INTEGRATED SOIL AND WATER MANAGEMENT IN ACID SULPHATE SOILS

Balancing agricultural production and environmental requirements in the Mekong Delta, Viet Nam

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Le Quang Minh

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To Lieng, Triet and Tran

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PROPOSITIONS

1. In severely acid sulphate soils of the Mekong delta, reforestation by *Melaleuca* is a very good concept. However, the target group for reforestation cannot be the poor farmers, who cannot support their living while waiting until the harvest, 8-10 years after planting.

2. During the dry season, aluminum is transported to the surface of vertical soil-cracks by evaporation and capillary rise. When the rainy season starts, this aluminum washes downwards through bypass flow to the ground water table, which rises during the rainy season until reaching the soil surface causing contamination. This mechanism contrasts with the one proposed by Hanhart and Ni assuming rapid swelling of soil causing contaminated water in the cracks to be pushed upwards to the surface.

This thesis.
Hanhart and Ni 1993. Water management on rice fields at Hoa An, Mekong delta, Vietnam. In: Dent and van Mensvoort (eds.): Selected Papers of the Ho Chi Minh City Symposium on Acid Sulphate Soils. ILRI Publication 53. Wageningen. pp. 161-175.

3. In land use evaluation studies of acid sulphate soils, accessibility of fresh surface water is an important land quality. Not only, however, should its presence be used as a rating factor, but also the distance between fields and water sources.

This thesis

4. Planning for flood control in the Mekong Delta, Vietnam, can most properly and effectively be carried out in Laos, Thailand and China.

5. Development of small and medium-scale industry in cities like Cantho, Rach Gia, Ca Mau and Ho Chi Minh City is crucial to improve living conditions of the farmers in the Mekong delta.

6. Sustainable development of sugar cane productivity in acid sulphate soils in Vietnam is not only a function of soil conditions but of price fluctuations within a two-year cycle. Constructing good facilities for storing sugar will be a proper measure for stabilizing the sugar price and, consequently, will improve sugar cane production.

7. Farmers in the Mekong Delta, who are cultivating upland crops on raised beds, will soon face a serious problem caused by two opposing processes. Their raised beds are getting lower by consolidation whereas flood-water levels are getting higher by upstream deforestation. A model to predict these processes should be developed to help them secure growing upland crops in future. This model consists of two components: flood-water levels, which are determined in a catchment and bed consolidation, which is a local phenomenon.

8. To plant pineapple in acid sulphate soils, the most suitable soil material to construct the raised beds is a mixture of 50% top soil (high organic matter content) and 50% sulfuric material (high clay content). Sulfuric material increases the water holding capacity and the stability of the beds.

This thesis
Anh Sau, farmer in Cai Lay, The Plain of Reeds, Mekong Delta, Vietnam (per. comm.).

9. A Vietnamese saying is “wisdom originates from adverse conditions”. But, another Vietnamese saying states: “wisdom is hampered by adverse conditions”. More realistically, ad-hoc, instant wisdom often results from adverse conditions which do, however, hamper development of more creative and innovative forms of wisdom.

10. Darcy’s law can be applied to the flux of immigrants. The “economic gradient” is defined as the difference in economic potential (e.g., income per capita) between two locations (districts, provinces, regions or countries, etc.) divided by their distance. The “immigration conductivity” is determined by factors such as infrastructure, transportation, regulations, and various types of physical obstacles.

11. In wild-life protection programs, the species needing most attention is *Homo sapiens sapiens*.

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My special thanks go to Prof. Dr. Vo-Tong Xuan, leader of VH 10 project, and Prof. E. Stamhuis for their support during the implementation of VH 10 project.

I would like to express here my gratitude to Karel Hanhart for all interesting discussions in the experiment fields in Binh Son, Hoa An, Dong Cat, etc. You encouraged me to start my Ph. D. thesis during our experiment in Binh Son, where we faced some "anomalous" phenomena in leaching this acid sulphate soil by salt water.

Many thanks go to my colleagues in Faculty of Agronomy: Dr. Truong Thi Nga for her help in analyzing all the soil and water samples during my 4-year experiments and for her valuable suggestion in the design of the experiments, Duong Van Ni (director of Hoa An station) for his support and interesting discussion, Le Quang Tri for sharing with me his field data.

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Finally to my parents; Lieng, Triet and Tran.

CONTENTS

Chapter 1

INTRODUCTION

1. Problems and potentials of acid sulphate soils

Over 90 million hectares of land in South and Southeast Asia, where population is high and arable land is scare, is potentially suitable for rice or fish production but remains idle because of various soil problems such as salinity, sodicity, excess organic matter, and strong acidity (Neue and Singh 1984). Strong acidity is often found in areas with acid sulphate soils (ASS) which are defined by Van Breemen and Pons (1978) as soils that have, somewhere within 50-cm depth, a pH below 3.5 (for Entisols) or 4 (for Inceptisols) that is directly or indirectly caused by sulfuric acid formed by oxidation of pyrite (cubic FeS_2). Adverse conditions for plant growth in ASS are caused by low pH, Al-toxicity, Fe-toxicity, P-deficiencies, low N, poor nutrient levels and unfavorable hydrological conditions (Dent 1986, Pons 1989). Aluminum is an important toxic element in ASS especially in upland conditions (Adams and Lund 1966, Evans and Kamprath 1970, Van Breemen 1980, Rorison 1982, Dent 1986). Soluble aluminum is one of the major factors for diagnosis of aluminum toxicity which limits upland crop growth (Bell and Edwards 1986) and rice growth (Wei Qi-fan 1981). At a concentration as low as 1 to 2 ppm, aluminum can be toxic for rice (Cate and Sukhai 1964). Due to these hostile conditions, only 2 million hectares (out of 12 million hectares) of ASS is cultivated (Neue and Singh 1984).

Innovative water management practices for leaching and flushing toxicities, controlling of ground water levels, reducing capillary rise, proper soil nutrient management etc. can be effective measures and promising to ameliorate soil conditions for agricultural production (Brady 1981, Van Breemen 1980, Dent 1986, Tuong 1993). These measures have been practiced widely in ASS areas of the Mekong Delta, Vietnam and elsewhere, allowing a variety of crops including rice, pineapple, yam, cassava, and sugar cane (Sen 1987, Tri et al. 1993, Xuan 1993) to be grown successfully. Rice is cultivated under submerged conditions, using shallow-drainage-and-raised-bed systems in the Mekong Delta (Xuan 1982), and in tidal areas where proper water management was imposed in Indonesia (Eelaart 1982), in Thailand (Panichapong 1982). Reclamation of ASS for rice cultivation have contributed greatly to the recent increased rice production and exportation from the Mekong Delta.

Upland crops are commonly planted on raised beds (i.e. piling up soil materials excavated from adjacent lateral ditches to form ridges 0.3 to 0.6 m higher than the original ground surface) to avoid flooding creating better conditions for leaching toxic substances (Panichapong 1982, Dent 1986, Sarwani et al. 1993, Tri et al. 1993, Xuan 1993). Upland crops supply an important extra source of income to farmers in large ASS areas in the Mekong Delta (Sen 1987, Tri et al. 1993, Xuan 1993, Durang 1994).

2. Conflict between agricultural production and environmental protection

The promising potential of ASS reclamation for agricultural production, however, has a basic and serious conflict with environmental protection. Leaching of ASS involves transferring of toxicities from the root zone to the surroundings and may well cause the contamination of surface water and create substantial negative effects on the crops and soils in surrounding areas (Dent 1992). In Vietnam, during the rainy season an surface area of 500,000 hectares in the Mekong delta has problems with water contamination by acidity (Kham 1988). Acidic toxicities, especially aluminum, are particular hazardous for fish and aquatic organism, since their threshold concentrations are far less than those for plant roots (Breemen, 1993). The tolerance limits of aluminum for most fishes is 0.2 to 0.5 ppm (Singh et al. 1988). Baker et al. (1993) reported a strong reduction in fish population due to an increase in the aluminum concentration. In Indonesia, Klepper et al (1990) reported a ten-fold reduction of fish yield in ASS reclaimed areas compared with other areas. Dat (1991) reported serious environment impacts of ASS reclamation projects on offshore ecosystems in West Africa. Therefore, in the planning phase of ASS projects, a sound analysis of the benefit and cost, in which environmental damage in a larger area has to be taken into consideration, must be carefully calculated.

Considering the major environmental impact of ASS reclamation, this study has taken an integrated approach: attention is not only focused on increasing agricultural productivity - as is usual - but also is paid to the environmental effects of ASS reclamation. Because aluminum has the high toxic potential for plant roots and imposes high risk for the environment, this study has paid particular attention to the fluxes of this substance, especially in raised-bed systems, which have not been adequately studied.

3. The importance of water management and soil physical properties in characterizing ASS

Studies on ASS have been strongly focused so far on its chemical properties

(Bloomfield and Coulter 1973, Van Breemen 1980, Dent 1986). Likewise, efforts to improve agronomic performance of ASS has focused on fertility amendments (Panichapong 1982, Tri et al 1993). This study address the problem of removing toxicities from the root zone and its consequences to the environment. It involves the transport of toxicities from soil to the surroundings. The study pay more attention to factors influencing the water movement and solute transport mechanism in ASS. Chemical processes are systematically related to solute fluxes which can be manipulated by soil and water management. This rather new and interdisciplinary approach is of crucial importance to allow a realistic and practical relevant assessment of the complicated process in ASS. Brinkman (1982) emphasized the importance of studies on soil-pore pattern and water movement and on the associated transport of toxins. Dost and Van Breemen (1982) proposed some promising areas of research such as effects of tillage on leaching, soil management and cropping systems in ASS, etc. Soil management to enhance the effectiveness of water management is equally important because removal of toxic elements is very slow under undisturbed soil conditions (Tuong 1993). The study, therefore, focused on the physical properties of ASS, such as bulk density, hydraulic conductivity, infiltration, pore system distribution, etc. They can play very important roles on the characteristics of water flows in and on ASS like bypass flow, overland runoff, capillary rise, etc., as the consequence, effectiveness of leaching toxic substances.

4. Objectives

Objectives of this study are:

1. To enhance the process-based understanding the effects of soil physical properties and water regime on solute, especially aluminum, transport in ASS;
2. to quantify environmental hazards from ASS amelioration activities; and
3. to identify measures which help increase agricultural product and reduce environmental consequences.

With the goal to improve the livelihood of farmers in ASS areas, studies were made in farmer's fields and experiments were based on long discussions with farmers, assuring that research results would be acceptable to them and would serve their objectives.

5. Structure of this thesis

The study was carried out on acid sulphate soils in the Mekong Delta, Vietnam. Findings are however equally applicable to similar ASS areas in Asia having tropical monsoon climate with a rainy (May to December in the Mekong Delta) and a dry season (January to May). Major water flow and transport processes in ASS in these areas can be summarized in Figure 1.

During dry season, under the influence of evaporation, the water and soluble substances are raised by the capillary rise. Aluminum and other acid toxicities are accumulated in the top soil layers. As the rainy season arrives, the soluble substances are dissolved by rainwater. They are leached (vertical removal from the root zone) or flushed (horizontal removal from the surface layers). Leaching is influenced by the vertical movement of water. In the macropore-dominated soils such as in the raised beds, bypass flow (Bouma 1984) is a prominent flow components. Flushing is carried out by surface drainage (in rice fields) or surface runoff (in raised beds). All or part of the leached or flushed substances will finally go into the drainage systems. In that sense, they become pollutants to the surface water network. Very often the contamination process is strongest at the beginning of the rainy season when the leaching and flushing processes take place actively.

The end of the rainy season is often characterized by flooding. The removal of flood water from the rice fields, in preparation for dry season cultivation, offer an opportunity for flushing out solutes from the surface layer. Reflecting the above considerations, this thesis is structured according to the sequence of the main flow and transport mechanism in ASS, starting with the dry season and ending in the rainy season (Fig. 1).

The mechanism of aluminum transport by capillary rise from the ground water table and subsoils to the top layers during the dry season was investigated in chapter 2. It also studied the effects of ground water table and land management techniques (mulching and plowing) in reducing the aluminum accumulation in the topsoil layers.

Chapter 3 compared the roles of bypass flow and surface runoff in removing of aluminum from different types of raised beds in ASS. These types differed in their methods of construction, which influenced both soil chemical and physical properties of the topsoil of the raised beds. These methods were assessed both from crop production and environmental point of views. Soil physical properties are influenced by soil management applied different land use types. In raised beds, they are also affected by the land use age, i.e. time from the construction of the raised beds. These physical properties, in turn, may affect the leaching of aluminum.

Chapter 4 focuses on the morphological characteristics of soil structures and macropore systems under different crops and times after construction. It high lights the effects of soil physical processes and land management on aluminum transport in raised beds.

The concentration and total amount of aluminum released to the surrounding from ASS reclamation is quantified in chapter 5. Special attention was paid to the question as to how aluminum concentration in drainage water varied in each type of land use (rice, pineapple and yam) as a function of rainfall and time.

The opportunity to use flood water for flushing toxicities out of the top soil of rice field is investigated in chapter 6. It offers an option for increasing productivity while reducing the associated environmental risk in reclaiming ASS for rice cultivation.

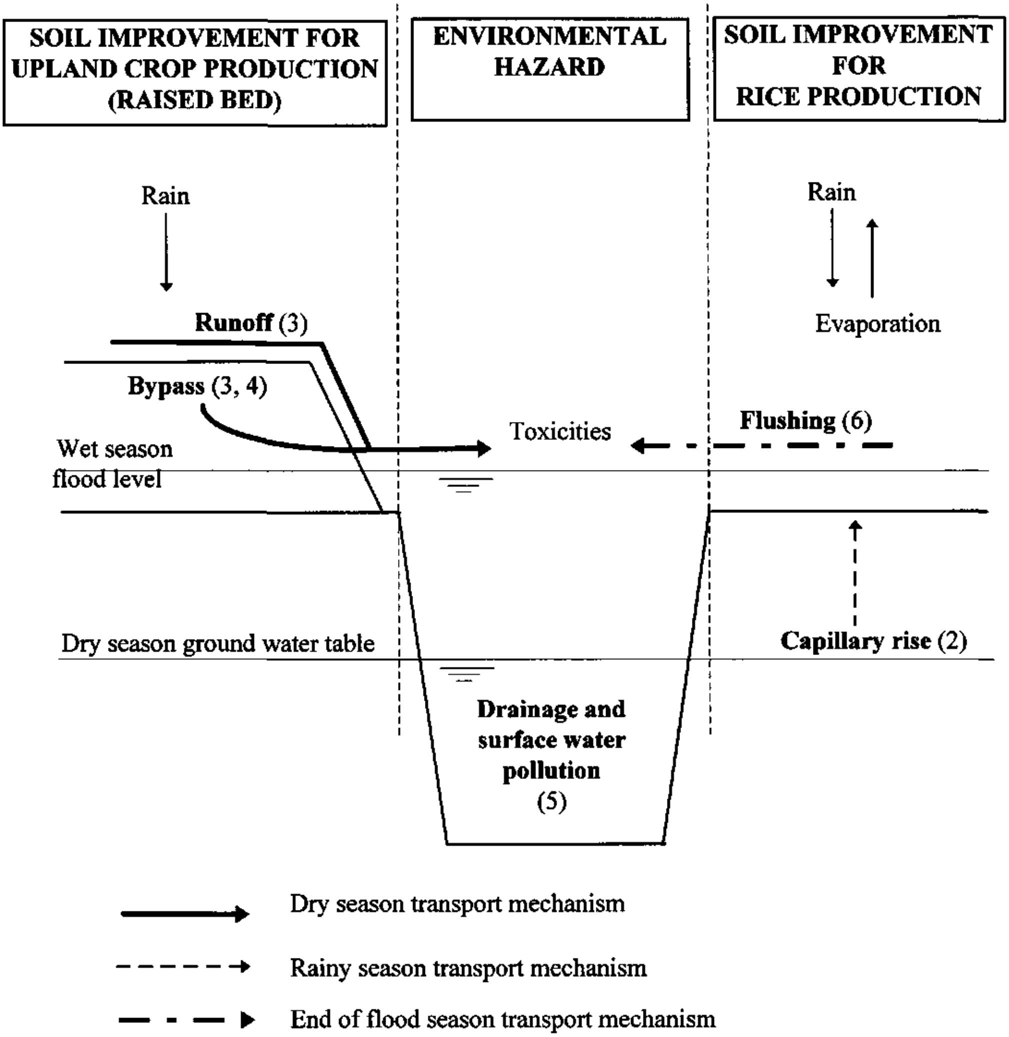

FIGURE 1 Two aspects of utilization of acid sulphate soils: agricultural production and environment hazard. Bold-faced letters indicated the main solute transport mechanism studied. Numbers in parentheses are chapters in which the transport mechanism are discussed.

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Chapter 2

EFFECTS OF LAND MANAGEMENT AND GROUND WATER TABLE DEPTH ON ALUMINUM ACCUMULATION IN SURFACE LAYERS OF ACID SULPHATE SOILS

EFFECTS OF LAND MANAGEMENT AND GROUND WATER TABLE DEPTH ON ALUMINUM ACCUMULATION IN SURFACE LAYERS OF ACID SULPHATE SOILS

L. Q. Minh[1], M. E. F. van Mensvoort[1], T. P. Tuong[2] and J. Bouma[1]

ABSTRACT

Accumulation of toxicities in the rootzone of acid sulphate soil (ASS) may harmful to plant growth. The effect of mulching and plowing on aluminum accumulation during the dry season and the first three weeks of the rainy season 1994 were studied in field and lysimeter conditions in an acid sulphate soil, in Mekong Delta, Vietnam. In the lysimeter, we also imposed different depth of ground water table level. High linear correlation between evaporation rate in lysimeters and class-A pan evaporation rate was found only under non mulching and non-plowing conditions and with 30-cm GWL. The amount of aluminum accumulation increased with increased evaporation. During the dry season, mulching significantly lowered the aluminum accumulation (0.6 cmol(+)kg^{-1}) as compared with non-mulching treatment (2.0 cmol(+) kg^{-1}), whereas plowing did not show significant effects on the accumulation. Rainfalls at the beginning of the rainy season raised the ground water rapidly and increased its aluminum concentration. Evaporation between rains in this period created high amount of aluminum accumulation in the top soil and nullified the differences previously caused by different land treatments. Maintenance a GWL at -30 cm might help to prevent further formation of acidity. Controlling ground water table, leaching with supplementary irrigation at the beginning of the rainy season to reduce the aluminum in the top soil may be more important than treatments in the dry season.

INTRODUCTION

In acid sulphate soils (ASS), acidity originates from the oxidization of pyrite and is mostly due to the lowering of the ground water level (Dent 1992, Ritsema et al.

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1992). Subsequently, evaporation from the soil surface may cause accumulation of toxic salts in surface horizons by upward capillary movement (Sen 1988a). These salts may be leached in the rainy season, creating environmental hazards to the surroundings.

Meteorological factors, groundwater depth, and physical properties of the soil, are the principal factors controlling the rate of capillary rise rate (Bloemen 1980). In saline soils, capillary rise plays a key role in the transport of salt from the groundwater to the top soil (Nakayama et al. 1973, Hassan and Ghaibeh 1977, Hellwig 1979, Sharma et al. 1985, Lal 1989, Bastiaanssen et al. 1990, Tuong et al. 1991). Studies on evaporation, accumulation of salts and measures to reduce it, in ASS have also been studied. Using soil cores, Tuong et al. (1991) investigated the effects of ground water table on accumulation of soluble aluminum at the top layer of a bare ASS during the dry season in the Mekong delta, Vietnam. Li Jinpei et al. (1989) reported that in China tillage, groundwater level control, and mulching techniques were applied in ASS to reduce evaporation and accumulation of toxicity. Other authors demonstrated positive effects of mulching on yields of several crops in ASS such as yam (Sen 1987 and Durang 1994), pineapple (Sen 1987), soybean and peanut (Manuelpillai et al. 1986). Previous investigators, however, did not quantify the toxicity transport process due to capillary rise in ASS in the field conditions. The relationships among evaporation, capillary rise and accumulation of toxic substances in ASS have not been studied in details under different land management methods. The effects of different land managements and ground water table level at the beginning of the rainy season, i.e. the main cultivation season, when the accumulated toxicities are re-distributed to the lower layers, have not been studied. It is possible that effects of land management methods and ground water table level during this period would be different from those in the dry season. These knowledge would be beneficial in selecting management strategies for increasing agricultural productivity and reducing environmental impacts of ASS. Duong et al. (1986) postulated that water management measures such as maintenance of a shallow water table and minimizing capillary rise could be useful to reduce the accumulation of toxicity in top soils during the dry season.

Objectives of this study were to quantify the relationship between the amount of aluminum accumulation and evaporation and to investigate the effects of land preparation methods (mulching and plowing) on aluminum transport from the groundwater to the top soil in ASS. The experiment was carried out in field as well as in lysimeter conditions, during two different periods of the year: (i) the dry season, (ii) the beginning of the rainy season.

METHODOLOGY

Experimental site

The experiment was conducted at Hoa An station (10°10 N, 106°15 E), in Mekong delta, Vietnam. It has are two distinct seasons: dry season from January to May and rainy season from June to December, with about 90% of the 1800-mm annual rainfall. Average evaporation rate varies from 4.0 mm d^{-1} in the rainy season to 6.5 mm d^{-1} in the dry season.

TABLE 1 Some physical properties at Hoa An station. K^H_{sat} and K^V_{sat} are saturated hydraulic conductivity in horizontal and vertical directions, respectively.

Horizon	Depth (cm)	Bulk density (Mg m^3)	K^H_{sat} ($\times 10^{-6}$ m s^{-1})	K^V_{sat} ($\times 10^{-6}$ m s^{-1})
Top soil	0-30	0.65	0.118	0.640
Firm layer	30-40	1.04	0.006	0.015
Sulfuric horizon	40-120	0.81	0.025	0.059
Sulfidic horizon	> 120	0.88	0.049	0.044

TABLE 2 Aluminum concentration (cmol(+) kg^{-1}), its standard deviation (S. D.), and pH of top soil (0 - 10 cm) in Hoa An before the treatments.

Chemical characteristics	Field			Lysimeter	
	Aluminum	S. D.	pH	Aluminum	pH
Exchange complex†	16.67	3.81	3.66	14.70	3.80
Soluble‡	1.94	0.61	3.83	1.46	3.92

† Extracted by KCl 1M (1:2.5)

‡ Saturation extracted (1:1.5)

The soil is classified as a very fine Typic Sulfaquept (USDA, Soil Survey Staff 1975) with a high organic matter content in the 30-cm top soil. There exists a firm layer, with low saturated hydraulic conductivity (Table 1) at depth 30-40 cm. The sulfuric horizon, with yellow mottles of jarosite, starts from 40 cm to 120 cm. From 120 cm, a grey permanently reduced sulfidic horizon is found. The soil was originally uncultivated and covered by *Eliocharis dulcis*. Chemical and physical characteristics of the soil are shown in Tables 1 and 2.

Field experiment

Field layout.

