst en de daarbij behorende waterbeheersmaatregelen. Deze kennis kon nu worden toegepast voor gronden in de Delta. Zestien veelbelovende landgebruikstypen werden gedefinieerd voor een algemene geschiktheidsclassificatie, die werd gebaseerd op de huidige landgebruikssystemen. In alle gebieden is sprake van de teelt van twee rijstgewassen, gebruikmakend van moderne varieteiten. Acht landkwaliteiten werden onderscheiden voor een land evaluatie op bedrijfsniveau. De landkwaliteit: (potentiele)zuurgraad is belangrijk voor alle geselecteerde landgebruikstypen. De landkwaliteiten "overstromingsrisico" , "droogte risico", "zout water intrusie" en "beschikbaarheid van zoet water" zijn alle belangrijk voor het telen van twee rijstgewassen. De landkwaliteiten: "potentieel voor dagelijkse getijdenbeweging en drainage" zijn kritiek voor het telen van garnalen. Beslisbomen werden ontwikkeld in het kader van een expert systeem, en deze werden gebruikt om zo goed mogelijke besluiten te kunnen nemen over de beste vorm van bodem- en waterbeheer onder de verschillende omstandigheden die in deze studie zijn onderzocht.

Naarmate deze beslisbomen werden ontwikkeld, werd het steeds duidelijker dat er nog veel onbeantwoorde vragen waren op het gebied van landgebruikseisen en bodem- en waterbeheer. Een aantal veldexperimenten werd daarom opgezet om deze vragen te beantwoorden. De volgende resultaten werden geboekt: (1) Bij het verbouwen van yam in kattekleigronden met een diepe overstroming, leidde het aanbrengen van een mulchlaag bovenop het "raised bed" tot een opbrengstverhoging van 46%. (2) Gebruik van zoet water in een irrigatiefrequentie van 20 dagen leidde (als het water beschikbaar was) tot een opbrengstverhoging van 20%. (3) "raised beds" waarbij de bovengrond zorgvuldig apart wordt gezet bij de constructie en vervolgens weer bovenop het bed wordt aangebracht, hadden hogere opbrengsten dan "raised beds" waarbij zure klei werd gemengd met bovengrond. (4) De relatief hoogste opbrengst van yam werd bereikt met een bemesting van N_{120}, P_{60} en K_{60} kg/ha of N_{80}, P_{160} en K_{100} kg/ha . Hogere bemestingsgiften leverden geen hogere opbrengsten. Het opbinden van de yam plant had geen effect, terwijl een plantdichtheid van 40cmx50cm de beste resultaten leverde. (5) De teelt van ananas in gebieden met zoutproblemen in de droge tijd, werd niet verbeterd door irrigatie in het begin van het droge seizoen. (6) De productie was hoger op de hogere "raised beds" vergeleken met de lagere, als gevolg van het onder water lopen van de lage beds. Oudere bedden gaven hogere opbrengsten dan de jongere omdat er meer zuur was uitgeloogd via de neerslag. (7) Een opbrengstvermeerdering van 20% kon worden verkregen bij ananas door een hoge P en K bemesting: per plant: 10 grN; 7 gr P_2O_5 en 10 gr K_2O. (8) Het niet bewerken van de grond in gebieden met een langdurige overstroming was gunstig omdat het het groeiseizoen voor twee rijstgewassen verlengt. Wanneer na het eerste gewas de grond bewerkt wordt, zoals vroeger gebruikelijk, duurt het zeker twee weken voordat het tweede gewas kan worden ingezaaid. Het weglaten van de grondbewerking betekent dat het tweede gewas veel sneller kan worden gezaaid. Resultaten van al deze proeven hebben kwantitatieve gegevens geleverd waarmee de landevaluatie kon worden verbeterd in termen van land kwaliteiten en landgebruikseisen. Specifiek gold dat voor "de beschikbaarheid van zoet water", "zuurgraad" en "risico voor overstroming". De verkregen agronomische gegevens werden gebruikt om de landgebruikssystemen te verbeteren.