The field experiment started at the beginning of the dry season, February 1994, when the groundwater depth was at 0.15 m and water content of the top soil was high (0.55 $m^3\ m^{-3}$). We used a split-plot design with 4 replications. The main treatment was the degree of plowing (P1 for plowed and P0 for non-plowed). Plowing was carried out at the beginning of the experiment by hoeing to the depth of 10 cm, breaking soil into clods of approximately 10 cm by 15 cm. Each 12-m x 16-m main plot was divided for the subtreatments: mulching (M1) and non-mulching (M0). The M1 subplots were covered by 15-cm thick *Eliocharis dulcis* dry straw. All plots were separated by compacted bunds (0.4 m high and 0.5 m wide) constructed with topsoil materials taken from outside the experimental field. This was to avoid the mixing of runoff water, which might occur in some heavy rains, from one plot to the next.

Soil and water measurements.

Soil and ground water sampling were carried out three times, at the start of the experiment (hereafter designated as week 0), at the end of the dry season (week 8), and in the first part of the rainy season (week 11). In each subplot, five 0-0.1 m topsoil samples were taken randomizedly and mixed into one sample for the analysis of pH (H_2O, 1:2.5), aluminum in the exchange complex (extracted by KCl 1M, 1:2.5), and soluble aluminum (in saturation extract, 1:1.5). We designate the amount of aluminum accumulation during the dry season as the difference between soluble aluminum concentrations at week 8 and 0, and during the experiment : between week 11 and week 0. From those values, accumulation during the beginning of the rainy season (between week 8 and 11) could also be derived.

Ground water was sampled using 2.7 cm dia. ground water tubes (Tuong et al. 1993) installed at the center of each field. One to two hours before sampling, ground water in the tubes was pumped out, using a hand pump, to get rid of the dead water which might have accumulated in the tube from the previous sampling. Ground water was then sucked into prevacuumed bottles as described in Tuong et al. (1993), Soil and water storage and analysis were carried out according to Bejeihn (1980).

Every week, soil tension at depths of 5, 15, 30, 35, 40, 45, and 65 cm were measured using tensionmeter cups (2 cm in diameter and 8 cm long) and a digital transducer. The battery of tensionmeter cups was installed at the center of each sub-plot. Daily rainfall and evaporation rate were measured in situ by mean of a rain gauge and class-A evaporation pan.

Lysimeter experiment

The lysimeter experiment was carried out from week 0 to week 10 and the same site as the field experiment. Each lysimeters was a 1 m long x 0.4 m diam PVC tube (Figure 1). The tubes were inserted into the soil by gradual hammering. In order to reduce friction and compaction of the soil core during the insertion, the tube-end was sharpened and the tube-walls greased. The soil outside the core was removed after every 5 cm of insertion. At 95 cm-insertion depth, the tube was lifted up using a hoist and a heavy duty tripod. The lower end of each tube was filled with coarse sand and covered by an asphalt-coated iron cap connected to a Mariotte bottle. The tubes were lowered in a trench so that the soil core surfaces were at the same level as the natural soil surface (Figure 1).

Exposing the side wall of the tube to radiation might cause higher evaporation rate in the soil core (Boast and Robertson 1982, Sen 1988, Daamen et al. 1993). To prevent the extra radiation, Nipa leaves were used to cover the opening between the tubes and the trench surface. At night and during rain events, the tubes were sheltered by a roof made of transparent nylon sheet.

Soil in the tube received similar land treatments (P0, P1, M0 and M1) as the field experimental plots. In addition, different groundwater levels (30, 60, and 90 cm from the soil surface) were imposed on the tubes. All together, there were 12 lysimeters, i.e. there was no replication. The ground water levels were controlled by the water level in the Mariotte bottles. Every day, the bottles were refilled to the predetermined treatment levels. The daily evaporation loss from the lysimeter (E) was taken as the volume of the refilling water divided by the surface area of the lysimeter. A linear regression function $E= a .E_0$ was used to relate E and daily Class-A pan evaporation E_0. a is the slope of the regression curve.

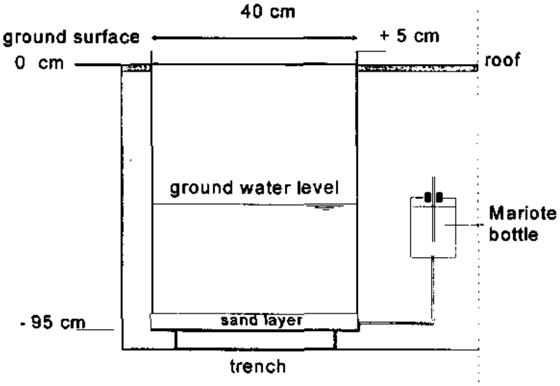

Figure 1 Sketch of a lysimeter

Soil samples were taken from each lysimeter, using 5-cm soil auger (8 cm in diameter) at depths 0-10 cm at the start and end of the lysimeter experiment for soluble aluminum analysis (in soil saturation extract, 1:1.5). Similar to the field experiment, aluminum accumulation was taken as the difference in soluble aluminum concentrations measured in week 10 and week 0.

RESULTS AND DISCUSSION

Lysimeter study

Evaporation rate.

The evaporation rate from each lysimeter reduced steadily as the soil dried out. Evaporation rates came to a rather steady values from week 3. This steady-state evaporation rate was reduced by soil surface treatments (Figure 2). The reduction was more pronounced when the ground water level was at 30-cm depth. At this ground water level, the lowest evaporation (2.4 mm d^{-1}) rate was found when both mulching and plowing (P1M1) were applied. Steady evaporation rate of control treatment was 5.9 mm d^{-1}, compared to the average Class-A pan evaporation of the same period (7.1 mm d^{-1}).

The finding of this study supported Sen (1988b) who found that mulching with thin peat layers on top of soil columns reduced 50% of the evaporation rate compared to non-mulching treatments. Tillage reduced evaporation and capillary rise by creating a discontinuity in the capillary system (Hammel et al. 1981) and by reducing water transmission properties (Benoit and Kirkham 1963, Papendick et al. 1973). In absolute terms, the reduction of evaporation caused by plowing was higher in this study than the reduction found by Sen (1988b). Differences may have been caused by the differences in potential evaporation, which were 3.0 mm d^{-1} in Sen' s report and 6.5 mm d^{-1} in this study.

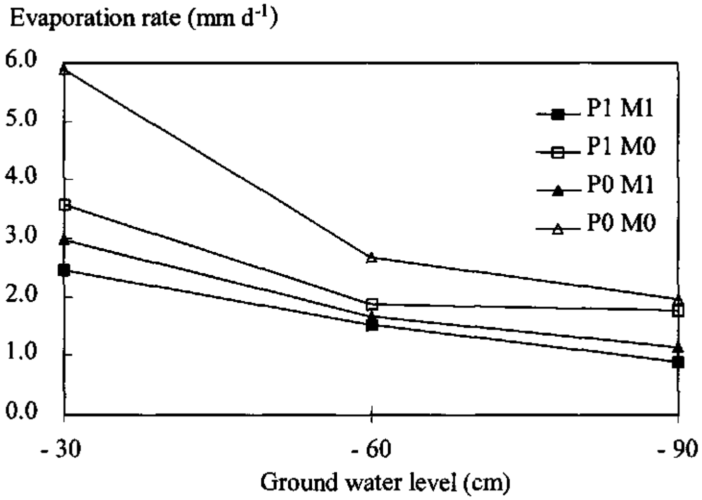

FIGURE 2 Steady-state evaporation rate as functions of soil treatments (P0: non-plowing, P1: plowing; M0: non-mulching, M1: mulching) and of groundwater levels (GWL:-30, -60, and -90 cm).

The steady-state evaporation rates also decreased with the increased ground water depths (Figure 2). Except in treatment P1M1, where the evaporation rate reduced almost linearly with ground water depth, evaporation rates decreased sharply when ground water levels were lowered from 30 cm to 60 cm and only slightly when the ground water level was lowered further to 90 cm. The mean evaporation rates of all treatments were 3.7, 1.9, and 1.4 mm d^{-1} when ground water depths were 30, 60, and 90 cm, respectively.

There was a significant correlation between daily lysimeter evaporation E and Class A pan evaporation E0 ($r^2 = 0.79$) in treatment P0M0 with ground water depth (GWL) of 30 cm. Regression coefficient (r^2) from all soil treatments reduced with the lowering of groundwater levels. Under other soil surface treatments and/or other GWL, values of r^2 were much lower (0.41 to 0.02) and indicated that the correlations were not significant (Table 3). This possibly implied that evaporative demand strongly dictated the actual evaporation of untreated soil under a shallow groundwater level. Under the deeper groundwater levels, and with soil mulching and/or plowing, other factors like soil moisture content, the continuity of the pore system might have played more important roles in controlling the actual evaporation rate (Unger and Stewart 1983).

TABLE 3 Correlation coefficients between evaporation rate (E) from lysimeters and potential evaporation from class-A pan (E_0) by the linear relationship ($E = a . E_0$) under different ground water levels (GWL) and different land management practices: M0 (non-mulching), M1 (mulching), P0 (non-plowing), and P1 (plowing).

Treatment	P0 M0	P0 M1	P1 M0	P1 M1
GWL -30 cm				
a	-0.81	-3.34	0.60	-0.69
r^2	0.79**	0.41 ns	0.15 ns	0.22 ns
GWL -60 cm				
a	0.92	-0.22	0.98	0.37
r^2	0.23 ns	0.26 ns	0.23 ns	0.18 ns
GWL -90 cm				
a	2.13	1.06	0.83	0.78
r^2	0.03 ns	0.02 ns	0.04 ns	0.03 ns

** significant at 1% level ns not significant

Aluminum accumulation

The aluminum accumulation in the lysimeter topsoil increased linearly with the cumulative evaporation from the lysimeters (Figure 3). At the 30-cm groundwater level, the increase in aluminum accumulation with the increased cumulative evaporation was less pronounced than that corresponding to GWL at 60 cm and 90 cm. This implied that more aluminum was brought up to the surface by the capillary water when GWL was lowered. Probably the 30 -cm GWL prevented further formation of acidity during the dry season, which could occur under the oxidized conditions when the ground water level was further lowered (Duong 1986).

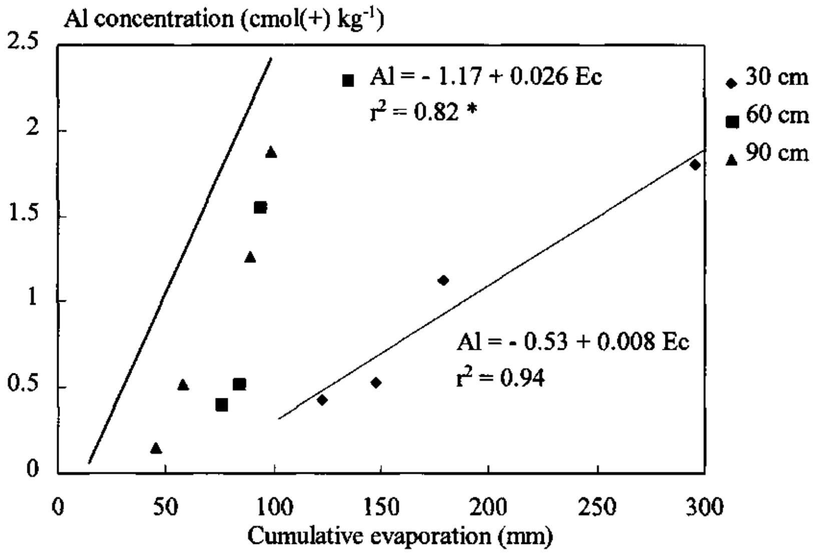

FIGURE 3 Relationship between soluble aluminum accumulation in top soil of lysimeters with cumulative evaporation (Ec) under different soil treatments. Ground water levels (GWL) were maintained at depths of 30, 60, 90 cm from ground surface.

Field study

Variation of soil tensions and groundwater depths.

Figure 4 shows the lowering of groundwater levels during the 11 weeks of the experiment. Differences of groundwater levels among treatments were negligible. Groundwater level dropped rapidly from 15 cm in all treatments to about 60 cm during the first week of the experiment. After the rapid decline, the groundwater levels further decreased slowly to 85 cm depth at week 8.

After several consecutive rains in weeks 8, 9, and 10, groundwater levels rose rapidly and reached a depth of about 0.1 m below the soil surface.

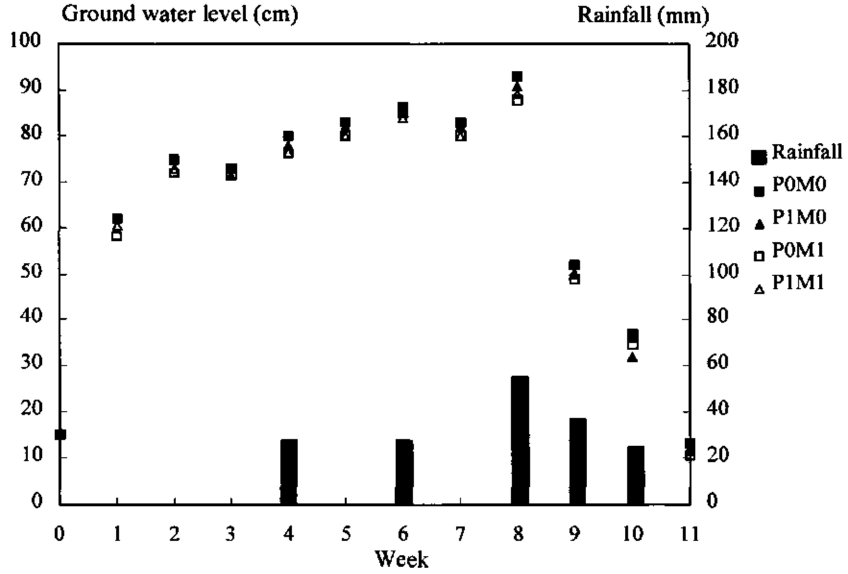

FIGURE 4 Variation of groundwater levels (GWL) during dry season and the beginning of rainy season. Week 8 and week 11 are soil sampling times. (P0: non-plowing, P1: plowing; M0: non-mulching, M1: mulching).

In the first four weeks, soil tensions increased. The most rapid change occurred in the first week (Figures 5a, 5b, 5c, and 5d). In top soil layers (5 and 15 cm), changes due to different treatments were clearly observed. Effects of land preparation treatments on soil pressure heads at 5 cm depth are clear. At lower sampling depths (35 and 40 cm), changes were small. Plowed soil, when not covered by mulch, dried out drastically when exposed to the air. In the third week, highest soil pressure head (-310 cm) was found in P1M0 treatment (at 5 cm) compared to -188 cm (P0M0), -80 cm (P0M1), and -61 cm (P1M1).

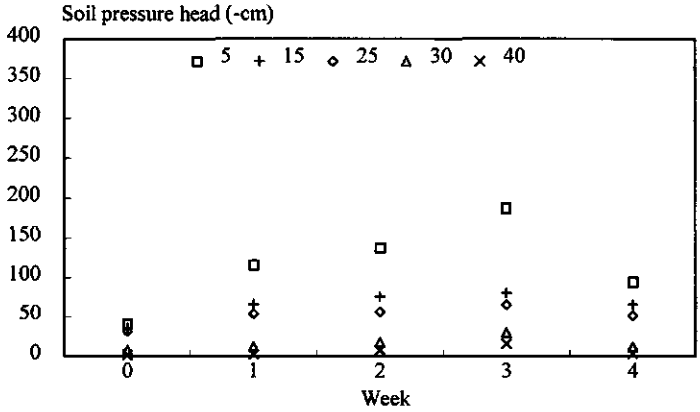

Figure 5a Variation of soil pressure heads (at 5, 15, 25, 30, 40 cm) of treatment P0M0 (nonplowed and nonmulched). Each data point is the mean value of 4 replications.

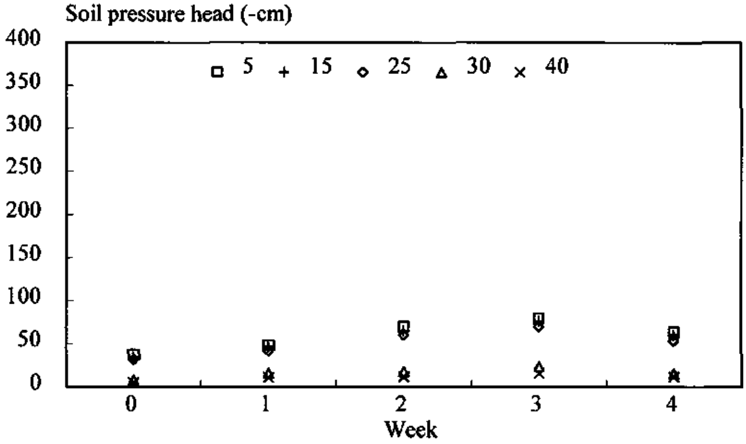

Figure 5b Variation of soil pressure heads (at 5, 15, 25, 30, 40 cm) of treatment P0M1 (nonplowed and mulched). Each data point is the mean value of 4 replications.

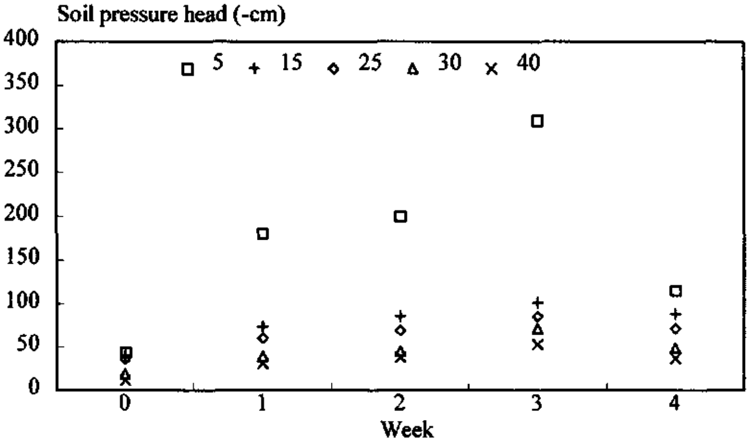

Figure 5c Variation of soil pressure heads (at 5, 15, 25, 30, 40 cm) of treatment P1M0 (plowed and nonmulched). Each data point is the mean value of 4 replications.

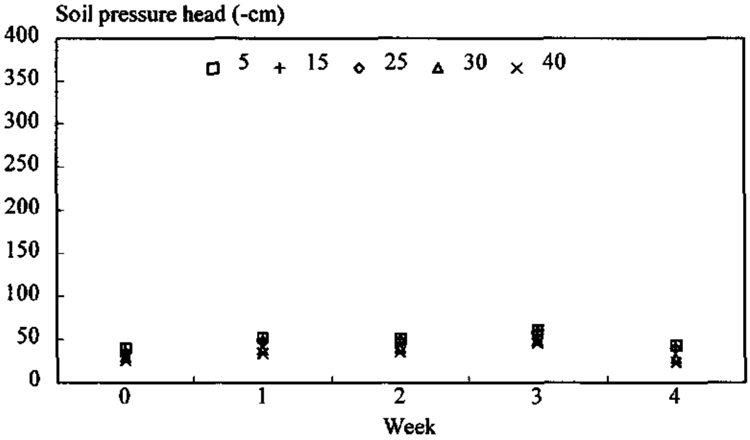

FIGURE 5d Variation of soil pressure heads (at 5, 15, 25, 30, 40 cm)of treatment P1M1 (plowed and mulched). Each data point is the mean value of 4 replications.

Accumulation of toxicity in top soils

Accumulation of toxicity in topsoils under different treatments of land preparation from the beginning of the experiment to week 8, mulching significantly reduced the accumulation of aluminum (Table 4). When the soil was not plowed (P0 treatments), aluminum accumulation of the mulching treatment was significantly lower than in non-mulching plots (0.59 cmol(+) kg^{-1} and 2.02 cmol(+) kg^{-1}, respectively). Although plowing also helped reduce aluminum accumulation, differences between plowing and non-plowing treatments (0.64 cmol(+) kg^{-1} and 2.02 cmol(+) kg^{-1}) were not statistically significant. When the surface was mulched, differences between plowing and non-plowing were very small (0.63 cmol(+) kg^{-1} and 0.59 cmol(+) kg^{-1}, respectively). These field results are in agreement with Sen (1988) who reported that a layer of peat on top of soil columns reduced the accumulation of toxic substances in the topsoil of an ASS. Li Jinpei et al. (1989) reported the reduction of toxins in top soil of an ASS due to the coverage of soil surface by sugar cane leaves. The reduction must have resulted from the reduced evaporation.

The amount of aluminum accumulation in the topsoil in the field condition was similar to that in lysimeters when GWL was maintained at -60 to -90 cm (Table 3 and Figure 3). This indicates that the field conditions were satisfactorily simulated in the lysimeters. The much higher values of aluminum accumulation in the field conditions compared to the lysimeter values at 30-cm GWL suggested that acidity, as represented by aluminum, was generated in the dry season. This acidity generation could be related to the oxidation of the deeper layers when the water level went down as a consequence of evaporation.

As shown in Figure 4, water table raise from week 8 to week 11 (the beginning of rainy season), indicating a net downward flow of water. Yet, aluminum continued to accumulate in the topsoil all treatments: the accumulation at week 11 was greater than that at week 8 (Table 3). The differences among different treatments were, however, not statistically significant. In some treatments, the accumulation during weeks 8-11 was even greater than that during weeks 0-8. Thus, aluminum continued to be brought to the topsoil by evaporative force (during dry spells in between the rains) despite the net downward water flow during the beginning of the rainy season. The findings suggested that the flows in two directions were in two different path ways. The downward flow was mainly the bypass flow in macropores while the upward flow, being capillary rise, was microscopic.

TABLE 4 Accumulation of Al (cmol (+) kg^{-1}) of the topsoil layer (0-10 cm depth) after 8 and 11 weeks of experiment. Treatments included M0 (non-mulching), M1 (mulching), P0 (non-plowing), and P1 (plowing). Al accumulation was the difference between the soluble aluminum concentration at the sampling time and at the start of the experiment.

Treatment	P0	P1	Difference
Week 8			
M0	2.02	0.64	1.38 ns
M1	0.59	0.63	-0.04 ns
Difference	1.43 *	0.01 ns	
Week 11			
M0	3.78	2.02	1.76 ns
M1	2.53	2.29	0.24 ns
Difference	1.25 ns	-0.17 ns	

* significant at 5% level
ns not significant

There was also an increase in aluminum concentration in the ground water at beginning of the rainy season (i.e. week 8 to 11, Figure 6). The increase in aluminum both in the topsoil and the ground water supported the hypothesis that extra acidity was generated during the dry season.

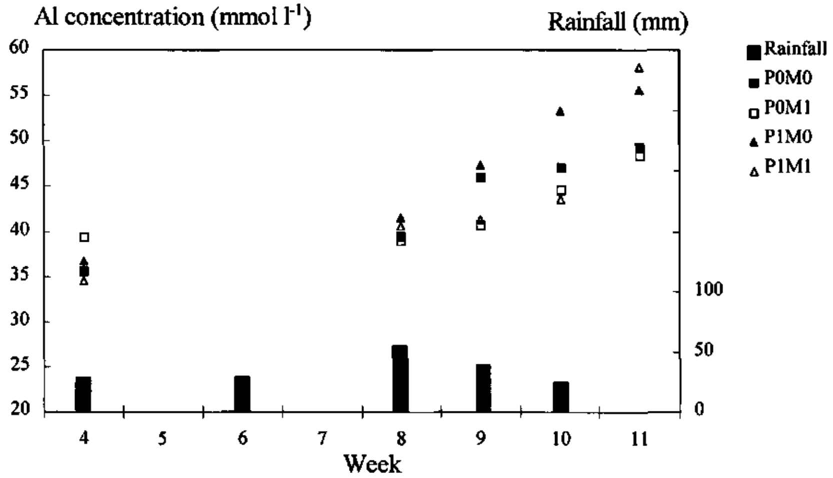

FIGURE 6 Aluminum concentration in groundwater during the beginning of the rainy season. The first rainfall occurred in week 4 from the beginning of the experiment. (P0: non-plowing, P1: plowing; M0: non-mulching, M1: mulching)

CONCLUSIONS

1. In ASS, evaporation is dictated by potential evaporation only under a shallow groundwater level and when the top soil is under natural (untreated) conditions. When the soil surface is covered by mulching or when the soil is plowed, relationship between evaporation and potential evaporation are not related. Discontinuity of capillary system might play an important role in reducing evaporation in plowed soils.

2. Evaporation clearly dictates the rate of accumulation of aluminum in top soil in the ASS area during the dry season. Mulching helps to reduce evaporation rates which, in turn, significantly reduce accumulation of aluminum in top soil, as compared with control plots. Although plowing gave a reduction in aluminum accumulation, this effect was not significant.

3. During the dry season, maintaining GWL at 30 cm might help to prevent further formation of acidity, which can occur under the oxidized conditions when

the ground water level was further lowered. This GWL, therefore, recommendable.

4. At the beginning of the rainy season, the positive effects of soil management treatments on aluminum accumulation during the dry season were diminished due to the raising of groundwater tables by rainfall and the remarkable increasing of toxic concentration in the ground water. This implied that supplementary irrigation at the beginning of rainy season might be an important practice to utilize the effects of early plowing and mulching. When groundwater levels were at about 60 cm, if fresh water is available (in case of a water control system was established), surface irrigation can be very crucial. Irrigation will impose a standing water layer on top of the land surface. This water layer helps to create downward percolation movement. Upward movement of capillary rise during this period (when aluminum concentration is high) can be avoided.

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Chapter 3

ALUMINUM TRANSPORT BY SURFACE RUNOFF AND BYPASS FLOW IN ACID SULPHATE SOIL RAISED BEDS, MEKONG DELTA, VIETNAM

(Paper submitted to J. of Agricultural Water Management)

ALUMINUM TRANSPORT BY SURFACE RUNOFF AND BYPASS FLOW IN ACID SULPHATE SOIL RAISED BEDS, MEKONG DELTA, VIETNAM

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ABSTRACT

The roles of surface runoff and bypass-flow in the removal of aluminum from three types of raised beds were studied in the rainy season in an acid sulphate soil, Mekong Delta, Vietnam. In the low raised bed type only topsoil material was used to construct the bed, in the high type: both top soil and the jarosite layer were used. The "traditional" raised beds also include pyritic material. Runoff amount increased with cumulative rainfall due to the decrease of infiltration rates and saturated hydraulic conductivities. Among three types, traditional gave highest runoff amounts due to surface crusting. Concentrations of aluminum in bypass flow were consistently higher than in runoff. In low and high beds, amounts of aluminum in bypass flow were also higher than in runoff, whereas in traditional type it was slightly lower. All three types posed the same degree of environmental hazard to the surrounding. The low raised bed is more recommendable from the production points of view.

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INTRODUCTION

Resulted from oxidation of reduced S-compounds in pyritic mud, acid sulphate soils are characterized by low pH, and high aluminum, iron and sulphate concentrations (Breemen and Pons, 1978). Farmers often construct raised beds to enhance the leaching of toxicities and to protect upland crops from submergence in flood prone areas (Panichapong 1982, Dent 1992, Sarwani et al. 1993, Tri et al. 1993, Xuan 1993). Raised beds are soil ridges (0.3 to 0.6 m higher than the original surface) formed by piling up soil materials excavated from adjacent lateral ditches (Tri et al. 1993). Depending on the environment conditions and the crops to be cultivated, farmers construct different types of raised beds in different ways (Tri et al. 1993, Xuan 1993, Sterk 1993). Construction of raised beds however invariably creates macropores in between soil lumps (Sterk 1993, Minh et al. 1995).

During a rainfall event on a macropore-dominated soil, two major types of water flow can occur: surface runoff (overland flow) and bypass flow (downward flow) (Falayi and Bouma 1975, Bouma 1990, Roth and Helming 1992). Surface runoff (thereafter called runoff) occurs when rainfall intensity exceeds the infiltration rate of the top soil (Horton 1933). Bypass flow is a rapid downward flow of free water along macropores through an unsaturated soil matrix (Bouma and Dekker 1978). The role of runoff in insecticide, herbicide, fertilizer transporting has been studied (Balwin et al. 1975, Rohde et al. 1981, Sharpley et al 1981a and 1981b, Wallach et al. 1989). In saline soils, runoff may help remove salt accumulated in top soil (Pepper and Morrissey 1985). Similarly, the transport of salts, fertilizers, pesticides and contaminants by bypass flow have been studied intensively (Chichester and Smith 1978, Thomas and Phillips 1979, Bouma et al. 1981, Smolen 1981, Dekker & Bouma 1984, Snyder and Woolhiser 1985, Booltink 1993, Smaling & Bouma 1992).

Most of previous studies on the role of runoff and bypass flow in solute transport were carried out on "natural" soils. Sterk (1993) and Minh et al. (1995) investigated the importance of bypass flow in the removal of toxic substances in acid sulphate soils. Their studies were however carried in laboratory , using undisturbed soil cores. The processes may differ under field conditions. Sterk (1993) also indicated that , under high rainfall intensity and on old raised beds, runoff could account for about one third of the rainfall but the role of runoff in transporting toxicities in acid sulphate soils has not been studied. The relative importance of bypass flow and runoff may depend on the soil chemical and physical properties of the raised beds, which in turn vary with the way the raised beds have been constructed, i.e. on the types of raised beds. An better understanding of the transport mechanism of toxicities by bypass and runoff flow is important in selecting the raised bed types for a particular land use in an environmental setting.

The objectives of this study was to assess the amount of runoff and bypass flow and their effectiveness in removing toxicities, especially aluminum, in different types of raised beds in acid sulphate soils of the Mekong Delta of Vietnam.

METHODOLOGY

Experimental site

This study was conducted at Hoa An station (10°10 N, 106°15 E), Can Tho, Mekong delta, Vietnam. The soil is classified as a very fine Typic Sulfaquept by USDA system (Soil Survey Staff 1975) with a high organic matter content in the 30 cm top soil (Hanhart and Ni 1993). At 30-40 cm depth, their exists a firm layer of remarkable low saturated hydraulic conductivity. This layer is not a plow pan since the soil has never been cultivated (Hanhart and Ni 1993). The sulfuric horizon with yellow mottles of jarosite is found from 40-cm to 120-cm depth. Deeper than 120 cm, there is a grey permanently reduced sulfidic horizon is located. The soil was originally uncultivated and covered by *Eliocharis dulcis*.

The climate of the experimental site is characterized by two distinct seasons, a dry season from January to May and a rainy season from July to December, which receives about 80-90% of the annual rainfall of 1800 mm. Evaporation rate is relatively high (5.0 to 6.5 mm d^{-1}) in the dry season and low (4.0 mm d^{-1}) in the rainy season (Tin 1985).

Raised beds and experimental layout

Raised beds are built in different ways in the Mekong delta depending on the environmental conditions. Their width is often controlled by crop type, whereas their length by the configuration of the parcel owned by the farmer. Their height, influenced by the flooding depth and crop type, determine the way they are constructed. Basing on the raised beds height and method of construction, previous investigators (Sterk 1993, Tri 1993) classified the raised beds into three types: "traditional", "low" and "high" (Figure 1):

- The traditional type (0.7 m higher than the original soil surface) was constructed by piling up the soil material in the same order as it was excavated. Consequently, soil layers in the raised bed are arranged in a reverse order as compared with natural soil. Pyritic soil material was put on top of the raised beds.
- The low type (0.3 m higher than the original soil surface) often built in shallow-flooded areas. Because the amount of soil material required to build this type is low, only shallow ditches (about 0.4 m deep) were excavated and only top-soil material was used to form the raised bed.
- The high type (0.5 m higher than the original soil surface), often found in the moderately-flooded area, is constructed with soil material taken from ditches of about 0.6 m deep. The top-soil material is first excavated and set aside at one side of the raised bed. This is followed by the excavation and spreading out the sulfuric material on the top of the original soil surface. Finally, the set aside top-soil material is spread out to cover the ulfuric material on the raised beds. Often, some sulfuric material is mixed with top-soil material and exposed on the surface of the raised bed.

All three types of raised beds were investigated in this study. The experimented raised beds were constructed in at the end of 1993 dry season. After the construction, they were left uncultivated and subjected to leaching during the first rainy season as commonly practiced by farmers in the Mekong Delta. After this fallow period, level of toxicity in raised beds was reduced by leaching and upland crops like pineapple, yam, sugar cane, etc. can be cultivated (Xuan 1993).

The experiment was carried out from February to July 1994. The experimental field was divided into 9 plots (3 replications vs. 3 raised bed types) following random block design. Each plot, 10 m long, consisted of 2 raised beds (4 m wide) and 3 lateral ditches (3 m wide), was isolated from the surrounding by earthen bunds. Table 1 characterizes some physical and chemical properties of the top layer (0-10 cm) of different types of raised beds at the beginning of the study.

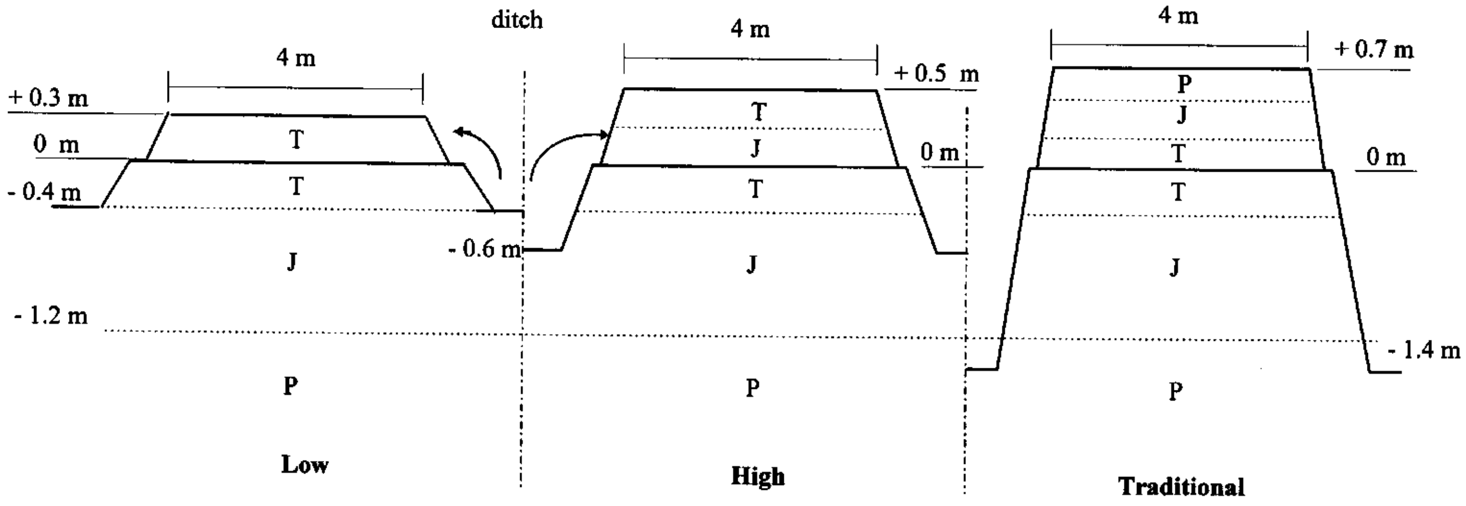

FIGURE 1 Schematic cross section of different types of raised beds (low, high and traditional). Soil material for raised bed construction was is indicated by T (top soil), J (sulfuric material), P (sulfidic material).

TABLE 1 Some chemical and physical properties characterize the top layer (0-10 cm) of different types of raised beds at Hoa An station. Numbers in parentheses are standard derivation.

Types of beds	Al † cmol(+)kg^{-1}	pH ‡	Bulk density Mg m^3	Clay %	Silt %	Sand %
Low	11.6 (3.9)	3.9	0.65 (0.21)	48.4	33.7	17.9
High	13.5 (5.9)	3.4	0.77 (0.33)	59.8	38.5	1.7
Traditional	21.8 (8.4)	3.1	0.82 (0.34)	52.7	42.6	4.7

† Extracted by 1 M KCl (1:2.5)

‡ H_2O (1:2.5)

A culvert made of 20-cm in diameter PVC tube connected each ditch to surrounding canals. Through the culvert, water collected in the ditch can be drained to the surrounding canal by opening a PVC cap attached to the culvert. A gauge for measuring water depth was installed in the central ditch of each plot. The water gauge readings were recorded daily and before and after each drainage. For each reading, the volume of water in the ditch could be derived, using a volume-depth relation previously determined for each ditch.

Measurement of flow components

Sterk (1993) reported that bypass flow and runoff were dominant flow processes in raised bed soils. We therefore neglected the components of infiltration into the dense clods and vertical displacement of water. The concept of microcatchment (Falayi and Bouma 1975, Bisonnais et al. 1989, Roo and Riezebos 1992) was used to quantify the runoff from the raised beds. The catchment was constructed by PVC tubes (15 cm long and 40 cm in diameter), which were sharpened, greased, and hammered slowly into the soil to a depth of 10 cm. A 1-cm diameter overflow hole was punched at a height of 5 mm above the soil surface. The amount of surface runoff after each rain was collected into a bottle collector via a hard tygon tube connected though the overflow hole into the bottle. The runoff could be converted into runoff depth by dividing the collected volume to the surface of the microcatchment.

Because of the difficulty in *in situ* measurement, bypass flow was not directly measured, but calculated from the water balance of the central ditch in of each plot (Figure 2), using the following equation [1] for each day when rainfall and drainage took place (all terms are in m^3). In figure 2, it was assumed that the central ditch in each plot collected runoff and bypass flow from the two halves of adjacent raised beds. The area responsible for the runoff and bypass flow thus equaled to the area of one raised bed.

$$R + Ro + By - E - Dr = W_2 - W_1 \qquad [1]$$

R is the amount of rainfall felt directly to the ditch. This was calculated multiplying the depth of precipitation (P, in m , measured by a rain gauge) by surface area of the central ditch (in m). Ro is the amount of runoff found by multiplying the runoff depth (measured as mentioned above, in m) by surface area of the raised bed. E is the volume of water evaporated from the ditch, derived from the Class A pan evaporation and the ditch surface. Dr is the volume of the drainage water, derived from the water depth gauge readings before and after the drainage. W_2 and W_1 are the dead water storages in the ditch, derived from the water gauge readings at the end and beginning of the rainy day. The volume of the bypass flow, By, can thus be calculated from equation [1].

Measurement water quality and aluminum balance

Water sample was taken every morning from each of the central ditch, using 200-cc water bottles. On each rainy day, water in the central ditch was again sampled after the drainage. For each rainy day, the two drainage water samples and water from the runoff collector were analyzed for aluminum concentration and pH, using method by Begheijn (1980).

Since water in the ditches was usually very acid (with pH ranged from 2.5 to 3.8), precipitation of aluminum (which possibly occurred at pH > 4) was not expected to occur in ditch water. Under this condition, the aluminum concentration in the bypass water (C_B) can be calculated, using the aluminum mass balance for all flow components following the equation:

$$C_B.By = C_D.Dr + C_E.E - C_R.R - C_{RO}.Ro + (C_{W1}.W_1 - C_{W2}.W_2) \qquad [2]$$

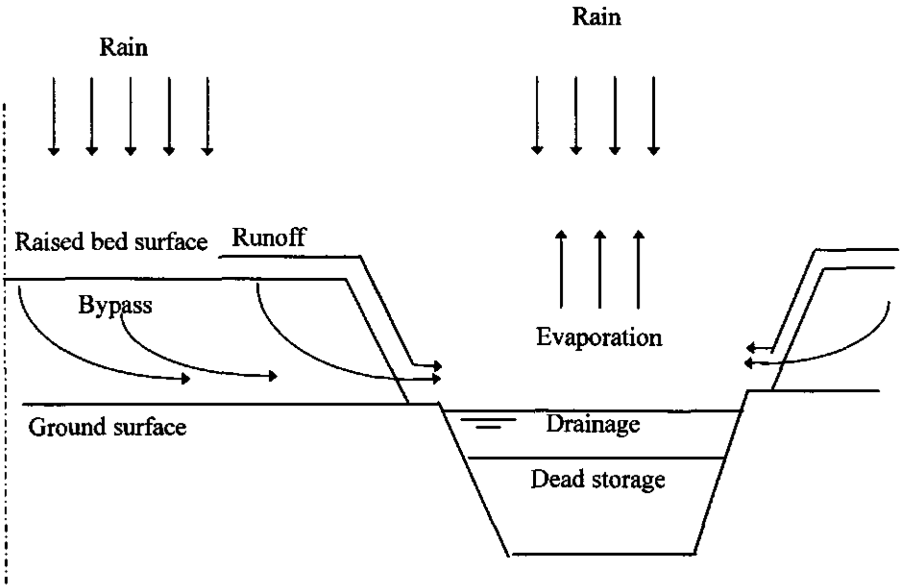

FIGURE 2 Water balance components of a ditch in between two raised beds

or

$$C_B = [C_D.Dr + C_E.E - C_R.R - C_{RO}.Ro + (C_{W1}.W_1 - C_{W2}.W_2)] / By \quad [2']$$

In the above equations all water balance terms , defined in equation [1], were converted into liters to be consistent with the unit expressing all aluminum concentration in mmol(+)l^{-1}:

C_D is aluminum concentration in drainage water

C_E and C_R are aluminum concentration in evaporation water and rainfall. They were set to zero in our calculation.

C_{RO} is aluminum concentration in runoff

C_{W1} is the aluminum concentration of dead storage water before the rainfall event, sampled in the morning of the rainy day.

C_{W2} is the aluminum concentration of dead storage water after the rainfall event, sampled in the morning of the rainy day. This is the same as C_D

Soil hydraulic properties

Infiltration characteristics of each experimental plot was studied in April (at the beginning of the experiment and the end of the dry season) and in the July (mid rainy season) by the double-ring method with 60-minute infiltration time.

Saturated hydraulic conductivity of the top layer (0-10 cm) of each type of raised bed was measured bi-weekly, with undisturbed cores, using 15 cm long, 20 cm diameter. PVC tubes and following method described by Booltink and Bouma (1991). It was expected that rainfall would create crusts on the raised bed surfaces. Rain water may also wash fine particles into the macropores in between soil lumps. These may reduce the overall saturated conductivity of the top soil. The saturated conductivity (k_S) was expressed as a function of cumulative rainfall, P_{cu}:

$$k_S = k_{Si} \cdot \exp(b\, P_{cu}) \qquad [3]$$

where k_{Si} is the saturated hydraulic conductivity of the top layer of the raised beds (in mm s^{-1}) at the beginning of the experiment, b is a fitting constant.

RESULTS AND DISCUSSION

Hydraulic characteristics of the top layers raised beds

Infiltration

In all types of raised beds, the one-hour cumulative infiltration (CI) in July was much less than that measured in April (Table 2 and Figure 3). In the low raised beds, the April cumulative infiltration was 392 mm compared with 68 mm for the July value. Corresponding values for the high raised beds were 320 mm and 47 mm and for the traditional raised beds 105 mm and 28 mm. In general, there was approximately 80% reduction in cumulative infiltration in between the two periods of measurement.

For all raised bed types and at for both measuring times, slope of the cumulative infiltration came to rather constant values, indicating steady infiltration rates were reached, after about 30 minutes from the start of the infiltration tests (Figure 3). Similar to the cumulative infiltration, the steady infiltration rates measured in July were about 7 to 11 times smaller than those measured in April (Table 2). The decrease in the steady infiltration rates was higher in the high (from 3.70 mm min^{-1} in April to 0.30 mm min^{-1} in July) and in traditional raised beds (0.50 mm min^{-1} to 0.04 mm min^{-1}) than in the low raised bed type (3.50 mm min^{-1} to 0.47 mm min^{-1}).

Among three types, low beds consistently had the highest cumulative infiltration values (in April and also in July). Traditional beds had the lowest values of cumulative infiltration.

From April to July, values of cumulative infiltration reduced about 6 times for low type, 7 times for high type, and 4 times for traditional. Low bed composed only with soil lumps from the top soil material with high organic matter content (Hanhart and Ni 1993) and with low bulk density (Table 1). This condition is more favorable for infiltration process compared with high type (composed partly with top soil material and partly with sulphiric material, which is less organic matter and high clay content). Traditional type had lowest value of cumulative infiltration possibly due to the sulphidic material found on its top. This muddy material might block the interplanar pores formed between adjacent soil lumps. These pores in turn have strong influence in infiltration process.

Saturated hydraulic conductivity

High correlation coefficients were found for all raised bed types between k_{s} and P_{cu} following equation [3]. The coefficient of determinant, r^2, ranged from 0.77 to 0.93 (Table 3). The initial saturated conductivity k_{si} were slightly different among the raised bed types. The differences were however not significant. At the beginning of the experiment in April the overall saturated conductivity was predominantly controlled by the macropore network (Bouma et al. 1978). As the experiment proceeded, saturated conductivity decreased rapidly. The findings agreed with Edwards and Larson (1969) who found an exponential decrease of saturated hydraulic conductivity with cumulative rainfall. The decrease was probably due to the blockage of macropore system by soil fragments which were dispersed by raindrops impact and moved with the water down the sides of clods, to be deposited at the points of contact between clods (Falayi and Bouma 1975) . Crust formation caused by rain drop impacts may be another reason for the decrease in the saturated conductivity (Falayi and Bouma 1975, Sharma et al. 1983).

TABLE 2 Cumulative infiltration, steady-state infiltration rate, soil moisture content and their standard deviations (in parentheses) of different types of raised beds measured in April and July.