Tenslotte zijn, op basis van alle verzamelde gegevens, geintegreerde beheerspaketten geformuleerd voor de vier gebieden die , naar verwacht mag worden, de beste resultaten zullen opleveren in de praktijk. Deze paketten zijn gebaseerd op boerenkennis, aangevuld met ervaringen van experts en op de resultaten van een groot aantal gerichte experimenten op bestaande boerenbedrijven. Het telen van twee rijstgewassen, en yam, ananas en suikerriet wordt aanbevolen voor gebieden waar zoet water beschikbaar is gedurende het droge seizoen. Garnalenteelt wordt aanbevolen voor gebieden met zout water intrusie gedurende het droge seizoen.Malaleuca bomen zijn het meest geschikt voor afgelegen gebieden. Herbebossing speelt een belangrijke rol bij het beschermen van het natuurlijke milieu. De verkregen resultaten geven aan welke landgebruikstypen op dit moment het meeste perspectief bieden. Zij bieden ook aanknopingspunten bij het formuleren van additioneel onderzoek in de toekomst met behulp van metingen of simulatiemodellen.

TÓM TẮT

(Summary in Vietnamese)

Lê Quang Trí, 1996. Developing management packages for acid sulphate soils based on farmer and expert knowledge. Field study in the Mekong Delta, Viet Nam. Luận án tiến sĩ. Đại học Nông Nghiệp Wageningen, Wageningen, Hà Lan, 200trang.

Hiệu quả tác động qua lại giữa kinh nghiệm chuyên môn của nông dân và kiến thức của chuyên gia là điểm chính được quan tâm trong nghiên cứu này. Mục đích của nghiên cứu là mô tả tiến trình tác động qua lại giữa nông dân và chuyên gia trong việc cải tạo và sử dụng đất phèn và tìm ra những khó khăn gặp phải trong tiến trình đó. Mô tả các điều kiện cụ thể và khả năng biến động của 4 khu vực chính. Bốn khu vực chính đại diện: Tân Thạnh, Tri Tôn, Phụng Hiệp, và Hồng Dân thuộc Đồng Bằng Sông Cửu Long, Việt Nam đã được chọn ra cho nghiên cứu trong đề án này. Những điều kiện tự nhiên được định nghĩa theo các đặc tính về đất phản ảnh bởi phân loại đất, và điều kiện nước được xác định thông qua các số liệu về khí hậu và ngập lũ. Phương pháp cải tạo đất đai trong các vùng khác nhau được định nghĩa trước nhất bằng sự đo lường, mô tả, và phân tích bởi nông dân, kế đến là các lược đồ về sự phát triển trong việc cải tạo đất đai được thực hiện bằng các kiến thức chuyên môn của các chuyên gia. Những lược đồ này được trình bày bằng các nhánh quyết định mà được xem như là một phần của hệ thống chuyên môn. Tuy nhiên nhiều câu hỏi thắc mắc vẫn còn chưa được trả lời một cách rõ ràng nên hàng loạt các thí nghiệm được vạch ra và thực hiện để giải đáp những thắc mắc trên mà những thắc mắc này chưa được các chuyên gia chuyên môn trả lời trong các nghiên cứu trước đây.

Bốn khu vực nghiên cứu được chọn ra với các đặc tính môi trường khác nhau như: Tân Thạnh và Tri Tôn (vùng Đồng Tháp Mười và Tứ Giác Long Xuyên, theo thứ tự) có đất phèn với tầng phèn xuất hiện trong vòng 50cm từ lớp mặt và có độ ngập sâu (>100cm) trong mùa mưa. Khu vực Phụng Hiệp với đất phèn trung bình, không bị ngập sâu và thuộc khu vực nước ngọt của vùng Bán Đảo Cà Mau. Khu vực Hồng Dân chủ yếu là đất phèn trung bình và phèn nặng bị nhiễm mặn trong mùa khô. Những hạn chế khó khăn trong sản xuất nông nghiệp của các khu vực nghiên cứu này là hầu hết người nông dân nghèo từ đó cho thấy sự áp dụng các kỹ thuật tiến bộ cũng như hệ thống cây trồng thích hợp cũng chưa được đều khắp. Cùng lúc với những khó khăn về đất phèn là sự ngập sâu trong mùa lũ và sự nhiễm mặn trong mùa khô, cơ sở hạ tầng về tưới tiêu còn nghèo nàn, và thiếu nguồn vốn cho sản xuất. Hơn nữa, sự biến động của giá cả thị trường đối cới hàng nông sản rất cao gây nên sự khó khăn về mặt kinh tế cho người nông dân.