	Types of raised beds		
	Low	High	Traditional
Soil moisture content (cm^3 cm^{-3})			
April	0.17 (0.05)	0.12 (0.07)	0.11 (0.03)
July	0.32 (0.11)	0.34 (0.10)	0.21 (0.04)
Cumulative infiltration in 60 min (mm)			
April	392.0 (171.7)	320.0 (105.3)	105.0 (18.8)
July	67.7 (26.6)	47.0 (2.5)	27.5 (2.3)
Steady-state infiltration rate (mm min^{-1})			
April	3.50 (1.73)	3.70 (1.72)	0.50 (0.38)
July	0.47 (0.43)	0.30 (0.20)	0.04 (0.01)

TABLE 3 Parameters characterizing the relationship between saturated hydraulic conductivities (k_S , mm s^{-1}) of the top layer (0-10 cm) and cumulative rainfall (P_{cu}, mm) for different types of raised beds. Fitting function is $k_S = k_{Si} \cdot \exp(b\, P_{cu})$, where k_{Si} is the saturated hydraulic conductivity of the top layer of the raised beds (in mm s^{-1}) at the beginning of the experiment, b is a fitting constant.

Type of raised bed	k_{Si}	b	r^2
Low	2.75 E-05	-0.0029	0.77
High	1.74 E-05	-0.0041	0.93
Traditional	3.10 E-05	-0.0066	0.96

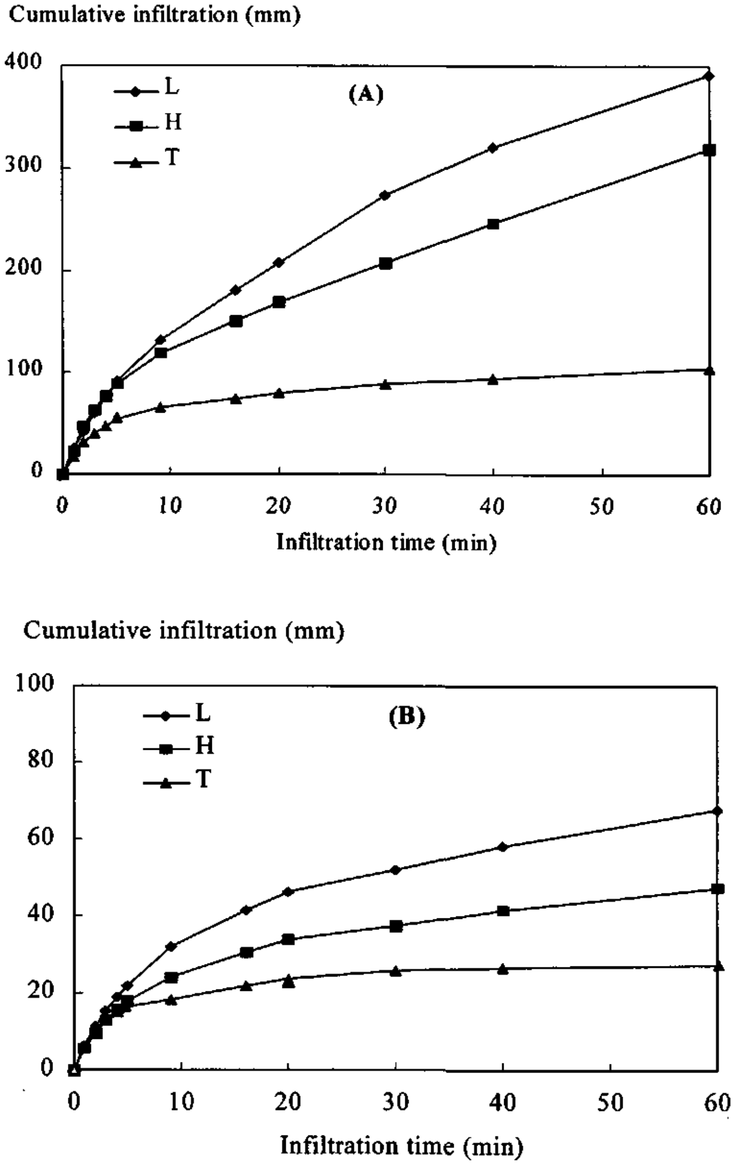

FIGURE 3
Cumulative infiltration of different types of raised beds (L: low, H; high, and T: traditional) in April (A) and July (B). Each data point is the mean value of 3 replications.

The absolute values of b, indicating the rate of decline of k_S with respect to cumulative rainfall, were highest for the traditional raised beds, followed by the high type and the low type. In other words, the conductivity of the traditional raised beds reduced the most rapidly with respect to cumulative rainfall. This agreed with the more rapid crust formation in the traditional raised beds. Due to the high organic matter content of the top soils in the low raised beds, soil structure was more stable, resulting in less rapid reduction in saturated conductivity compared to other types of raised bed.

Surface runoff

Runoff started on traditionally raised beds at week 5 after the first rain, when cumulative rainfall was 166 mm. On the other two types runoff started at a cumulative rainfall of about 210 mm (Figure 4). Cumulative runoff depth increased most rapidly in the traditional raised beds, followed by the high raised beds and the low type (Fig. 4). By the end of the experiment, cumulative runoff depth from low raised beds was 55.0 mm (corresponding to 11.7 % of total rainfall) compared with 66.3 mm of high raised beds (14.0 %) and with 109.0 (23.1 %) of the traditional type. The increase of runoff depth with cumulative rainfall corresponded to the decrease in infiltration rate and hydraulic conductivity discussed previously. The increase in soil moisture content further reduced the soil intake capacity and increased runoff toward the end of the experiment. Hino et al (1988) found a similar trend of runoff increasing with increased water content in a lysimeter study. Higher runoff in the traditional were related to the thicker crust and the sealing of macropores compared to other two types. The increase of runoff and the corresponding decrease of cumulative infiltration with increased crust thickness were also reported by Roth and Helming (1992).

Aluminum concentration in runoff and in bypass flow

Figure 5 shows weekly mean values of aluminum concentration in the runoff and the bypass water from different types of raised beds. Aluminum concentration in bypass water was consistently higher than concentrations in runoff (Figure 5). Aluminum concentration in bypass water tended to increase with time. In week 5 (from the first rain), when runoff process started on the traditional raised beds, the low type gave lowest concentration (8 mmol(+) l^{-1}) in comparison with the high type (12 mmol(+) l^{-1}) and the traditional one (9 mmol(+) l^{-1}). Aluminum concentration in bypass flow from the low and high raised beds increased steadily from week 5 to the end of the experiment (week 10). While, the traditional type showed some decrease of aluminum concentration at the end of the experiment (weeks 9 and 10).

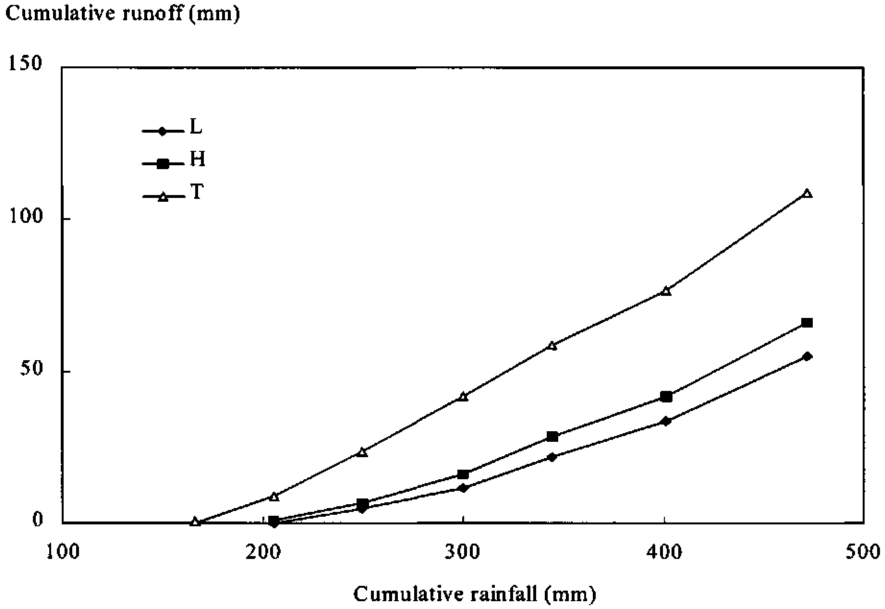

FIGURE 4 Cumulative runoff from different types of raised beds (L: low, H: high, and T: traditional) as a function of cumulative rainfall from start of the experiment (April) to July. Each data point is the mean value of 3 replications.

Aluminum concentration in runoff water of all types of raised beds increased with time until about week 8 (9 mmol(+) l^{-1} for the low type, 13 mmol(+) l^{-1} for the high type and 14 mmol(+) l^{-1} for the traditional type). Thereafter, there was a tendency to decrease in the concentrations.

Compared aluminum concentration of runoff water among the three types, highest values were consistently found in the traditional type (Figure 5). This was probably due to a higher aluminum content in the top layer as it contains more oxidized pyritic material (Table 1).

The degree of continuity of macropores might be higher in low and high types than in the traditional type. Macropore systems strongly governed bypass flow and, possibly, its aluminum concentration. With a very complex geometry, macropores might give a longer path for bypass flow compared with runoff, which flows on a rather straight path (formed by bed surface and its side). Along this long water-conducted path, bypass flow can have more change to dissolve soluble aluminum accumulated on the soil lump surface. Therefore the contact change can be less than bypass. Besides, during the first part of one rainfall event, when soluble aluminum accumulated on bed surface (ready to be transported) is still high in concentration, infiltration did not take place. This high aluminum content water might be absorbed into the soil lumps or, possibly, move downward as bypass flow. In short, infiltration only takes place when soluble aluminum concentration in top soil was relatively low.

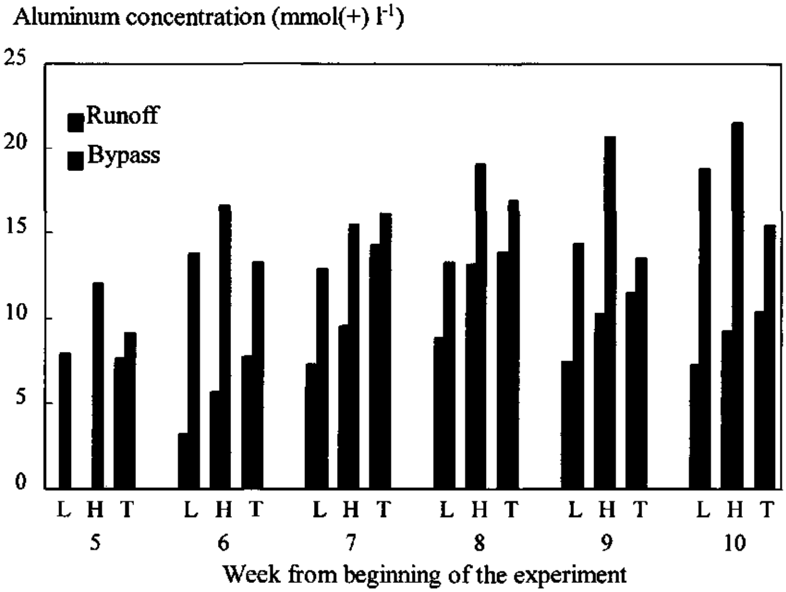

FIGURE 5 Al concentration in bypass and surface runoff water from three types of raised beds (L: low, H; high, and T: traditional). Runoff started in week 5 from beginning of the rainy season. Week 10 was the end of the study.

Minh et al. (1995) reported that when three one-day-interval consecutive showers applied, a significant increase of aluminum concentration of bypass with number of showers found. Their postulation was that after one shower, absorption capacity of the soil lumps decreased with an increased soil water content. Therefore, amount of water available for bypass flow was higher from one shower to the others. Consequently, contact areas between water and soil increased with increased amount of bypass flow.

Total aluminum released to runoff and bypass water

Table 4 shows total aluminum released from the soil to runoff and bypass water. It indicates the importance of each flow process in removing soluble aluminum from different types of raised beds. Total amounts of aluminum drained to surrounding (in runoff and bypass flows together) were not significant different between three types (Table 4). However, each flow component contributed significantly differently into the total amounts of aluminum released. The amount of aluminum in the bypass flow was significantly higher than that in the runoff in the low 20 kmol(+) ha^{-1} for bypass compared with 4 kmol(+) ha^{-1} for runoff) and in the high type (16 kmol(+) ha^{-1} in bypass and 6 kmol(+) l^{-1} in runoff). In the traditional bed, however, this difference was not significant (11 kmol(+) ha^{-1} and 12 kmol(+) ha^{-1}, respectively).

High and low beds released significantly less aluminum into runoff than the traditional type (4 kmol(+) $ha^{-1}$and 6 kmol(+) ha^{-1} compared with 12 kmol(+) ha^{-1}, respectively). A reverse tendency was, however, found for bypass where aluminum removed from the soil of low and high beds was significantly higher than from traditional bed (20 kmol(+)ha^{-1} and 16 kmol(+) ha^{-1} compared with 11 kmol(+) ha^{-1}, respectively). The high value of aluminum released to runoff in the traditional bed was due to the relatively high amount of runoff in this type of raised bed and due to higher aluminum content of its top soil material.

Since three types of raised bed released about the same total amount of aluminum, they posed the same degree of environmental hazard to the surroundings. Runoff can remove solute only in a thin layer (2 cm) of the very top part of the soil surface (Ahuja and Lehman 1983). Bypass flow can be more effective than runoff in improving ASS since it can remove more toxicities at deeper layer. The low raised bed type may thus be more recommendable from the production point of view.

TABLE 4

Total aluminum (kmol(+) ha^{-1}) released in bypass flow and runoff water from different types of raised beds

Type of raised bed	Runoff	Bypass	Total
Low	4.0 b	20.1 a	24.1 a
High	6.5 b	16.2 a	22.7 a
Traditional	11.9 a	11.3 b	23.2 a

In a column, means followed by a common letter are not significantly different at the 5% level by DMRT.

CONCLUSIONS

1. Method of microcatchment can be applied to study runoff and bypass flow under raised bed conditions. With a straightforward and simple calculation based on water balance, bypass flow can be determined under field conditions. Together with a soluble balance equation, similarly to the salt balance equation frequently used in saline soils, in ASS aluminum concentration in bypass flow can also be calculated.

2. Total amounts of aluminum (from runoff and bypass flows) released to the surrounding areas were not significantly different among three types of beds. In other words, there were no difference in negative impact to the environment between three types of raised bed construction. Consequently, low type is recommended because of its effectiveness of leaching.

3. The traditional type of construction of raised beds, which is already chemically damageful, creates physically adverse conditions (crust formation) which hinder aluminum leaching.

4. Bypass plays a significantly more important role in leaching aluminum from low and high beds than runoff. In all three types of raised beds, aluminum concentrations in bypass flow are higher than in runoff. Total removal of aluminum by bypass flow is significantly higher than runoff in low and high beds. In the traditional beds, the difference between these two flows is not significant.

5. Runoff increases with the increased cumulative rainfall (especially in week 9 and 10 from the rainy season started). Meanwhile, aluminum concentrations in runoff during this period are decreased. Combination of these two effects gives a low effectiveness in removal of aluminum. Reducing or preventing runoff on top of raised beds (by hoeing, for instance) at the middle of rainy season is possibly a good measure to improve leaching efficiency.

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Chapter 4

BYPASS FLOW AND ITS ROLE IN LEACHING OF RAISED BEDS UNDER DIFFERENT LAND USE TYPES ON AN ACID SULPHATE SOIL

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BYPASS FLOW AND ITS ROLE IN LEACHING OF RAISED BEDS UNDER DIFFERENT LAND USE TYPES ON AN ACID SULPHATE SOIL

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ABSTRACT

A better understanding of leaching processes in raised beds is useful in assessing management options for acid sulphate soils. Field and laboratory studies were carried out to quantify the effects of soil physical properties and bypass flow on leaching processes of new, 1-year old and 2-year old raised beds for yam and pineapple cultivation in a Typic Sulfaquept in Tien Giang, Vietnam. The methylene blue staining technique was used to characterize the water-conducting pores in terms of number, stained area, and total pore perimeter at 10-cm depth intervals of six 1 x 1m subplots. Undisturbed 20 cm x 25 cm soil cores taken from the raised beds were subjected to three 30 mm h^{-1} rains. Volume, aluminum and sulphate concentration of the outflows were monitored. Consolidation with time decreased the area and perimeter of water-conducting pores in 2-year old pineapple beds to about a third, and bypass flow rate to about 80% of those in newly constructed beds. Consolidation did not affect macropore network geometry in yam beds because they were subjected to annual tillage and yam tubers were uprooted regularly. Al^{3+} and SO_4^{2-} concentrations in the outflows of the newly constructed and 1-year old raised beds were higher in pineapple, while those in 2-year raised beds were higher in yam.

1. INTRODUCTION

There are an estimated 12 million hectares of acid sulphate soils (ASS) in the world. Most of these soils are located in low-lying coastal plains, often subjected to flooding during the wet season. Resulting from oxidation of reduced S-compounds in pyritic mud, these soils are also characterized by low pH, and high

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aluminum, iron and sulphate concentrations (Breemen and Pons, 1978). Farmers in South east Asia construct raised beds -- i.e. piling up soil materials excavated from adjacent lateral ditches to form ridges 0.3 to 0.6 m higher than the original ground surface to avoid flooding in the rainy season -- to grow upland crops on ASS. Raised beds also enhance the drainage and leaching of toxic elements from the root zone (Dent, 1986; Sarwani et al., 1993; Tri et al., 1993; Xuan, 1993).

The piling up of excavated materials creates large voids between soil clods, forming a network of macropores. Water can move in the macropores, by passing the unsaturated soil matrix (Bouma, 1990). Previous studies indicate that macropore geometry and bypass flow strongly affect salt movement and leaching of fertilizers, pesticides, and other contaminants in soils with "natural" macropore systems which are formed by shrinkage upon drying, by plant roots, and by soil fauna (Chichester and Smith, 1978; Thomas and Phillips, 1979; Bouma et al., 1981; Dekker and Bouma, 1984; Smaling and Bouma, 1992; Booltink et al., 1993). The effects of bypass flow in the "man-made" macropores -- such as in the raised beds-- on leaching of ASS are less understood. Solute transport in ASS is probably the most complex of all soil processes because soil structure changes continuously as a result of swelling and shrinkage while complex chemical transformations create a soil solution with highly variable composition (Bouma et al., 1993). Sterk (1993) and Tuong (1993) recognized the importance of bypass flow in the leaching of ASS but they did not quantify the macropore geometry, the associated bypass flow and its influence on the leaching process of raised beds in ASS. These data are important in assessing soil management options and possible environmental hazards caused by leachates from different land uses in the ASS areas (Minh et al., 1995).

This study was conducted to (i) obtain a more quantitative understanding of the bypass flow process and its role in the leaching of toxic substances in raised beds in ASS, and to (ii) compare the processes in two different land use types in Vietnam --for yam and for pineapple cultivation.

2. ENVIRONMENT AND LAND USE TYPES OF THE STUDY SITE

2.1. Soil, climate, and hydrology

We carried out our field study in April - June 1993 in Tien Giang province (10°25' N, 106° 06' E), Vietnam. Using the USDA Soil Taxonomy System (Soil Survey

Staff, 1975), the natural soil was classified as a Typic Sulfaquept. The top soil (0-40 cm) had 28% organic matter content. The sulfuric horizon (40-85 cm) was characterized by pH < 3.5, high Al^{3+} (Table 1) and presence of jarosite [$KFe_3(SO_4)_2(OH)_6$] mottles. The pyrite layer, deeper than 85 cm, contained sulphidic materials with high SO_4^{2-}concentration (Table 1). All soil horizons had more than 50% clay (Table 1).

TABLE 1 Some physical and chemical characteristics of the natural soil at the study site.

Horizon	Depth (m)	Sand (%)	Silt (%)	Clay (%)	Bulk density ($Mg\ m^{-3}$)	pH	Al^{3+} ($cmol(+)kg^{-1}$)
Top soil	0-0.4	0.6	44.2	55.2	0.867	3.45	14.85
Sulfuric	0.4-0.95	2.4	40.3	57.3	1.070	3.32	18.75
Sulfidic	0.95	6.9	42.2	50.9	0.946	4.23	3.33

The study site has two distinct seasons: a dry season (December - April) with virtually no rain and a rainy season (May - November) with more than 90% of the annual rainfall of 1,300 mm (Fig. 1). Heavy rainfall in the wet season and river overflow create floods which start annually in July-August and recede in November. At the peak of the flood, in October, the soil surface is under a water depth of 0.4 - 0.6 m (Fig. 1).

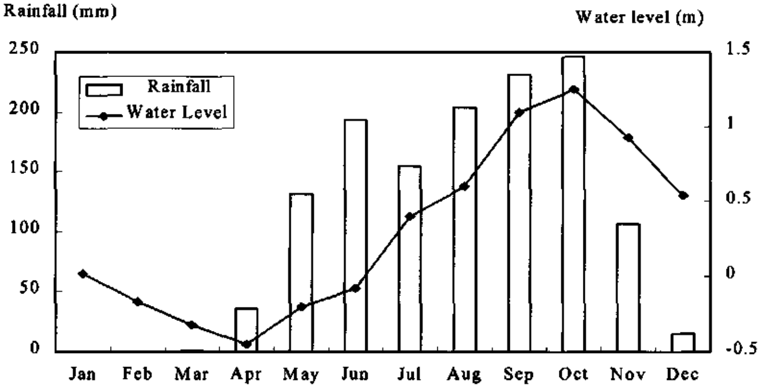

FIGURE 1 Monthly rainfall distribution (My Tho station, 30 km from the study site) and monthly water level in Vam Co river (15 km from the site).

Elevations of water and ground surface are above mean sea level.

2.2. Raised beds for yam and pineapple

Originally, the area was uncultivated and covered by *Melaleuca cajiputi*. Since 1990, part of the area has been reclaimed for agricultural production with yam (*Dioscorea esculanta*), pineapple, and rice as main crops. Yam and pineapple are planted on raised beds with soil excavated from adjacent lateral ditches (Fig. 2).

Raised beds for yam are 0.3-0.4 m higher than the natural soil surface. Only the top layer of the natural soil is used for raising the ridges (Fig. 2). The raised beds are often constructed in February and left fallow during the remainder of the dry season and the following rainy season. As the flood arrives, the ridges are gradually submerged to reduce toxic substances (Xuan, 1993). As the flood subsides, the raised beds are tilled and yam cuttings are planted in December. The crop is harvested in June of the following year, before the whole raised bed is submerged again under flood water. Raised beds are tilled, cuttings are planted again during the flood recession and the whole cycle is repeated annually (Tri et al., 1993; Xuan, 1993).