Nghiên cứu ở mức độ nông dân cho thấy các giai đoạn lịch sử trong sử dụng đất đai của người nông dân, trong đó bao gồm luôn cả về thực hành quản lý đất nước và cây trồng, xác định rỏ sự thay đổi về sử dụng đất đai qua các khoảng thời gian khác nhau và vai trò quan trọng của các kiến thức chuyên môn của các chuyên gia trong bước đầu của sự thay đổi. Sự phát triển này cũng chứng minh cho thấy hiệu quả thuận lợi trong sự tác động qua lại giữa nông dân và các chuyên gia chuyên môn trong việc phát triển hệ thống quản lý mới có cải tiến. Theo thứ tự với mười, bốn, mười sáu và mười một kiểu sử dụng đất đai hiện tại cùng với các cách thực hành quản lý đất và nước của các khu vực Tân Thanh, Tri Tôn, Phụng Hiệp, và Hồng Dân cũng đã được xác định và mô tả. Thực hành quản lý đất, nước như xây dựng hệ thống tưới, đào mương lên liếp cho cây trồng cạn và xây dựng hệ thống mương có bờ bao cho cơ cấu lúa-tôm càng xanh/hay tôm nước mặn là những yêu cầu cần thiết cho các hệ thống sử dụng đất đai này.

Những kết quả nghiên cứu của các chuyên gia trước đây hầu hết tập trung vào cho canh tác cây trồng, trong đó chủ yếu là lúa, và đồng thời kết hợp với các kỹ thuật thực hành quản lý. Mười sáu kiểu sử dụng đất đai có triển vọng được chọn lọc ra cho phân hạng thích nghi đất đai dựa trên cơ sở của hiện trạng sử dụng đất đai trong bốn khu vực nghiên cứu. Tám chất lượng đất đai được xác định cho đánh giá thích nghi đất đai ở cấp độ nông trang. Chất lượng đất đai "độ phèn (tiềm tàng) của đất" thì quan trọng cho tất cả các kiểu sử dụng đất đai đã được chọn lọc. Chất lượng đất đai "nguy hại do ngập lũ", "nguy hại do hạn", "nhiễm mặn", và "khả năng hữu dụng của nước ngọt" thì quan trọng cho cơ cấu lúa cao sản 2 vụ. Chất lượng đất đai "tiềm năng ngập và thoát theo triều" là điều kiện tiên quyết cho nuôi tôm càng xanh và tôm nước mặn. Để đánh giá đất đai ở cấp độ nông trang, nhánh quyết định được phát triển và được sử dụng như là một hệ thống trợ tuyển quyết định. Nhánh quyết định được xây dựng cho tất cả các kiểu sử dụng đất đai có triển vọng mà đã được chọn ra. Sử dụng nhánh quyết định như là hệ thống trợ tuyển quyết định cho đánh giá đất đai ở cấp nông trang thì cho thấy rất hửu dụng trong việc xác định những quyết định quản lý tối ưu. Những điều kiện để cải tiến nâng cấp thích nghi cũng được xác định và mô tả trong những nhánh quyết định đó, cải tiến thực hành quản lý đất nước được dựa trên cơ sở kinh nhiệm chuyên môn của nông dân và những kiến thức khoa học của chuyên gia.