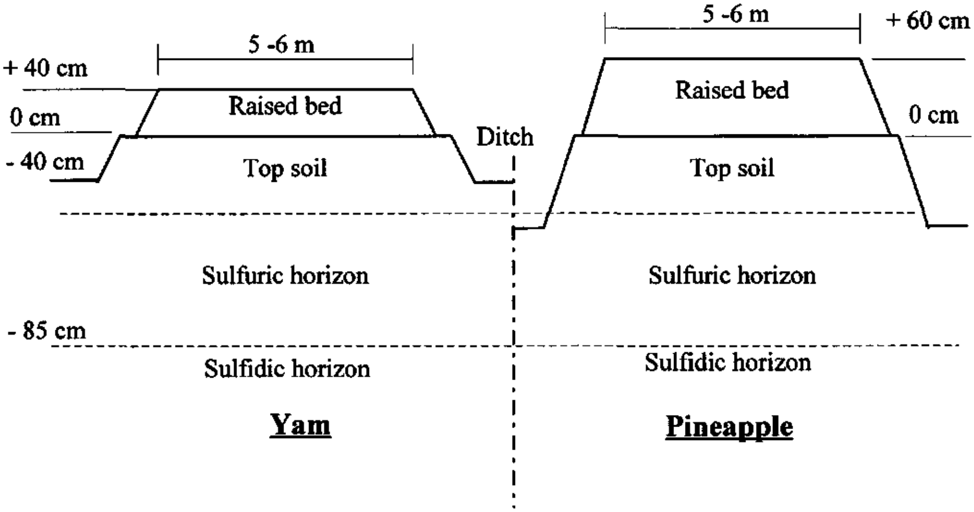

FIGURE 2 Schematic cross section of raised beds.

Raised beds for pineapple were similarly constructed in February. Both top soil and soil materials from the sulfuric horizon are used to raise the height of the ridges to 0.6-0.8 m above the natural soil surface (Fig. 2), keeping the ridge surface 0.2-0.3 m above peak flood level. After being left fallow for one rainy season, the raised beds are tilled and pineapple shoots are planted in December. The first fruit picking is carried out about one year later. Subsequent harvests are carried out annually for about 3 to 5 years. During this period, the plants remain on the raised beds without further land preparation and replanting.

3. Materials and methods

3.1. Chemical and physical properties of raised bed soils

The study was carried out on 6 typical raised beds:

- Y0: constructed for yam cultivation in February 1993. At the time of the study, Y0 has not been cultivated,
- Y1: constructed for yam cultivation in February 1992, has been planted to yam since December 1992,
- Y2: constructed for yam cultivation in February 1991, planted to yam from December 1991 to June 1992 and from December 1992 to the study period,
- P0: constructed for pineapple cultivation in February 1993. At the time of the study, P0 has not been cultivated,
- P1: constructed in February 1992, planted to pineapple since December 1992,
- P2: constructed in February 1991, planted to pineapple since December 1991.

Hereafter, the above mentioned raised beds are sometimes referred to as treatments.

Soil samples for chemical and physical analyses were taken in April 1993. This sampling time was selected because toxicity accumulation at the soil surface was at its peak at the end of the dry season, differences in soil properties and in leaching effectiveness in the different treatments could easily be studied.

On each of the selected raised beds , one composite soil sample was taken at 0-20 cm depth. The soil samples were prepared to determine pH (in 1:2.5 extract), Al^{3+}, SO_4^{2-}, and total acidity using the methods by Begheijn (1980). These are the most common indicators of toxicity in ASS. Al^{3+}, in particular, has high potential toxicity for plant roots (Thowornwong and van Diest, 1974).

Dry bulk density and initial soil moisture content of the top soil of each raised bed were determined from fresh and oven-dry weight of three undisturbed core samples, 20 cm in diameter and 25 cm long. The large size was necessary to take into account the heterogeneity of the macropore-dominated soils.

3.2. Soil morphology and macropore characterization

Careful morphological study was carried out for each of the selected raised beds. Special attention was given to soil structure; size and distribution of soil clods; size and distribution of voids, cracks and pores; color and hue (using the Munsell chart) of different soil layers; presence of half-decomposed organic matter; and occurrence of jarosite mottles.

To quantify the amount and distribution of the water-conducting pores, a staining method was used. The method was selected because of its simplicity and accuracy (Bouma and Dekker, 1978; Bouma, 1984). Thirty liters of concentrated methylene blue dye solution was sprayed on a 1 m x 1 m area on each of the selected raised beds. One hour after, the soil was excavated at 10-cm depth intervals until the original ground surface was reached. At each cross section, the observed water-conducting pores (stained by the dye) were traced on a transparent plastic sheet. The stained patterns on each sheet were fed into a computer by an AGVISION computer-imaging analysis system which consists of a video digitizer (with resolution of 512 X 488 pixels and 256 gray levels) and a CDD video camera (RS170 type, with the resolution of 510 X 490 pixels). Data were analyzed by AgImage Plus 1.03 software. The outputs included the position (in x-y coordinates), area, and perimeter of each stain pattern.

The number of stains indicates the amount of water-conducting pores in each cross section. Water-conducting capacity of soil pores is determined by their size, geometry, and continuity. Bouma and Dekker (1978) used the term "intermediate" pores to describe very fine pores inside peds which conduct liquid very slowly. Brewer (1964), quoted by Beven and Germann (1982), has defined fine macropores (as those with equivalent diameter (D) of 1-5 mm) and very fine macropores as those with (D = 0.075 - 1 mm). The definition of mesopores (D < 1 mm) to macropores (D >= 1 mm) by Luxmoore et al. (1990) is used in this paper. The criterion used to distinguish meso- to macropores was changed slightly to take into account better the effect of pore geometry on the flow. We used hydraulic radius (R_h). R_h, a measurement widely used in hydraulics (Chow, 1965), is the ratio of wetted cross sectional area (an indication of the flow capacity) divided by the wetted perimeter (an indication of the friction to the flow) of the conduit. Mesopores were pores with R_h smaller than 1 mm; macropores were pores with $R_h > 1$ mm.

3.3. *Bypass flow and leaching experiment*

The bypass flow and leaching processes of soils in the raised bed were studied in a laboratory experiment using 18 soil cores 20 cm in diameter and 25 cm long. Three samples were taken from each of the selected raised beds in April 1993. Samplers were sharpened at the bottom edge and greased on the inside before sampling to reduce friction, which may cause consolidation of samples and may prevent edge-flow along the wall (Smaling and Bouma, 1992).

Rainfall simulators made of needle arrays (Booltink and Bouma, 1991) were used to apply rainfall to the top of the soil cores. Each core was subjected to three showers, each of them had intensity of approximately 30 mm h^{-1} and lasted for one hour. The period between showers was 24 hours. The applied intensity corresponded to a 50% probability of occurrence in May and June (beginning of the rainy season, when leaching is most effective) at the study site.

The outflow was collected from a funnel at the bottom of each sample. Time from the start of rainfall application to the start (Ts) and end (Te) of outflow was recorded. Every 5 minutes, the outflow of water was characterized in terms of volume, EC, and pH. The outflow was sampled in 50 cm^3 bottles at 15, 25, 35, 45, and 55 minutes after the start of rainfall application for aluminum and sulfate determination (Begheijn, 1980). Samples were weighed before each rainfall application and at the end of the experiment to calculate average soil moisture content and absorption of water after each rainfall.

4. Results and discussion

4.1. *Physical properties and morphology of the raised bed top soil*

Each raised bed consisted of an excavated top layer (20-30 cm for yam 40-50 cm for pineapple) overlaying the original soil. The bulk density of the excavated top layer was higher than that of the natural soil (Tables 1 and 2). For pineapple, dry bulk density increased with age of the raised beds (Table 2).

The soil matrix of the excavated layer of the yam raised beds was dark gray (Munsell chart: 5YR4/1 for new raised beds) to brownish black (10YR3/1 for 1-

and 2-year old raised beds), indicating high organic matter content. Newly raised beds consisted mainly of very coarse (5-10 cm in size) blocky and friable clods. In 1- and 2-year old raised beds, the coarse angular clods were mixed with 10-20 % medium granular crumbs (2-5 mm in size). These crumbs were possibly formed by fragments broken off from the large ones. Planar pores 0.5 to 1.5 mm wide could be observed between the soil clods. Fine biopores, most likely formed by decayed root systems, were observed inside the clods, especially in 1-year raised beds.

TABLE 2. Some physical and chemical characteristics of the raised-bed top soils under study.

Type and age of raised bed	Bulk density ($Mg\ m^{-3}$)	Initial soil moisture ($cm^3\ cm^{-3}$)	pH	Al^{3+} ($cmol(+)\ kg^{-1}$)
Yam				
New	0.755	0.31	3.53	14.16
One-year	0.660	0.31	3.66	15.09
Two-year	0.750	0.30	4.18	13.58
Pineapple				
New	0.767	0.32	3.40	16.26
One-year	0.860	0.33	3.21	15.57
Two-year	0.934	0.33	3.60	16.80

The top layer of the pineapple raised beds consisted of reddish brown (5YR4/3) clay mixed with decomposed organic matter. The soil matrix itself was characterized by straw-yellow (2.5Y8/6) jarosite mottles. In the newly raised beds, this soil material accounted for approximately 20% of the raised bed soil surface. The newly raised beds for pineapple and yam have similar soil structure. In 1- and 2-year old pineapple beds is characterized by weak coarse angular blocky with fewer interpedal planar pores (almost nil in 2-year old beds) than in new ridges. A dense crust layer about 1 cm thick covered about 30% of the soil surface of the 1- and 2- year old pineapple beds. Crust was not observed on the new pineapple raised beds and yam raised beds.

The difference in top layer morphology between yam and pineapple beds reflected different methods of bed construction and crop management. Deep excavation into the sulfuric horizon resulted in the presence of reddish brown clay and jarosite mottles on the pineapple beds. Reduction in the observed planar macropores in the older pineapple raised beds corresponded to the increase in dry bulk density with age of raised beds (Table 2) and indicated the effect of consolidation of the raised beds (Sterk, 1993). For yam, there was no indication of such a consolidation, probably because tubers were annually uprooted and raised beds were tilled.

4.2. Water-conducting pores

The properties of the water-conducting pores are presented in table 3. The number of stains per unit cross section in all depths of the newly raised beds is comparable, in the range of 100-300 m^{-2}. This and the dominance of macropores (less than 25% were mesopores) reflected the excavation process where soil lumps were piled up randomly from the original soil surface to the required level.

In 1-and 2-year old raised beds, the number of stains decreased with depth. This reduction concurred with other findings (Stiphout et al. 1987) and reflected the decrease in root activities and the increase in consolidation effects with respect to depth.

In both land use types, the number of stains attained maximum values in 1-year old raised beds, irrespective of depth. This was associated with an increase in mesopores percentage (Table 3) compared with the new beds. The increase in mesopores supported the field observation of an increased amount of fine biopores inside the soil clods of 1-year old raised beds. These pores were probably caused by the decomposition of the root system of the original vegetation after one year of bed construction. A similar high percentage of mesopores caused by a decayed root system was found by Watson and Luxmoore (1986) in forest soils. The increase in the number of pores substantially increased the area and perimeter of the water-conducting pores of 1-year old yam raised beds. For pineapple, the soil underwent natural consolidation, reducing the number of macropores, especially at the greater depths. At 10 cm depth, the increase in area of the mesopores in 1-year old raised beds probably was compensated by the decrease in macropore area, keeping the area of the water conducting pores comparable with that of the newly raised beds. At greater depths, consolidation effects were more pronounced, resulting in a decrease of both perimeter and area of the water-conducting pores.

The effect of consolidation was manifested in 2-year old pineapple beds; the number, perimeter, and area of water conducting pores in pineapple beds were further reduced to values less than those in new beds. Yearly uprooting and hoeing of yam beds minimized the effects of consolidation and kept the perimeter, and area of the water conducting pores comparable with those of newly constructed beds.

These data indicated the importance of tillage action and consolidation on the water-conducting pore morphology. Vermeul et al. (1993) have reported a sharp increase in macropore number between nontilled (8,000 m^{-2}) and tilled (94,000 m^{-2}) soils.

4.3. Bypass flow and absorption

Typical hydrographs of outflow from the soil columns show a rising section, a rather steady state section and a falling section (Fig. 3). The flow rate of the steady state section increased after each rain (Fig. 3, Table 4). Water infiltrated the soil matrix during its passage through the water-conduction pore systems and thereby reduced the absorption rate of the soil matrix (Bouma et al., 1978, Bouma et al., 1981, Kneale and White, 1984). This was confirmed by the decrease in the amount of water absorbed in the soil columns after consecutive rains-- about 45, 21, and 11% of the first, second, and third rain, respectively (Table 4). Soil moisture content in the cores increased from 0.30-0.33 cm^3 cm^{-3} before shower application (Table 2) to 0.40-0.43 cm^3 cm^{-3} after the third shower, indicating that the soil matrix remained unsaturated.

Hydrographs of 1-year old pineapple beds (represented by Fig. 3b) differed from those of other raised beds (represented by Fig. 3a). After the rainfall application, it took longer for the water to start coming out from 1- and 2-year old pineapple bed soil samples (13 min for the first, 9 min for the second, and 6 min for the third shower compared with 8, 5, and 4 min in other samples). This hydrograph also had a longer rising section (10 - 15 min compared with 5 - 10 min), and longer falling section (25 - 40 min as compared with 20 - 30 min). In 1- and 2-year old pineapple bed soil samples, the steady section of the hydrograph continued for 5 - 15 min after the end of the shower (Fig. 3 b). In other soil samples, the falling section began right at the end of the shower (Fig. 3 a). The mean (average of the three rains), steady outflow rate from 1- and 2-year old pineapple bed samples was also less than that from other soil samples (Table 4).

These different bypass flow responses can be related to the effect of consolidation which reduced the area and perimeter of the water-conducting pores at 10 and 20 cm depths (within the length of the soil columns) in 1-, and especially, in 2-year old pineapple beds (Table 3) and slowed down water movement (Bouma et al., 1978).

The effect of the morphology of the water conducting pores was exacerbated by the presence of the surface crust in 1- and 2-year old pineapple beds. The crust hampered vertical infiltration. As a consequence, water ponded on the soil column surface, continued to supply water to the column, and prolonged the steady state section of the hydrograph after the end of the rains.

Under field conditions, ponded water probably resulted in runoff over the surface of the raised beds to the adjacent ditch. In our study, since runoff was not allowed, the amount of water that went through the pore network was probably higher than that under field condition. This may partly explain the much higher absorption in this study compared with values reported by Sterk (1993).

Some trials were carried out to explain the steady state outflow rate (OR_{st}, in mm min^{-1}) in terms of several physico-morphological factors (White, 1985; Bouma, 1990). The best multiple regression equation gave a correlation coefficient of 0.89, which was significant at the 1% level:

$$OR_{st} = -0.12 + 1.15\,\theta_i{}^{ns} + 1.95\,A_{st}\,(min)^{**} \qquad (1)$$

where θ_i = mean moisture content of the soil column ($m^3\ m^{-3}$); A_{st} (min) = the smaller (i.e. "bottle neck") of the two values of the area (in $m^2\ m^{-2}$) of the water-transmitting pores at 10-cm and 20-cm depths; ns = non significant; ** = significant at 1% level. In the analysis, only depths up to 20 cm were taken into account since that was the length of the soil columns.

Thus, the bottle neck area of the water-transmitting pores governed the outflow rate. The variation in soil moisture content of the soil probably was not large enough to significantly influence outflow.

TABLE 3. Number, mesopore percentage, area (per unit cross section), perimeter of stains at different depths of raised beds. Mesopore percentage is portion (in %) of stains with hydraulic radius $R_h < 1$ mm where R_h=area/perimeter of a stain. na = not available.

Depth		Yam raised bed			Pineapple raised bed		
(m)		New	1-year	2-year	New	1-year	2-year
10	Number of stains (m^{-2})	295	1721	729	186	868	155
	Mesopores percentage	15.8	62.2	42.6	20.0	46.4	60.0
	Area ($m^2\ m^{-2}$)	0.05	0.04	0.05	0.04	0.04	0.01
	Perimeter ($m\ m^{-2}$)	21.63	28.47	25.46	13.62	28.88	5.93
20	Number of stains (m^{-2})	233	775	155	155	403	62
	Mesopores percentage	6.7	48.0	40.0	10.0	30.8	25.0
	Area ($m^2\ m^{-2}$)	0.04	0.10	0.04	0.05	0.02	0.01
	Perimeter ($m\ m^{-2}$)	17.16	21.02	20.67	14.75	11.20	4.72
30	Number of stains (m^{-2})	109	527	248	155	295	78
	Mesopores percentage	25.6	61.7	12.5	41.7	89.5	80.0
	Area ($m^2\ m^{-2}$)	0.02	0.06	0.04	0.01	0.01	0.01
	Perimeter ($m\ m^{-2}$)	7.18	25.30	13.20	7.30	15.00	2.08
40	Number of stains (m^{-2})	na	na	na	140	155	47
	Mesopores percentage	na	na	na	0.0	80.0	0.0
	Area ($m^2\ m^{-2}$)	na	na	na	0.03	0.01	0.01
	Perimeter ($m\ m^{-2}$)	na	na	na	9.63	4.81	2.88
50	Number of stains (m^{-2})	na	na	na	124	109	47
	Mesopores percentage	na	na	na	12.5	57.1	33.0
	Area ($m^2\ m^{-2}$)	na	na	na	0.03	0.01	0.01
	Perimeter ($m\ m^{-2}$)	na	na	na	10.38	6.61	7.15

TABLE 4. Steady state outflow rate (mm min^{-1}) and amount of absorbed water (mm) in soil columns taken from yam and pineapple raised beds subjected to three consecutive rains at 24 h-interval, each of 30 mm hr^{1}, 60-min intensity duration.

Age of raised bed	After individual rain						Mean of three rains		
	First rain		Second rain		Third rain				
	Yam	Pineapple	Yam	Pineapple	Yam	Pineapple	Yam	Pineapple	Difference
				Steady state outflow rate					
New	0.29	0.3	0.39	0.42	0.45	0.47	0.38 a	0.40 a	ns
1-year	0.26	0.29	0.38	0.35	0.44	0.38	0.36 a	0.34 b	ns
2-year	0.28	0.27	0.39	0.33	0.40	0.36	0.36	0.32 b	*
				Absorbed water					
New	13.75	13.03	6.75	6.96	3.00	2.80	7.83 a	7.60 a	ns
1-year	14.17	13.00	6.90	6.92	2.96	3.92	8.01 a	7.94 a	ns
2-year	14.83	11.86	6.07	5.08	4.99	2.86	8.63 a	6.60 a	**

In a column, means having a common letter are not significantly different at the 5% level by DMRT.

- and **: significant at 5% and 1% level by LSD; ns: not significant.

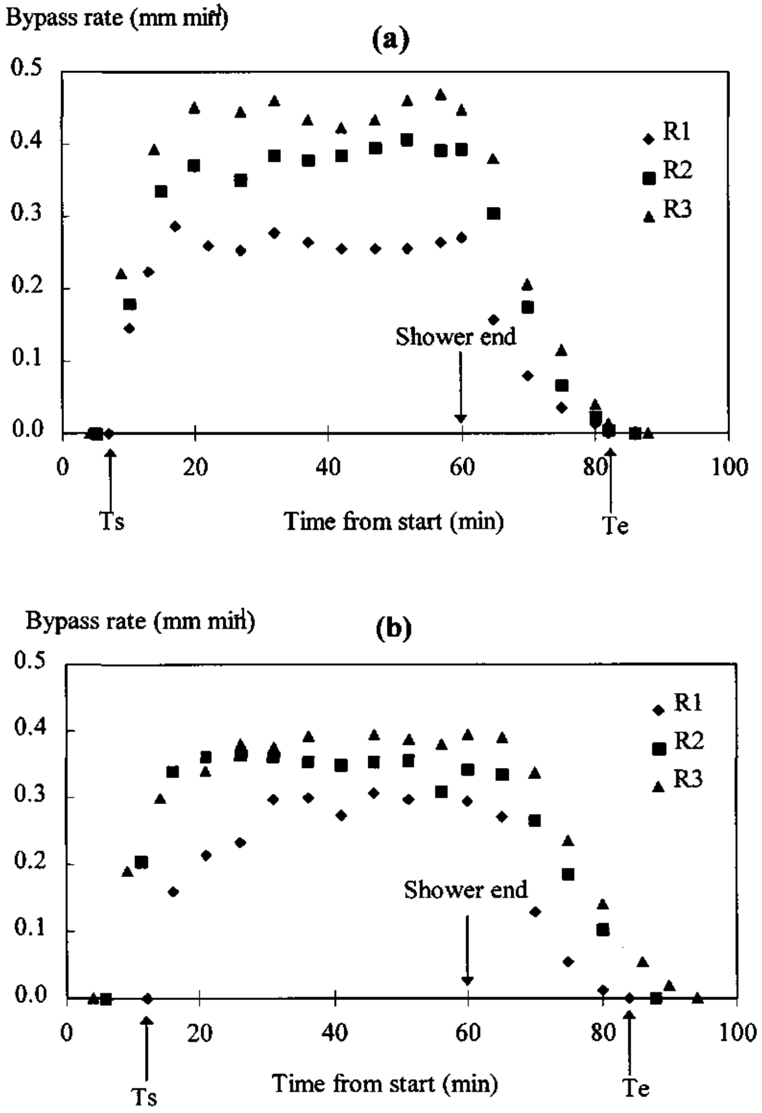

FIGURE 3 Hydrographs of the outflow from core samples (20 cm long, 20 cm in diameter) taken from 1-year yam raised bed (Y1) and 1-year pineapple raised bed (P1) after the first (R1), second (R2) and third (R3) showers. Shower intensity = 0.5 mm min^{-1}, duration = 60 min, and at 24 hrs interval. Time: after the start of shower.

4.4. Leaching of toxic elements

Though we monitored other chemical parameters, for brevity, only variation of Al^{3+} will be discussed in detail in this paper. Linear regression analyses indicated that the correlations among Al^{3+}, SO_4^{2-}, and EC were significant at the 5% level (r^2 for EC × Al^{3+} = 0.81, EC × SO_4^{2-} = 0.88, Al^{3+} × SO_4^{2-} = 0.91, full data not shown). Findings related to Al^{3+} would also be applicable to SO_4^{2-} and EC.

The Al^{3+} concentration measured in the outflow from each individual rain decreased with time (Fig. 5). This decrease was also reported by previous investigators (Tuong et al. 1993). As water moved through the pores, it quickly removed the soluble substances on the water-soil interfaces, i.e. on the surface of the soil clods. Once the readily available substances were removed, the rate of leaching was governed by the solubility of the toxic elements. In the study, solubility and not the flow rate was probably the determinant factor in the leaching process during each rain.

After the interval between showers, Al^{3+} concentrations at the start of the outflow of the subsequent rain were generally higher than those at the end of the previous rain (Fig. 4). This increased concentration probably came from solutes that had dissolved in the soil water during the interval in between rains.

Al^{3+} concentrations during the second and third rains was generally higher than that during the first one (Fig. 4). Sterk (1993) also found similar tendency for total acidity concentration in the leachate of the second rain compared with the first. We do not have a substantiated explanation for this phenomenon, but we hypothesize that the increase in concentration may have been the result of the increase in contact surface areas between soil clod and bypass flow brought about by the increasing total water applied (Bouma and Dekker, 1978).

Mean aluminum and sulfate concentrations in the outflow from three showers are shown in Table 5. For each crop, maximum concentrations of Al^{3+} and SO_4^{2-} were found in 1-year old raised beds.