Trong khi phát triển những mô hình này, thì nhiều câu hỏi thắc mắc được đặt ra về thực hành quản lý cũng như yêu cầu của sử dụng đất đai mà vẫn chưa trả lời được. Những thắc mắc này được xác địng rõ ràng và hàng loạt các thí nghiệm được đề ra và thực hiện nhằm giải đáp các thắc mắc tồn tại trên. Một số kết quả từ các thí nghiệm cho thấy: (1) để canh tác khoai mỡ trong vùng ngập sâu trong mùa mưa, khoai mỡ được trồng trong mùa khô với việc áp dụng kỷ thuật tủ rơm trên bề mặt liếp làm gia tăng năng suất 46% so với không tủ; (2) sử dụng nước ngọt tưới với khoảng cách 20 ngày trong giai đoạn cần nước của mùa trồng thì làm gia tăng năng suất 31%. (3) Liếp cuốn chiếu cho năng suất cao hơn một cách có ý nghĩa so với liếp xáo trộn. (4) Năng suất khoai mỡ tăng cao khi áp dụng N_{120}-P_{8u}-K_{60} , đây là mức độ mà người nông dân trong vùng đang sử dụng, hay N_{80}-P_{160}-K_{100} . Tăng lượng phân bón cao hơn thì không cho sự gia tăng năng suất có ý nghĩa. Trồng khoai mỡ với giàn leo thì không làm tăng năng suất có ý nghĩa so với không giàn leo. Mật độ 40x50cm thì cho năng suất cao. (5) Đối với canh tác dứa trên đất phèn nhiễm mặn trong mùa khô, khi trữ nước tưới dặm thêm trong đầu mùa khô thì không có hiệu quả tăng năng suất dứa. (6) Sản lượng dứa sẽ cao hơn khi trồng trên liếp cao do trên liếp thấp quá úng nước trong mùa mưa. Liếp củ thì cho năng suất cao hơn so với liếp mới do được rửa phèn sau những mùa mưa. (7) Áp dụng phân N và K ở mức độ cao (10gN - 7gP_2O_5 - 10gK_2O/cây) làm tăng năng suất dứa 20% so với lượng phân thấp hơn. Và (8) áp dụng kỷ thuật sạ chay thì có kinh tế và rút ngắn được thời gian trồng của lúa 2 vụ Hè Thu - Đông Xuân trong vùng có thời gian ngập lũ dài. Những kết quả tổng hợp này đã cung cấp một lượng số liệu đáng kể để đặc tính hóa các chất lượng đất đai và yêu cầu của sử dụng đất đai liên quan đến khả năng hữu dụng của nước ngọt, độ phèn của đất, và nguy hại do ngập lũ. Những số liệu về đặc tính nông học trong các kết quả này cũng dược sử dụng để xác định phương cách quản lý tối ưu trên đất phèn.

Với những điều kiện tự nhiên khác nhau, phương cách quản lý tối ưu trên đất phèn đã được xác định cho bốn khu vực nghiên cứu. Phương cách quản lý tối ưu này được dựa trên cơ sở về kinh nghiệm thực tế của nông dân, kiến thức chuyên môn của các chuyên gia, kết quả từ đánh giá thích nghi đất đai ở cấp độ nông trang và cũng từ kết quả của các thí nghiệm bổ sung. Có nhiều phương cách trong việc chọn ra các kỹ thuật canh tác và cách thực hành quản lý đất và nước dưới các điều kiện tự nhiên khác nhau. Lúa cao sản 2 vụ, khoai mỡ, dứa, mía thì thích hợp cho các vùng có điều kiện nước ngọt trong mùa khô. Đối với những vùng bị nhiễm mặn trong mùa khô, thì nuôi tôm nước mặn thường cho kinh tế hơn. Tràm thì thích nghi cho các vùng phèn xa, nơi mà các cây trồng khó canh tác được, với kiểu sử dụng này có ý nghĩa trong việc tái tạo rừng để bảo vệ môi trường tự nhiên. Những kết quả này là một sự bắt đầu cho việc mô tả các hệ thống thực tế và có thể chấp nhận được. Trong tương lai, kết quả này có thể sử dụng để xác định những lảnh vực nghiên cứu thêm bằng các kỹ thuật đo lường hiện đại hay bằng các mô hình giả định.

Curriculum vitae

Le Quang Tri was born on March 1, 1956 in Minh Hai Province, Viet Nam. From 1974 - 1979, he studied at Can Tho University, Viet Nam and graduated as Agricultural Engineer, specializing in Soil Survey with a major assignment on Land Evaluation. Since 1979, he was employed at the Soil Science Department of Can Tho University as lecturer and researcher. From 1980 to 1992, he participated in the project VH-10 "Research for the Management of Acid Sulphate Soils", a co-operation project between Wageningen University and the Can Tho University sponsored by NUFFIC. In 1988, he followed the Post Graduate and Master Courses at ITC (International Institute for Aerospace Survey and Earth Science), Enschede, The Netherlands on a two-years scholarship of the VH-10 project and ITC. He obtained his Master degree in September, 1990, specializing in Land Evaluation. Since 1990, he continued his work at Can Tho University and participated as consultant in local and international projects such as the Master plan project of the Mekong Delta (NEDECO), the problem soils in the Mekong Delta project of SAREC, funded by SIDA via the Mekong Secretariat), Forestry Development of Long Xuyen Quadrangle project (funded by the Australian Government). In March, 1992 he started his research leading to the degree of Doctor in Agricultural and Environmental Sciences at the Wageningen Agricultural University after the Fourth International Symposium on Acid Sulphate Soils held in Ho Chi Minh City.