Although not significantly different at the 5% level, Al^{3+} and SO_4^{2-} concentrations in the leachate from 1-year old and newly constructed pineapple beds were higher than those from yam beds of the same age (Table 5). On the other hand, the leachate concentrations from 2-year old pineapple bed soil column were lower than those from the 2-year old yam soils.

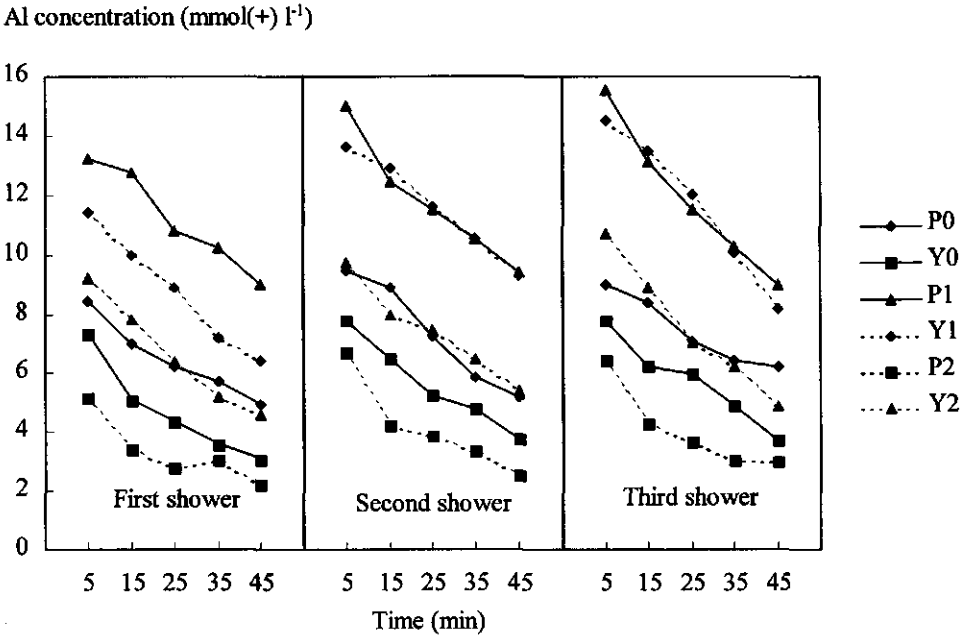

FIGURE 4 Aluminum concentration in the outflow from soil cores taken from pineapple (P) and yam (Y) raised bed: (A) newly constructed (P0, Y0); (B) 1-year old (P1, Y1) and (C) 2-year old (P2, Y2). Al^{3+} is plotted against time after the application of three showers (R1, R2, R3), each of 30 mm hr^{-1}, in 60 min, at 24 hrs interval.

TABLE 5 Concentration (mmol(+) l^{-1}) of Al and SO^{4} in the leachate from soil column taken from raised beds subjected to three consecutive rains at 24-h interval, each of 0-5-mm min^{-1} intensity and 60-mm duration. Each value is the mean of 455 samples (samplings per rain × 3 rains × 3 replications).

Age of raised bed	Type of raised bed		Difference
	Yam	Pineapple	
	Al^{3+}		
New	5.3 a	7.0 a	ns
1-year	10.7 b	11.8 b	ns
-year	7.2 c	3.8 a	*
	$S0_4^{2-}$		
New	9.1 a	11.6 a	ns
1-year	17.4 b	19.8 b	ns
2-year	10.6 a	6.5 a	*

In a column, means having a common letter are not significantly different at the 5% level by DMRT.

* significant at 5% level by LSD; ns = not significant.

The best multiple regression equation between Al^{3+} concentration ($[Al^{3+}]$, in mmol l^{-1}) and several physiochemical and morphological factors gave a correlation coefficient of 0.95, and significance level at 5%:

$$[Al^{3+}] = -15.47 + 0.40\, P_{st}\,(\max) + Al_{is} \qquad (2)$$

where P_{st} (max) is the larger value of the perimeter (in m m^{-2}), of the water-conducting pores at 10-cm and 20-cm depths; and Al_{is} is the initial (before leaching) aluminum concentration of the soil (cmol kg^{-1}).

Both regression coefficients were statistically significant at 1% level. In the new and 1-year raised beds, higher Al^{3+} and SO_4^{2-} concentrations from pineapple soil columns were the result of higher concentration of Al^{3+} and SO_4^{2-} in top soil (Table 2), coming from the sulfuric soil materials used in pineapple raised beds construction. As the raised beds got older, consolidation reduced the contact surface (as represented by the perimeter of the water-conducting pores) between the moving water body and the soil matrix in 2-year pineapple raised beds (Table 3), resulting in low Al^{3+} and SO_4^{2-} concentrations in the leachate. With high Al^{3+} and SO_4^{2-} concentrations in the soil before leaching (Table 2), low concentrations in the leachate from 2-year pineapple soil columns was a clear indication that the physical characteristics of the water conducting pores and the bypass flows can sometimes be more important than the chemical actions in the leaching process of raised beds made of ASS.

5. Conclusions

This study shows that the staining technique, using Methyl blue, is useful in quantifying the morphology of water-conducting pores in raised beds made of ASS. Water-conducting pores in the top soil layer of the new raised beds for yam and pineapple were characterized by a high percentage of macropores. After construction, two major processes occurred simultaneously: consolidation of the top soil and the formation of mesopores by decaying roots. The effect of root decay was predominant in one-year old raised beds, resulting in an increase in the amount of mesopores for both crops. The effect of consolidation was manifested in pineapple raised beds because they were left undisturbed after the construction, reducing the number, area and perimeter of the water-conducting pores in 2-year pineapple raised beds. Regression analyses showed that the flow rate of the bypass flow depended on the area of the water conducting pores and the Al^{3+} concentration of the bypass flow leachate on the perimeter of the water-conducting pores and on the initial Al^{3+} concentration in the soil. This implies that leaching of ASS is influenced by soil management which affects the water-conducting pore system geometry bypass flow. Under field conditions, this outflow, together with the toxicity, will finally flow into the canal system by drainage or by seepage. This contaminated water flow can affect the surrounding area. This effect has to be taken into account when planning ASS reclamation projects.

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Chapter 5

CONTAMINATION OF SURFACE WATER AS AFFECTED BY LAND USE IN ACID SULPHATE SOILS IN THE MEKONG RIVER DELTA, VIETNAM

(Paper accepted for publication by Agriculture, Ecosystem & Environment)

CONTAMINATION OF SURFACE WATER AS AFFECTED BY LAND USE IN ACID SULPHATE SOILS IN THE MEKONG RIVER DELTA, VIETNAM

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ABSTRACT

Leaching toxicities out of the rootzone is an effective measure for improving soil quality and crop yield in acid sulphate soils (ASS). Leaching of ASS may however pollute the environment. We quantified the concentration and the amount of pollution from leaching of ASS for rice, pineapple and yam cultivation in a Typic Sulfaquept in the Mekong river delta, Vietnam. The studied fields were originally uncultivated and have been reclaimed for 2 months, 1 and 2 years, respectively. Pineapple and yam were cultivated on raised beds formed by soil materials excavated from adjacent lateral ditches. The pH of the drainage water ranged from 2.9 to 3.9 and aluminum concentration from 3 to 13 mmol(+) l^{-1}. The mean monthly aluminum concentration in the leachate from pineapple and yam raised beds was about 3 times higher than from rice fields. Monthly total amount of aluminum released by the upland raised beds could be as high as 16 690 mol ha^{-1}, and was 3 to 5 times higher than that from rice fields. Consolidation and crust forming in pineapple raised beds reduced the concentration and amount of aluminum released with respect to the age of raised beds. Pollution from ASS leaching was probably most hazardous to the environment in June due to a combination of highest total aluminum released to the canal network and low river discharge. Environmental hazards make it imperative to carefully plan the reclamation of ASS such that the toxicity carrying capacity of the surface water is not exceeded.

INTRODUCTION

Acid sulphate soils (ASS) occupy more than 40 % of the Mekong river delta of Vietnam. Resulting from oxidation of reduced S-compounds in pyritic mud, these soils are characterized by low pH and high aluminium, iron and sulphate

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concentrations (Breemen and Pons 1978). Leaching these toxicities out of the rootzone is an effective measure for improving soil quality and crop yield (Mensvoort et al. 1991, Tuong et al. 1993, Xuan 1993). Leaching, in combination with other cultural practices, allows farmers in the Mekong river to reclaim a vast track of ASS for rice cultivation and other upland crops such as yam (*Dioscorea esculanta*), sugar cane, and pineapple (Xuan 1993). These upland crops are grown on raised beds 0.3-0.6 m higher than the original ground surface and formed by soil materials excavated from adjacent lateral ditches.

Leaching of ASS means transferring acidity to the surroundings and may result in environmental hazards to the surrounding water and land. Severe acidification of the surface water was reported for many reclaimed ASS areas (Dent 1986, Laudelout 1989, Klepper et al. 1990). Acid polluted water may harm aquatic organisms, and crops in the surrounding and downstream areas, where this contaminated water is used for irrigation, and may become unsuitable for domestic uses (Mormann and van Breemen 1978, Dent 1986, Klepper et al. 1990, Dat 199, Dent 1992).

The type of land use may affect leaching of ASS and acid pollution to the environment in many ways. More water is drained to surrounding areas from raised beds for upland crops than from rice fields. Different raised bed construction and management (Tri et al. 1993, Xuan 1993) will change the soil chemical and physical properties, affecting the leaching processes (Tuong 1993) and the amount of toxicities transferred to the surrounding.

Few studies quantify the amount of toxicities transferred from the fields to the surroundings and investigate how this amount changes with land use. This knowledge is important to evaluate the environmental hazard of ASS leaching and to formulate sound land use planning.

The objectives of this study were to assess the source of pollution from leaching of ASS and to investigate how the pollution hazard was influenced by three common land uses -- rice, pineapple and yam -- in the ASS area in the plain of Reeds of the Mekong delta, Vietnam.

METHODOLOGY

Soil, climate and hydrology of the study site

We carried out our field study in April - September, 1993 in Tien Giang province (10°25' N, 106° 06' E), Vietnam. Using USDA Soil Taxonomy System (Soil

Survey Staff 1975), the natural soil was classified as a Typic Sulfaquept. The top soil (0-0.4 m) had 28% organic matter content. The sulphuric horizon (0.4-0.95 m) was characterized by pH < 3.5, high aluminum (Table 1) and by jarosite [$KFe_3(SO_4)_2(OH)_6$] mottles. The pyrite layer, deeper than 95 cm, contained sulphidic materials. All soil horizons had more than 50% clay (Table 1).

TABLE 1. Some physical and chemical parameters of the natural soil of the study site.

Horizon	Depth	Sand	Silt	Clay	Bulk density	pH†	Al‡	SO_4^{2-}
	m	%	%	%	Mg m^{-3}		cmol(+)kg^{-1}	%
Top soil	0-0.4	0.6	44.2	55.2	0.867	3.45	14.85	0.01
Sulfuric	0.4-0.95	2.4	40.3	57.3	1.070	3.32	18.75	0.04
Sulfidic	0.95	6.9	42.2	50.9	0.946	4.23	14.23	0.87

† H_2O (1:2.5)

‡ extracted by 1M KCl (1:2.5)

The study site has two distinct seasons: a dry season (December - April) with very little rain, and a rainy season (May - November) with more than 90% of the annual rainfall of about 1,300 mm (Fig. 1). Heavy rainfall in the wet season and river overflow create floods which start annually in August and recede in November. At the peak of the flood, in October, the soil surface is under a water depth of 0.4 - 0.5 m (Fig. 1). Water level and discharge gradually recede in November, attain minimum values in April and rise again at the start of the rainy season.

To facilitate irrigation, drainage and transportation, a network of canals was constructed in the area. Typically the network comprises (i) primary canals at 20-40 km intervals, 15-30 m wide, 2-4 m deep; (ii) secondary canals at 5-10 km intervals, 8-15 m wide, 1.5-2 m deep; and (iii) tertiary canals at 2-5 km intervals, 5-8 m wide and 1-2 m deep. Farmers constructed farm canals (less than 5 m wide, 1 m deep) to drain their farms to the tertiary canals.

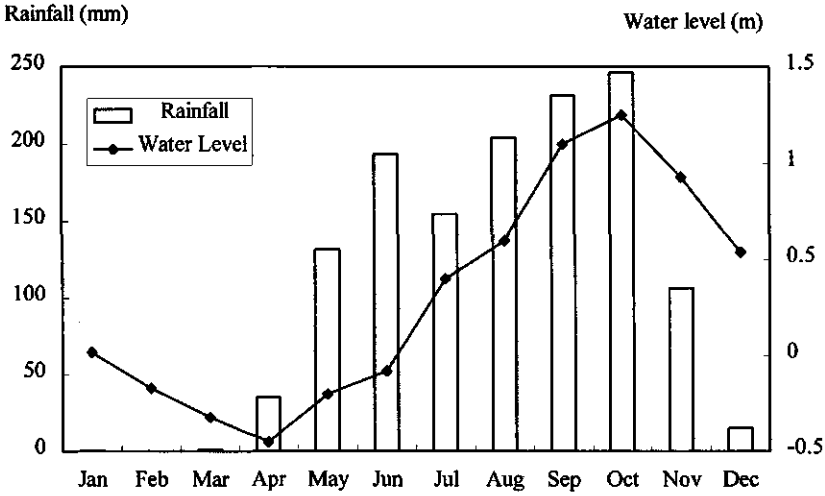

FIGURE 1 Average monthly rainfall distribution and water level. Water and ground levels are in cm above the mean seas level.

Land use types

Originally, the area was uncultivated and covered by *Melaleuca cajiputi.* Since 1990, parts of the area have been reclaimed for agricultural production with yam, pineapple and rice as main crops.

Yam cultivation

Raised beds for yam are 0.3-0.4 m higher than the natural soil surface. Only the top layer of the natural soil is used for raising the ridges (Fig. 2). New raised beds are often constructed in February and left fallow during the remainder of the dry season and the following rainy season. As the flood arrives, the ridges are gradually submerged to reduce toxic substances during subsequent leaching when the flood recedes (Xuan 1993). As the flood subsides, the raised beds are tilled and yam cuttings are planted in December. The crop is harvested by uprooting yam tubers in June of the following year, before the whole raised bed is submerged again under flood water. Raised beds are tilled, cuttings are planted again when the flood recedes and the whole cycle is repeated annually (Tri et al. 1993; Xuan 1993).

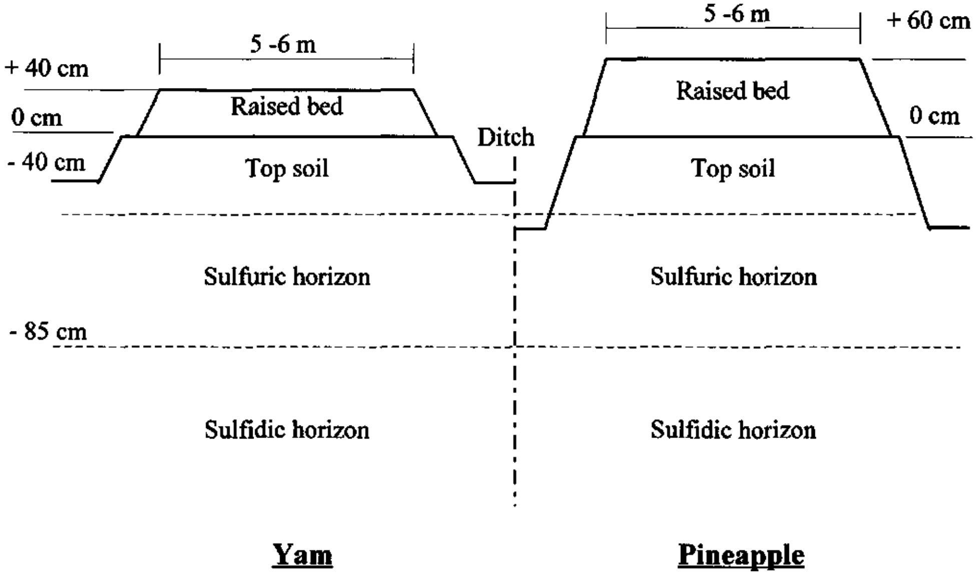

FIGURE 2 Schematic cross section of raised beds.

Pineapple cultivation

New raised beds for pineapple were also constructed in February. Both soil materials from the surface layer and the sulphuric horizon are used to raise the height of the ridges to 0.6-0.8 m above the natural soil surface (Fig. 2), keeping the ridge surface 0.2-0.3 m above the peak flood level. After being left fallow for one rainy season, raised beds are tilled and pineapple shoots are planted in December. First fruit picking is carried out about one year later. Subsequent harvests are carried out every year for about 3 to 5 years. During this period, the plants remain on the raised beds without further land preparation and replanting.

Rice cultivation

Rice land reclamation begins with land clearing and building bunds in February-March. A typical rice field measures 30-50 m wide, and 50-150 m long. Soil is plowed by buffaloes and moldboard plows at the onset of the rainy season. The land is left fallow and submerged during the flood period. When the flood recedes, the land is leveled and puddled by toothed harrows under submerged condition. Surface water is flushed out, via shallow drains (0.2 m wide x 0.2 m deep, at 7-10 m distances) after the puddling. To facilitate drainage and flushing of shallow drains, fresh water from surrounding canals is then pumped in and the whole cycle of harrowing-flushing is repeated for 3 to 5 times before rice seeds are broadcast. The rice crop is irrigated by gravity at high tides or by pumping and is harvested in March. Farmers then spread about 5-6 tons/ha straw evenly over the whole field. The straw layer is left to sun-dry for several days before being burned. The field is irrigated by pumping from surrounding canals, rice seeds are sown onto untilled soil for the second rice crop. This crop is harvested in July. Land is left fallow during the flood period and the 2-rice cropping pattern is repeated annually.

Experiment treatments and layout

The experiment was carried out in farmers fields in three locations of similar soil type along a tertiary canal. At each location, we selected randomly one rice, one pineapple, and one yam farm. Each farm was served by one farm drain and was comprised of three adjacent plots, one having been reclaimed for 2 years, one for 1 year and the other for only 2 months before the experiment. With this arrangement, monitored variables could be analyzed statistically in split-plot design with land use types as main plots and age of land use as sub-plots.

Soil chemical and physical properties

Soil samples for chemical and physical analyses were taken in April 1993. This sampling time at the end of the dry season was selected because toxicity accumulation at the soil surface was at its peak and the differences in soil properties could easily be studied.

In each of the subplots, one composite soil sample was taken at 0-20 cm depth. The soil samples were analysed for pH (in 1:2.5 extract), exchangeable aluminum, SO_4^{2-}, and total acidity using methods by Begheijn (1980). These are the most common indicators of toxicity of ASS. Aluminum, in particular, has high potential toxicity for plant roots (Thowornwong and van Diest, 1974).

Bulk density of the top soil of each of the raised bed subplots was determined from fresh and oven-dry weight of an undisturbed core sample, 20 cm in dia. and 25 cm long. Their large size was necessary to take into account the heterogeneity of the macropore-dominated soils.

During soil sampling, careful observation was given to the presence of half-decomposed organic matter, of the surface crust and of the occurrence of jarosite mottles on the top soil layer of the raised beds.

Monitoring quantity and quality of leachate in the field

Leachate collected by ditches in each subplot after each rain was drained to the surrounding network by a manually controlled sluice. The drainage volume was calculated from the difference in water level before and after drainage, using a volume-water level curve which had previously been determined for each plot. Before drainage, pH and EC of water at five locations in each subplot were recorded. Composite samples from the five locations were taken for the analyses of aluminum, and SO_4^{2-} (Begheijn 1980).

The amount of aluminum and SO_4^{2-} released from each subplot after each rain was calculated by multiplying their concentration and the drainage volume. The monthly amounts of pollutants and the monthly average concentration of pollutants could then be computed. They were statistically analyzed according to split plot experiment design.

RESULTS AND DISCUSSION

Initial soil physical and chemical properties of the raised beds

Bulk density and some important soil chemical properties of the top soils are shown in Table 2. The low bulk density of the top soil of the raised beds reflected the loosely packed condition of the excavated soils. For pineapple, bulk density increased with the age of the raised beds (Table 2). Aluminum and sulfate concentrations of the surface soil of yam raised beds were similar to those of the natural soils, while those of the pineapple raised beds were slightly higher (Tables

1 and 2).

TABLE 2. Some physical and chemical parameters of top soil of the raised-bed under study

Type and age of raised bed	Bulk density Mg m⁻³	pH †	Concentration Aluminum‡ cmol(+) kg⁻¹	SO_4^{2-} %
Yam raised bed				
New	0.75	3.53	14.16	0.15
One-year	0.66	3.66	15.09	0.11
Two-year	0.75	4.18	13.56	0.08
Pineapple raised bed				
New	0.77	3.40	16.26	0.21
One-year	0.86	3.21	15.57	0.12
Two-year	0.93	3.60	16.80	0.28
Rice field				
New	0.82	3.72	15.55	0.19
One-year	0.88	3.44	14.13	0.28
Two-year	0.83	3.65	13.03	0.20

† H_2O (1:2.5)

‡ extracted by 1M KCl (1:2.5)

The top layer of pineapple raised beds was characterized by straw-yellow (2.5Y8/6) jarosite mottles. In the new raised beds, this soil material accounted for approximately 20% of the raised bed soil surface. A dense crust of about 1 cm thick covered about 30% of the soil surface of 1- and 2 year pineapple raised beds. On new pineapple raised beds, such a crust was not observed initially but it was noticeable in July, August. The crust was created by raindrop impact on the soil surface and associated soil structure deterioration (Shainberg and Levy 1992).

Differences in the top layer soil conditions between yam and pineapple raised beds reflected different methods of bed construction and crop management. Deep excavation into the sulphuric horizon resulted in the presence of the jarosite mottles on pineapple raised beds. These were also responsible for lower pH and higher concentrations of aluminum and sulphate in pineapple raised beds. The increase in bulk density with age of raised beds indicated the effect of consolidation of the raised beds (Sterk 1993). This was because the top soil had been hardly disturbed after the first pineapple planting. For yam, there was no indication of such consolidation, probably due the annual uprooting of the tuber and tillage of the raised beds.

Effect of land use types on leachate concentrations

Though we monitored other chemical parameters, for brevity, only changes in pH and Al will be discussed in detail in this paper. Linear correlation coefficients among concentration of aluminum, SO_4^{2-} and EC in the leachate ranged from 0.9 to 0.95 and were significant at 5% level (data not shown). Findings related to aluminum are therefore also applicable to SO_4^{2-} and EC. Aluminum was selected because of its high potential toxicity.

Figures 3a and 3b show the variation in pH and aluminum concentration of the drainage water from different land use types. Each pH and aluminum value in the graphs was the mean of 9 values (3 land use ages by 3 replications). In general, the aluminum concentration was highest with the first rain following dry spells and decreased when rainfall occurred on more than three consecutive days. Variation in pH was in the opposite direction. These tendencies were more noticeable in drainage water from yam and pineapple raised beds than drainage water from the rice fields.

The decrease of aluminum concentration with continuing leaching of soils with macro pores was also reported by previous investigators (Tuong et al. 1993, Minh et al. 1995). As water moved through the pores, it quickly removed the soluble substances on the water-soil interfaces, i.e. on the surface of the soil clods. Once the readily soluble substances were removed, the rate of solute leaching was governed by the accessibility to soluble components. Continuing rains also increased the soil moisture and decreased the infiltration rate of the soil, resulting in more surface runoff which did not contribute to effective removal of toxic elements from the soil matrix (Sterk 1993).

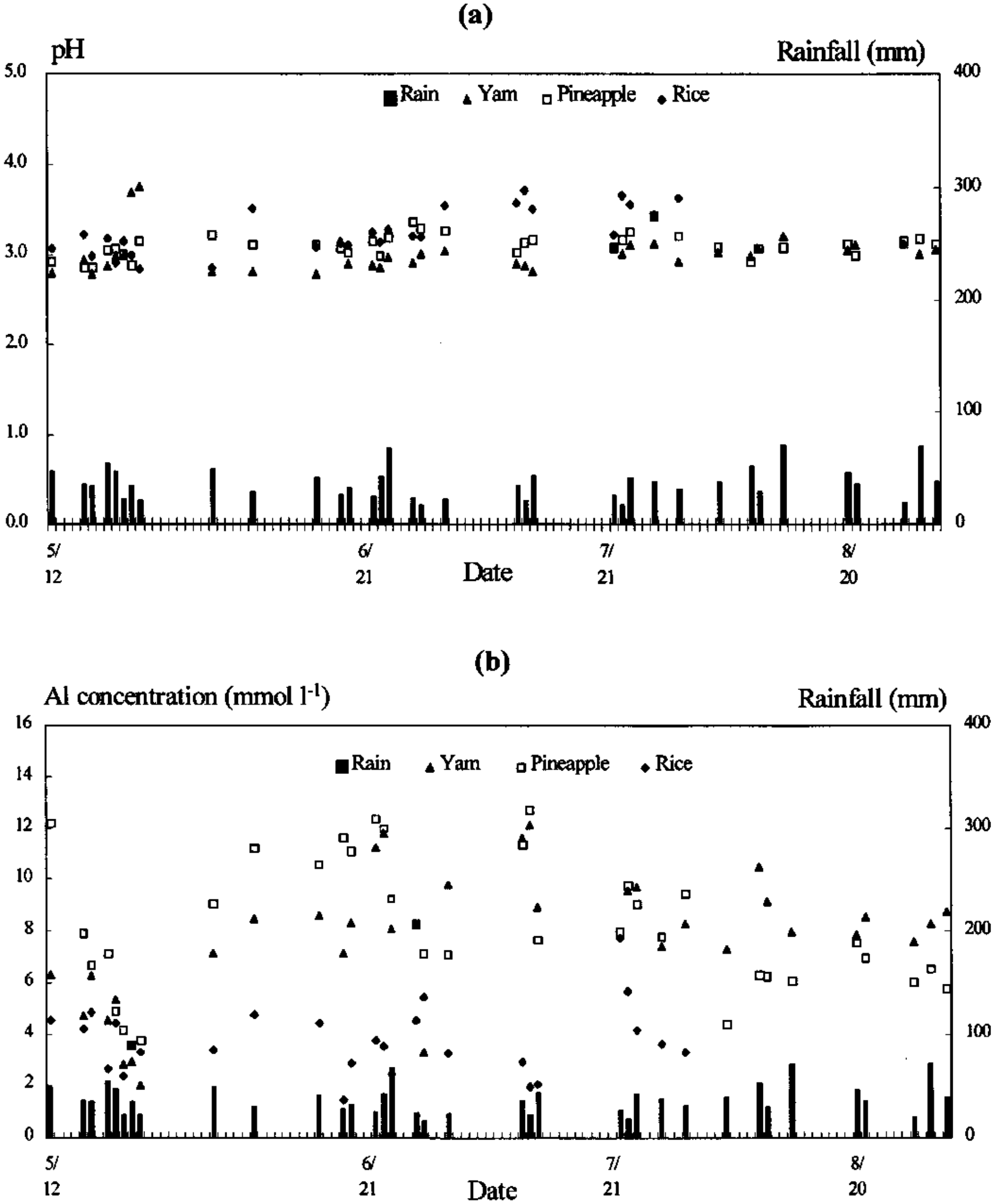

FIGURE 3 pH (a) and (b) aluminum concentration in daily drainage water from pineapple, yam and rice fields. Each value was the average of 9 measurements (3 land use ages by 3 replications).

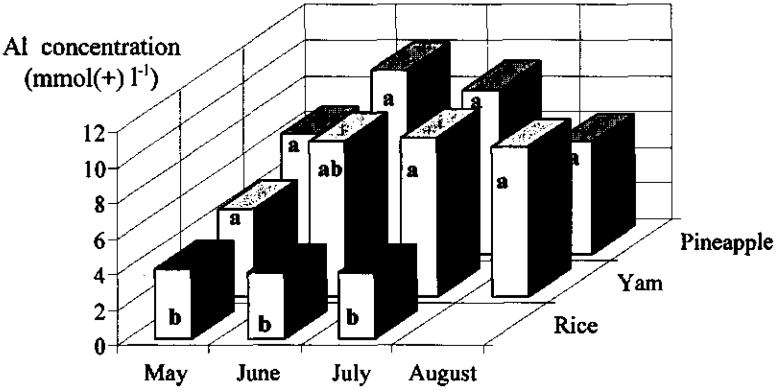

FIGURE 4 Monthly mean aluminum concentration in water drained from pineapple, yam raised beds and rice fields. In the same months, means (represented by column height) having the same letters are not significantly different at 5% level by DMRT.

Drainage water after each rain event from raised beds had lower pH and higher aluminum concentrations than that from the rice fields (Figs. 3a, 3b). Mean monthly aluminum concentrations in the leachate from rice were therefore significantly lower than those of yam and pineapple raised beds (Fig. 4). Under double rice cropping, the fields were submerged for about 10 to 11 months per year. Under the reduced condition, the pH increased resulting in aluminum precipitation (Ponnamperuma et al. 1973; Satawathananont et al. 1991). While in the raised beds, soils are mostly in an oxidized condition, with more dissolved aluminum which can be removed by leaching. Leaching of the raised beds was also enhanced by the larger number of macropores as compared to rice soil.

Mean monthly aluminum concentrations in the leachate from rice fields remained rather constant during the wet season. Mean monthly aluminum concentrations from raised beds attained maximum values in June (Fig. 4). The decline in aluminum in July and August was prominent in the case of pineapple. This decline could be due to increased surface runoff from the raised surfaces as soil water content of raised bed increased with rainfall. The surface runoff was enhanced in pineapple raised beds by surface crusts.

Early in the rainy season, in May and June, aluminum concentration in the leachate from pineapple raised beds exceeded that of the yam raised beds. The trend reversed in August (Figs. 3b and 4). Initial aluminum came from the leaching of easily soluble aluminum salts, which had accumulated at the soil surface during the dry season (van Breemen 1993). Higher concentration of aluminum and more compacted soil in the top layer of the pineapple raised beds (Table 2) may have resulted in a higher accumulation of soluble aluminum salts. After the removal of the accumulated salts, formation of crust and consolidation reduced the amount of water that could infiltrate into the soil matrix, resulting in lower aluminum concentrations in the leachate as compared to yam raised beds.

Effect of land use age on leachate concentration

There was a tendency for aluminum in the leachate to decreased with land use age (Table 3). Leachate from a 2-year pineapple raised bed had a significantly lower aluminum content than from the new and 1 year raised beds. In rice and yam, leachate from 2-year plots had, in general, lower aluminum contents than leachate from newer plots. Differences were, however, not always significant.

Consolidation of the pineapple raised beds, as reflected by the increased bulk density with respect to time (Table 2), might be responsible for the marked reduction of aluminum concentration with age. Consolidation reduced the number of water conducting pores and the infiltration rate into the raised beds (Brakensiek and Rawls 1983, Mwendera and Feyen 1993) resulting in more surface runoff and less leaching in older raised beds as compared with the younger ones.

Two-year old pineapple raised beds had the highest aluminum concentration in the soil among the raised beds (Table 2). They, however, had lowest aluminum concentration in the leachate (Table 3). Soil physical properties thus played a more important role in controlling leaching out of toxicities.

TABLE 3. Monthly average values of aluminum concentration in the leachate (mmol(+) l^{-1}) from different types of land uses and ages.

Month	Age	Land use		
		Yam	Pineapple	Rice
May	New	4.4 a	7.9 a	4.2 a
	One year	5.9 a	7.6 a	3.8 a
	Two year	4.3 a	4.5 b	3.7 a
June	New	10.2 a	12.3 a	4.3 a
	One year	7.1 b	11.4 a	3.8 a
	Two year	8.7 ab	7.2 b	3.0 a
July	New	11.1 a	11.4 a	4.1 a
	One year	9.4 a	9.7 a	3.6 a
	Two year	8.9 a	6.6 b	3.5 a
August	New	8.2 a	7.6 a	nd
	One year	8.7 a	6.1 b	nd
	Two year	8.4 a	5.1 b	nd

In a column and in the same month, means following by a common letter (a, b, c) are not significantly different at the 5% level by DMRT.
nd: no data

Total aluminum released to surrounding canals

The amount of water that drained from rice fields ranged from 480 - 690 m^3 ha^{-1} $month^{-1}$. For yam and pineapple, the corresponding values ranged from 770 to 1,954 m^3 ha^{-1} $month^{-1}$. The difference was due to the storage capacity of the rice fields where farmers tried to retain a 5- to 10-cm water layer. Farmers carried out intensive drainage for upland crops. Evapotranspiration of from rice field was also higher than for yam and pineapple plots where only about half of the surface area was open water.

Due to lower leachate concentrations and a lower drainage amount, the monthly total amount of aluminum released from the ricefields to the surrounding canal system was significantly lower than from yam and pineapple (Fig. 5).

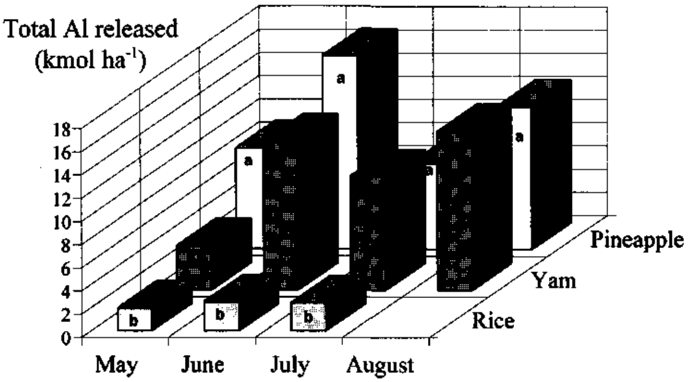

FIGURE 5 Monthly mean amount of aluminum released to the surrounding canal network from pineapple, yam raised beds and rice fields. In the same months, means (represented by column height) having the same letters are not significantly different at 5% level by DMRT.

For pineapple, the total amount of aluminum released to the surrounding water was maximum during June. This corresponds to the period of highest aluminum concentration in the leachate (Table 2, Figs. 3 and 4). For yam, the maximum release of aluminum occurred in August and was due to higher drainage discharge compared to other months.

General discussion and conclusions

The pH and aluminum concentrations in drainage water in this study were comparable to earlier reports (Minh et al. 1995, Hanhart and Ni 1993). Aluminum concentrations in the leachate by far exceeded the toxicity threshold level of 0.1 to 6 mmol/liter for fish and plant roots (Thawornwong and van Diest 1974, Singh et al. 1988). If the toxic substances are to be diluted to an acceptable level (e.g. 1 mmol l^{-1}), approximately 15.000 m^3 of fresh water are required per month for each ha of reclaimed ASS for upland crops. This is equivalent to a runoff (or rainfall) depth of 1500 mm month^{-1}. The corresponding value for one hectare of rice is 200 mm month^{-1}. Rainfall (Fig. 1) and discharge from the Mekong river is not adequate to supply that amount of water. As a consequence, surface water in a large ASS area of the Mekong river is heavily being polluted with acidity. Kham (1988) reported that the pH of the surface water remained below 5 during the rainy season on almost of 500 000 ha of the Plain of Reeds of the Mekong river delta.

Pollution from ASS leaching was probably most hazardous to the environment in June due to a combination of highest total aluminum released to the canal network (Fig. 5) and low river discharge. This conclusion is in agreement with Nien (1995) who reported that in 1994 the area with water in the primary and secondary canals with a pH of less than 4 was largest in June (about 150 000 ha). In July the area was reduced to about 50 000 ha and concentrated in areas reclaimed for upland crops.

Since toxic threshold concentrations are often lower for aquatic organism than for plant roots, leaching of newly reclaimed ASS (especially where raised beds are created for upland crops) may have serious consequences on fish and the aquatic food chain in the canal network. Smith (1990) reported "acid shock" at the early part of the rainy season in drainage water from acid sulphate soils of the Plain of Reeds. In 1988, almost all invertebrates of the entire area were wiped out after the acid shock in May-June.

Environmental hazards make it imperative to carefully plan the reclamation of ASS in such a way that the toxicity carrying capacity of the surface water is not exceeded.

In ASS reclamation project, the type of land use which releases a high aluminum concentration in drainage water (like yam beds in this study) must be limited within a certain area in a given time. Other types of land uses like rice or *Melaleuca* are needed to be promoted.

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Chapter 6

TILLAGE AND WATER MANAGEMENT FOR INCREASING RICELAND PRODUCTIVITY IN THE FLOOD PRONE ACID SULPHATE SOIL AREA OF THE MEKONG RIVER DELTA OF VIETNAM

(Paper submitted to Soil Tillage)

TILLAGE AND WATER MANAGEMENT FOR INCREASING RICELAND PRODUCTIVITY IN THE FLOOD PRONE ACID SULPHATE SOIL AREA OF THE MEKONG RIVER DELTA OF VIETNAM

L.Q. Minh[1], T.P. Tuong[2], M. E. F. Mensvoort[1], and J. Bouma[1]

ABSTRACT

Effectiveness of using flood water, in combination with harrowing, in flushing out toxic substances from the top soil of acid sulphate soils (ASS) was studied. We carried out the experiment during the flood recession period of 1992, at three sites in the Mekong Delta, Vietnam, ranging from slight, moderate to strong acidity. Treatments included the number of harrowing (one, H1 and three times, H3) and number of flushing (one, F1 and three times, F3), when F1 is practiced, H3 showed no significant difference in reducing soluble aluminum concentrations compared to H1. In slightly ASS, amount of aluminum removed by H1 did not differ from neither between F1 and F3. Under moderately acid conditions, the reduction of soluble aluminum concentrations caused by H3 does not show any significant differences compared with H1, whereas F3 and F1 does. Under severe ASS, H3 combined with F3 removed significantly higher amount of soluble aluminum compared to F3H1. The reduction in aluminum concentration in soil exchange complex was not affected by different harrowing and flushing treatments. F3H3 also gave a significantly higher rice yield compared with other treatments. When combining with harrowing, flushing by flood water is an alternative for flushing of ASS, which has high water requirement and may create environmental hazard.

INTRODUCTION

Two of the main constraints for agricultural development of the Northern part of the Mekong river delta, Vietnam, are a vast area (1.6 million hectares or approximately 40% of the total area of the delta) of acid sulphate soils (ASS) and the annual flood from September to December. Formed after the oxidation of

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pyrite-rich sediments, ASS are characterized by low pH and high concentration of aluminum, iron, sulphate, and hydrogen sulfide (van Breemen and Pons 1978). Flushing these toxicities out of the rootzone is the prerequisite for, and an effective way to improve ASS (van Breemen 1993). Flushing, however, requires a large quantity of fresh water (over 1000 mm) before the concentration of toxic elements in the root zone is brought to a level low enough for plant development (Tuong 1993, Tuong et al. 1993). Flushing also involves the transfer of toxic elements into, and thus polluting, the surrounding water body (van Breemen 1993, Tuong 1993, Tuong et al. 1993).

Traditionally, rice is cultivated in the rainy season and flushing carried out in May at the beginning of the rainy season. This coincides with the period of the lowest discharge of Mekong river and the canal networks. This timing of the flushing is not attractive from a point of view of the water availability and environmental protection. High flushing water requirement competes with the needs for other water uses, especially for the maintenance of a minimum river discharge to prevent salinity intrusion in the coastal part of the delta during the low flow period. Low river and canal discharge may not enough to transport and dilute the polluting leachate. Water quality at the beginning of the rainy season in and surrounding the acid sulphate soil area of the Mekong river delta deteriorates to a level harmful to aquatic population (Kham 1988, Grimas 1988). In many cases, due to insufficient water sources, farmers rely on rainfall for flushing and land preparation. In some cases, rice cannot be cultivated until mid July, if flood comes early, rice crop can be completely inundated. Flushing-related environmental hazards can be reduced when flushing is carried out in period with high surface water runoff so that acid and often toxic products are diluted as much as possible (van Breemen 1993). In the Mekong river delta, this may be at the end of flood season. After flushing the soil, farmers can grow an irrigated rice crop from December-March/April. This crop often yields better than the main rain season rice crop due to higher photosynthetic energy and better water management possibilities (Hanhart and Ni 1993). Flushing at the end of the flood season, however, may not be effective. High water table and water level in the surrounding canals inhibit vertical water movement. The natural surface water movement of the flood water in enclosed fields is not adequate to transport the soluble ions (Tuong 1993).

Rice cultivation often includes puddling, i.e. harrowing or rototilling the 0.15-0.2 m top soil under a submerged condition. Puddling helps weed control and facilitates transplanting (De Datta 1981, De Datta and Barker 1978). In acid sulphate soils, puddling can increase the soil-water contact, thus enhancing the solubility of toxic elements in the ponded water layer. It is envisaged that when the surface water is drained away, the dissolved acidity can be flushed out of the field and toxic elements can be removed from the top soil.

This paper investigates the effectiveness of puddling and flushing in removing toxic elements from the top soil of acid sulphate soils at the end of the flood season in the Mekong rive delta. The environmental implications of this land improvement practice is discussed.

MATERIALS AND METHODS

Study sites

The experiment was carried out in July 1992- March 1993 at three sites in the Plain of Reeds, Mekong river delta, Vietnam: Cai Lay (10°25'N, 106° 06'E), Tam Nong (10°45' N, 105°30' E), and Tan Thanh (10°40' N, 106° E). All sites are subjected to annual flooding from August to November or December. Soils at three sites were classified by the USDA system (Soil Survey Staff, 1975) as very fine Typic Sulfaquept.

Cai Lay (10°25'N, 106° 06'E) represented severe, young, recently oxidized ASS conditions. Originally, the site was covered by natural vegetation of *Melaleuca cajiputi* and *Eliocharis dulcis.* The land was reclaimed for rice cultivation one year before the experiment. The 0.15 m surface soil is characterized by very low pH and high concentration of Al (Table 1). The area is submerged under a 0.3-0.6 m flood depth from September to the end of December. Water samples, taken from irrigation canal at the beginning of the experiment had high acidity (Table 2).

Soil and water at Tam Nong (10°45' N, 105°30' E) was less acidic then in Cai Lay. The site was reclaimed from natural vegetation of *Melaleuca leucodendron* and *Eucalyptus* spp. one year before the study. Though the maximum flood depth was much higher than in Cai Lay, but flood recedes earlier, at the end of November (Tables 1 and 2).

Tan Thanh (10°40' N, 106° E) was the least acidic of the three sites (Table 1). Two years prior to this experiment, local farmers removed the natural weed, *Eliocharis* spp., to grow rice. Since the yield was low (0.8-1.0 t ha^{-1}) the field was left fallow until the experiment.

TABLE 1 Some chemical parameters characterizing the top soil (0-0.15 m) at the study sites. Number of samples and standard deviations are included in parentheses.

Site	pH (H_2O) (1:2.5)	EC (1:2.5) mS cm^{-1}	Total acidity† cmol(+) kg^{-1}	Exchangeable Al† cmol(+) kg^{-1}	Soluble Al ‡ cmol(+) kg^{-1}
Cai Lay	3.15	1.37	25.2	21.9	1.44 (12, 0.25)
Tam Nong	3.69	0.85	14.9	13.6	0.58 (12, 0.12)
Tan Thanh	4.06	0.50	9.1	8.3	0.23 (12, 0.07)

† 1 M KCl extract

‡ saturation extract (1:1.5)

TABLE 2 Flood depth, receding date and some chemical parameters of irrigation water used for flushing at the study sites. Water for chemical analysis was sampled at the beginning of the experiment.

Site	Flood		Chemical parameters		
	depth (m)	Receding date	pH	EC (mS cm^{-1})	Al (mmol(+) l^{-1})
Cai Lay	0.3-0.6	15-30 Dec	4.35	0.62	1.10
Tam Nong	1.5-2.0	15-30 Nov	4.92	0.55	0.15
Tan Thanh	0.6-1.0	01-15 Dec	5.48	0.32	0.13

Land preparation and experiment lay-out

The experimental fields were plowed, using a moldboard plow pulled by water buffaloes in July (Tan Thanh) or August (Cai Lay and Tam Nong) 1992. Similar to farmer's practice (Xuan 1993), the fields were left fallow and submerged during the flooding period. Construction of the experimental fields began when the flood had just receded. December 1992 in Cai Lay and Tan Thanh, January 1993 in Tam Nong, water in the surrounding canals was about 0.2-0.3 m below the ground surface.

The experiment comprised of two factors arranged in split-plot design with three replications at each site. The main plots were numbers of flushing (F) and sub plots numbers of harrowing (H). A combination of 2 levels in each factor resulted in four treatments as follows:

- F1H1 (flushing once and harrowing once): 22-cm depth of water was pumped from the surrounding canals to the experimental plot. After being soaked for one day, the plot was subjected to 8 passes of harrowing to 0.1-0.15 m depth, using a wooden-toothed harrow pulled by water buffaloes. One day later, standing water was drained by gravity (flushing) to the surrounding canals. The plot was then sown with pregerminated seeds.
- F1H3 (flushing once and harrowing three times): After the first irrigation and harrowing as in F1H1, two more harrowings were carried out at one day interval. Standing water was drained one day after the third harrowing, before sowing is carried out.
- F3H1 (flushing three times and harrowing once): After the first irrigation, harrowing and drainage as in F1H1, the cycle of irrigation + one-day soaking + flushing was repeated twice before the final irrigation and sowing.
- F3H3 (flushing three times and harrowing three times): the cycle of irrigation + flushing + harrowing activities described in F1H1 were repeated three times before sowing.

Flushing and harrowing were arranged such that sowing was carried out on the same day at each site (15 December 1992 for Cai Lay, 20 December 1992 for Tan Thanh and 15 January 1993 for Tam Nong).

Each main plot, measured 10 x 16 m, was hydraulically isolated from the surrounding by plastic sheets covering the inner sides of the 0.4 x 0.4 m bunds, and reaching down to 0.5 m below ground surface. Subplots (10 x 8 m) were separated by bunds, without plastic linings. Since the water levels in adjacent subplots were the same, it was assumed that there was no water exchange between them. The earthen material for bund construction was collected from outside of the experimental field.

Soil and water sampling

In treatment F1H1, soil samples at 0-0.1 m depth were taken for chemical analysis at the start of the experiment (before the first irrigation) and after the last flushing. In other treatments, two other samplings were taken before the second and third cycle of harrowing and/or flushing (Fig. 1). Soil samples were taken by inserting a 10 cm long, 200 cm^3 ring vertically into the soft soil. An air-tight cap was screwed to the top end of the ring. The operator reached down and covered the bottom end of the ring before he turned it upside down and pulled the sample out of the soils. At each sampling, five samples were collected per subplot. They were mixed into a composite sample for analysis.

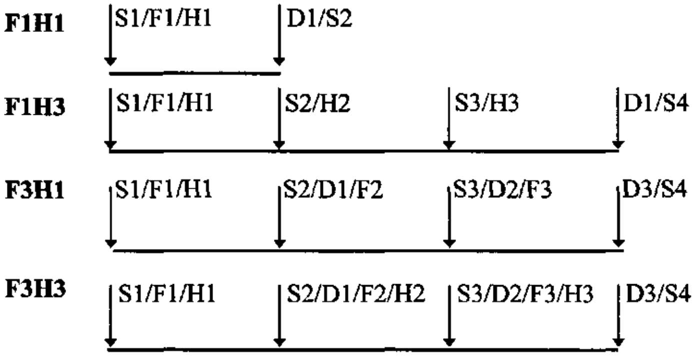

FIGURE 1 Schedule of experimental activities. S: sampling, F: flushing, H: harrowing, D; drainage and the numbers (1, 2, 3, 4) are the order of activities.

Soil samples were air-dried and analyzed for pH (1:2.5 soil-water ratio), EC (1:2.5 soil-water ratio), exchangeable Al (extracted by 1 M KCl solution), and soluble Al in saturation (extracted by 1:1.5 H_2O) as described in Begheijn (1980).

Water the irrigation canal was sampled, using 0.5 l bottle, before each irrigation. During each flushing, drain water was sampled three times (at the beginning, half way and at the end of flushing) and mixed for chemical analysis. Water samples were analyzed for pH, EC, and Al (Begheijn, 1980). This paper reports only results with Al concentrations. This is because high aluminum concentration characterizes ASS and Al can be toxic to plants in concentrations as low as 0.04 to 0.08 mmol(+) l^{-1} (Dent 1986).

In this study flushing efficiency was defined as the removal of soluble aluminum from soil saturation extracts by amount of flushing water (expressed as cmol(+) kg^{-1} /100 mm). The removal of soluble aluminum was calculated by from the differences in soluble aluminum concentrations in soil samples taken before and after each flushing treatment. These differences were then divided by the amount of flushing water (in 100 mm).

Agronomic practice and sampling

After completion of the treatments, 200 kg ha^{-1} of IR 50404-57 pregerminated seeds were broadcast. Rice variety and rate of seeding were similar to those used by surrounding farmers. For the first week after seeding, fields were kept saturated until rice seeds fully emerged. From one to three weeks after seeding, water level in the field was adjusted 1-5 cm according to the height of the rice plant. Water level afterward was maintained at about 5 cm until rice reached the ripen stage.

Fertilizer was applied at 90-90-30 kg N-P-K per ha. P and K and a 1/3 N were applied as a basal dressing. The rest of N was top-dressed in two splits at 30 and 60 days after sowing.

Rice was harvested in 2 m x 4 m sampling area in the middle of each subplot.

RESULTS AND DISCUSSION

Effect of flushing and harrowing on Al concentration

Soluble Al concentration.

Figure 2 presents the changes in soluble Al concentration of the 0-0.1 m soil depth during the process of harrowing and flushing in different treatments at the three sites. Differences - or reduction- between concentration before the first irrigation and after the last flushing (S1 and S2 or S4 in Fig. 1) of the treatments are presented in Table 3. These differences represents the amount of dissolved aluminum removed from the 0-0.1 m top soil by harrowing and flushing treatments.

In general, the reduction in soluble aluminum was highest for the most acidic soil (Cai Lay, mean value for all treatments: 0.44 cmol(+) kg^{-1}) and lowest for the least acidic soil (Tan Thanh, 0.13 cmol(+) kg^{-1}). Solubility of aluminum in acid sulphate soils increases strongly with decreased soil pH (van Breemen 1976). Probably more aluminum was dissolved and could be removed from Cai Lay soil with the lowest soil pH (Table 1).

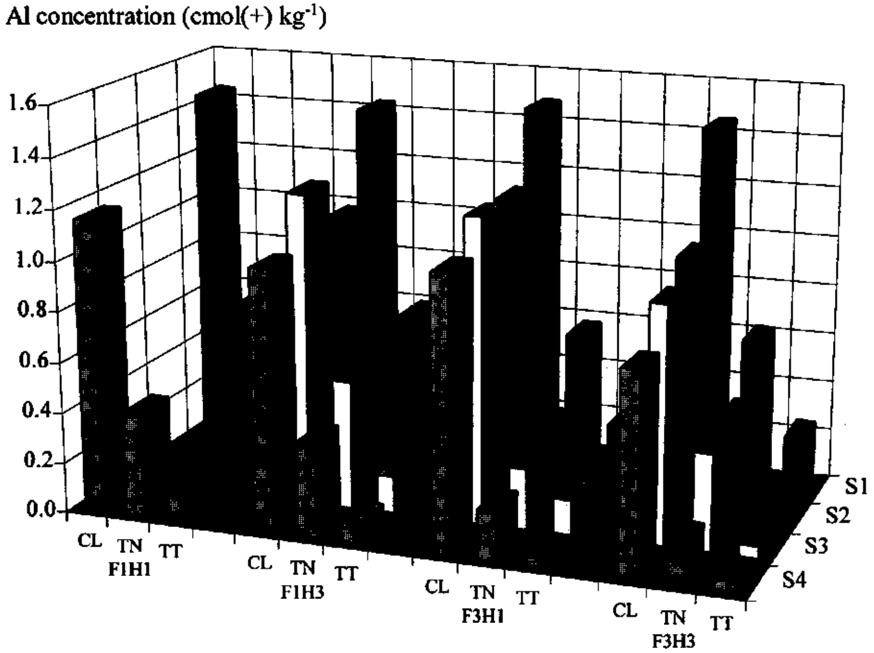

FIGURE 2 Soluble aluminum concentration (cmol(+) kg^{-1}) from different treatments of flushing (F) and harrowing (H), 1 and 3 folds in Cai Lay (CL), Tam Nong (TN), and Tan Thanh (TT). Sampling (S) orders were denoted by a number (1, 2, 3, 4).

In the same mainplot, except for the case of F1 in Tan Thanh, triple harrowing resulted in greater reduction in soluble aluminum concentration. The differences among treatments were however statistically significant at 5% level only in F3 mainplot in Cai Lay (Table 3). Soluble Al concentration decreased appreciably after each cycle of harrowing + flushing in F3H3. While the second and third flushing without harrowing (i.e at sampling S3, S4, Fig. 2) in F3H1 did not change soluble Al concentration. Harrowing under flooded condition helped break down large soil clods and soil aggregates and increase porosity (Ghilyal 1978, Bouma 1985, Sharma and De Datta 1986). The soil-water contact surface was thus increased by puddling action. Puddling also created turbulence which helped diffuse dissolved aluminum into the main water body to be flushed away by drainage.

Flushing three times reduced soluble aluminum in soil more than flushing once (Fig. 2 and Table 3). The difference between the two flushing treatments were higher in plots harrowed three times than in plots harrowed once, especially in Cai Lay and Tam Nong. The differences in the amount of aluminum reduced by flushing treatments in Tan Thanh were not significant (Table 3).

TABLE 3 The decrease (difference between initial and final values) of soluble soil Al concentration (cmol(+) kg^{-1}) in different flushing (F) and harrowing (H) treatments. Numbers 1 and 3 refer to times that flushing or harrowing were carried out.

Site		Treatments		Difference†
		F1	F3	
Cai Lay	H1	0.29 a‡	0.40 a	NS
	H3	0.40 a	0.67 b	*
Tam Nong	H1	0.13 a	0.40 a	*
	H3	0.25 a	0.46 a	*
Tan Thanh	H1	0.14 a	0.18 a	NS
	H3	0.13 a	0.20 a	NS
Mean at	H1	0.19 a	0.33 a	NS
Three sites	H3	0.26 a	0.44 a	NS

†NS: not significant; * significant at 5% level by DMRT.

‡In a column at the same site, means followed by a common letter are not significantly different at 5% level by DMRT.

On the average in three sites, 0.44 cmol(+) kg^{-1} soluble aluminum (or about 60% of the initial value) was removed from the 0-0.1 m top soil by F3H3, 0.33 cmol(+) kg^{-1} (or 54% of the initial value) by F3H1, 0.26 cmol(+) kg^{-1} (or 33% of the initial value) by F1H3 and 0.19 cmol(+) kg^{-1} (or 28% of the initial value) by F1H1.

Exchangeable Al concentration

Exchangeable Al concentration of the 0-0.1 m top soil decreased during the process of harrowing and flushing in different treatments at all three sites (Fig. 3). However, the decrease (i.e. difference between initial and final values) of exchangeable soil Al concentration did not differ significantly among treatments (Table 4). Averaging values from the three sites, exchangeable Al concentrations decreased by 3.5 %in F1H1 compared to the initial value, 5.8 % in F1H3, 12.5 % in F3H1 and 8.2 % in F3H3. Given the heterogeneity of the sites, the decrease was not enough to significantly distinguish effects of different treatments.

TABLE 4 The decrease (difference between initial and final values) of exchangeable soil Al concentration (cmol(+) kg^{-1}) in different flushing (F) and harrowing (H) treatments. Numbers 1 and 3 refer to the times that flushing or harrowing were carried out.

Site		Treatment		Difference[†]
		F1	F3	
Cai Lay	H1	0.54 a[‡]	1.56 a	NS
	H3	0.33 a	0.93 a	NS
Tam Nong	H1	0.64 a	2.58 a	NS
	H3	0.62 a	1.88 a	NS
Tan Thanh	H1	-0.02 a	0.34 a	NS
	H3	1.03 a	-.0.01a	NS
Mean at three sites	H1	0.39 a	1.49 a	NS
	H3	0.66 a	0.94 a	NS

[†] NS: not significant; * significant at 5% level by DMRT.

[‡] In a column at the same site, means followed by a common letter are not significantly different at 5% level by DMRT.

In absolute values, exchangeable Al decreased more than soluble Al (Tables 3 and 4). This indicates that the treatments also removed a portion of Al adsorbed in the soil complex.. This amount, however, was less than 5% of the total exchangeable Al. The limited effect of the treatments on the reduction of adsorbed Al could be explained by the strong bond between the complex and Al (van Mensvoort et al. 1991). Tuong (1993) also indicated that after ASS improvement, a considerable quantity of toxicity still remains adsorbed to the exchange complex.

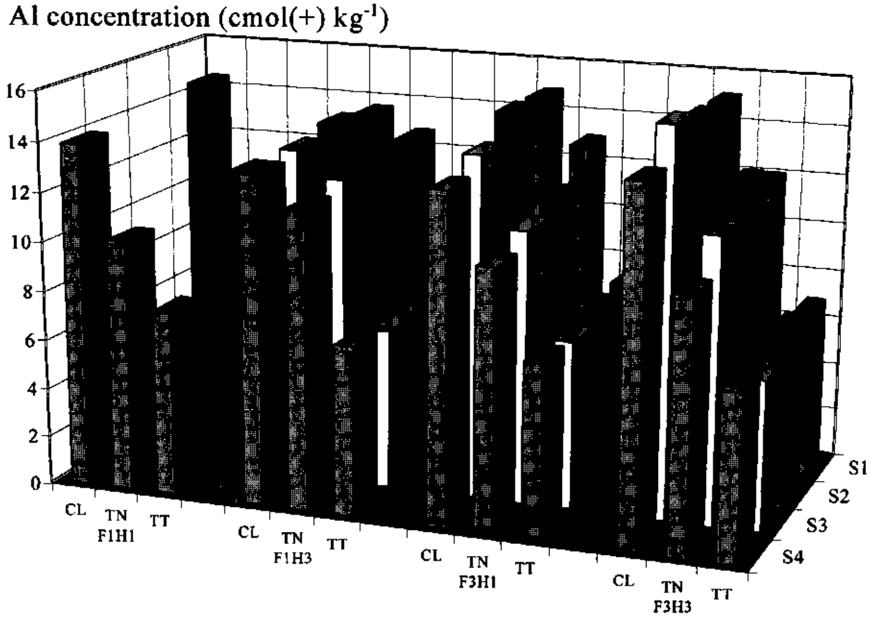

FIGURE 3 Exchangeable aluminum concentration (cmol(+) kg^{-1}) from different treatments of flushing (F) and harrowing (H), 1 and 3 folds in Cai Lay (CL), Tam Nong (TN), and Tan Thanh (TT). Sampling (S) orders were denoted by a number (1, 2, 3, 4).

Flushing efficiency

Combined with H3 treatment, F3 gave significantly high flushing efficiency as compared to F3 combined with H1 (Figure 4). Among three sites, Cai Lay had a highest flushing efficiency (0.90 cmol(+) kg^{-1} /100 mm). In Tam Nong this value was 0.63 cmol(+) kg^{-1} /100 mm and in Tan Thanh it was 0.27 cmol(+) kg^{-1} /100 mm.

In case of one time of harrowing (H1), the efficiency of flushing was much lower than with H3 in Cai Lay (0.54 cmol(+) kg^{-1}/100 mm), somewhat lower in Tam Nong (0.53 cmol(+) kg^{-1}/100 mm) and significantly lower in Tan Thanh (0.24 mol(+) kg^{-1}/100 mm).

The differences in flushing efficiencies between H3 and H1 demonstrated the role of the stirring up process which increased the contact area between water and soil clods. However, with one time of flushing only (in F1), the effect of harrowing was limited (Figure 4). The lower efficiency of the F1 H3 treatment at three sites was likely due to the high concentration of toxic element in soil solution after the first harrowing. Without flushing with fresh water, toxic concentrations of soil solution were high, the solubility of toxic substances were possibly reduced. Therefore, the second and the third harrowing, which might cause a further increase of contact surface area, gave low efficiency.

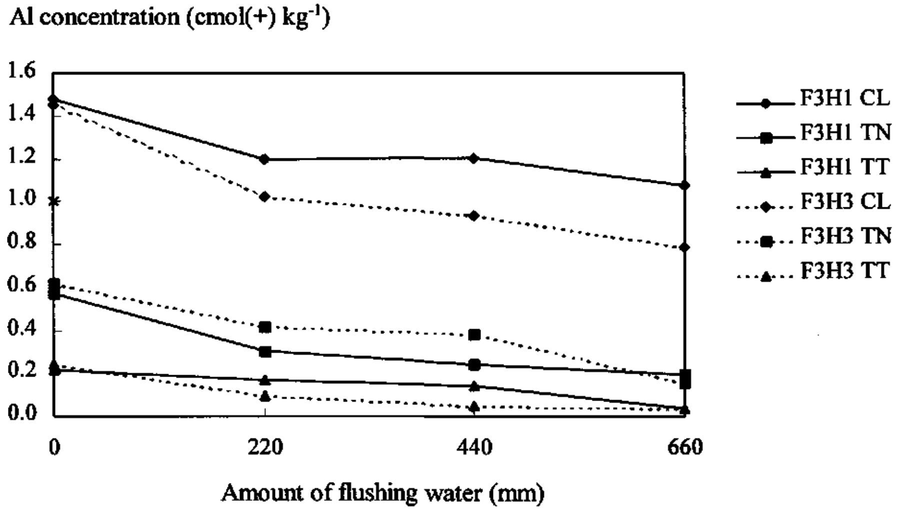

FIGURE 4 Soluble aluminum concentration (cmol(+) kg^{-1}) as a function of amount of flushing water from different treatments of flushing (F) and harrowing (H), 1 and 3 folds in Cai Lay (CL), Tam Nong (TN), and Tan Thanh (TT).

From Figure 4, a sharp reduction in the efficiency of the first flushing, in comparison with the second and the third one, can clearly be observed. This indicates that the first treatment removed the soluble toxins more efficiently than the second and third.

At Cai Lay and Tan Thanh in F3H1, there was a clear reduction tendency of aluminum concentration in the second flushing (1.05 mmol(+) l^{-1}) and third flushing (1.00 mmol(+) l^{-1}) in comparison with first flushing (1.54 mmol(+) l^{-1}). This tendency did not occur in F3H3.

Effect of flushing and harrowing on rice performance

After the emergence, the rice in Cai Lay died at 12 to 14 days after sowing. Its root system was heavily damaged, deformed and stunted in a fashion typical of Al toxicity (Dent, 1986). Even in treatment F3H3, the final (after the last flushing) soluble Al concentration in the root zone (0.79 cmol(+) kg^{-1} in Fig. 3) exceeded the tolerance of rice roots, which is about 0.20 cmol(+) kg^{-1} (Cate and Sukhai 1964).

Yields of rice in Tam Nong and Tan Thanh are shown in Table 5. The mean yield (for two sites) of treatment F3 H3 was the highest (4.86 Mg ha^{-1}) and significantly different from F1 H3 (4.10 Mg ha^{-1}) and F1 H1 (4.12 Mg ha^{-1}). The difference between F3 H3 and F3 H1 was, however, not significant. At each site, yield had a tendency to increase with number of harrowing and flushing, though the differences due to harrowing were not significant. Rice yield was correlated to the final soil soluble Al (after the last flushing) according to the equation (Figure 5):

$$Y = 5.17 - 4.38\ Al_{sol} \qquad (1)$$

where Y is rice yield (Mg ha^{-1}) and Al, is soluble aluminum concentration (cmol(+) kg^{-1}). A significantly high correlation coefficient between Y and Al_{sol} was found (r^2 = 0.84).

By reducing the concentration of soluble toxins (e.g. Al) in the rootzone, harrowing (puddling) and flushing contributed to the increase in rice yield. This is in agreement with Kselik et al. (1992) who reported that puddling in ASS without added fertilizer and lime could significantly improve rice yield. Husson et al. (1993) also demonstrated that harrowing resulted in a high rice yield in an ASS area of the Mekong river delta, while without- land- preparation treatment gave no yield , even with high levels of fertilizer.

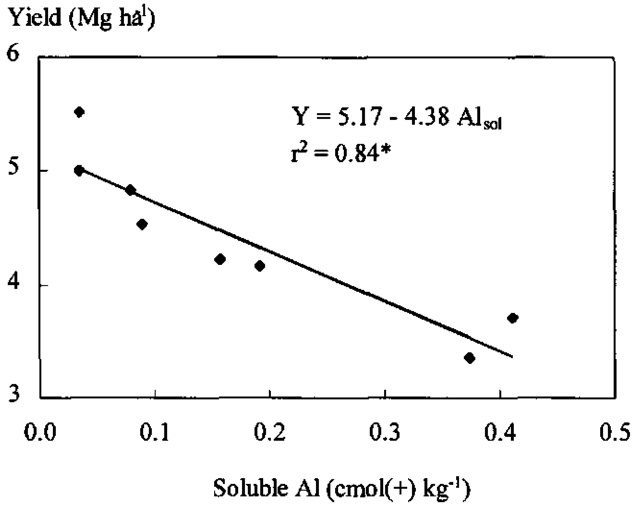

FIGURE 5 Relationship between rice yields (Y) and soluble aluminum (Al_{sol}).

TABLE 5 Mean rice yields (in Mg/ha) in different flushing (F) and harrowing (H) treatments. Numbers 1 and 3 refer to times that flushing or harrowing was repeated.

Site		F1	F3	Difference
Tan Thanh	H1	4.54 a[‡]	5.00 a	ns
	H3	4.84 a	5.51 a	ns
Tam Nong	H1	3.71 a	4.16 a	*
	H3	3.36 a	4.22 a	*
Average of 2 sites	H1	4.12 a	4.58 a	*
	H3	4.10 a	4.86 a	*

[†] ns: not significant; * significant at 5% level by DMRT.

[‡] In a column at the same site, means followed by a common letter are not significantly different at 5% level by DMRT.

Implication on environmental effect of ASS reclamation for rice cultivation

Al concentration in the drain water varied from 0.2 mmol(+) l^{-1} (at Tan Thanh) to 1.55 mmol (+) l^{-1} (at Cai Lay) in Figure 6. Al concentration of the water drained from ricefield reclaimed for rice cultivation at the beginning of the rainy season (May-June) at the Cai Lay site was 3.5 mmol(+) l^{-1} (Minh, 1995 unpublished data) and at Tan Thanh 0.8 mmol(+) l^{-1} (Tuong, 1995 unpublished data). Higher concentration of Al in the drain water at the beginning of rainy season might have come from flushing of water-soluble aluminum sulphates which precipitated at the surface of soil aggregates under strong evaporative conditions (van Breemen and Pons, 1978) throughout the dry season in the Mekong river delta.

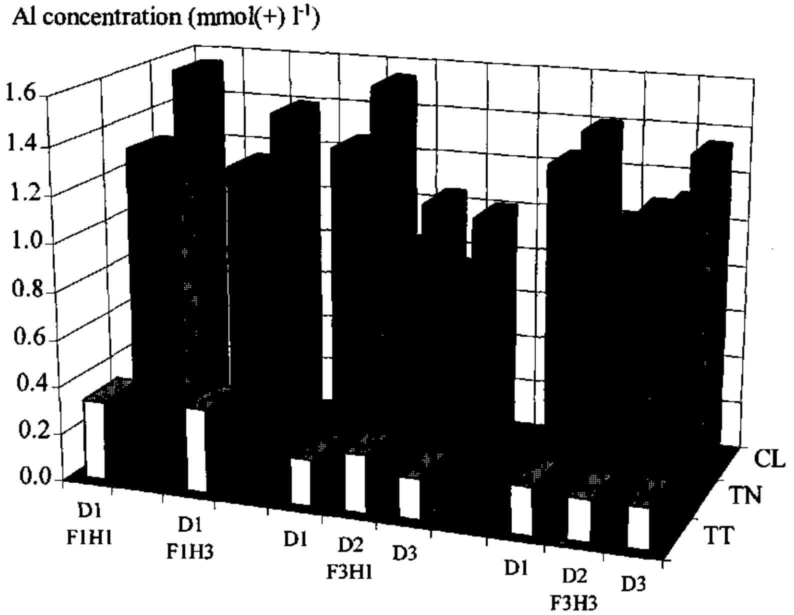

FIGURE 6 Aluminum concentration (mmol(+) l^{-1}) in drain water from different treatments of flushing (F) and harrowing (H), 1 and 3 folds in Cai Lay (CL), Tam Nong (TN), and Tan Thanh (TT). Sampling (S) orders were denoted by a number (1, 2, 3, 4).

Water drained from the ricefields is diluted and transported by the discharge of the canal network. The December - i.e end of the flood season- discharge of the Mekong river and of the canal network is from twice to three times the discharge in May, beginning of rainy season (NEDECO 1993). Lower Al concentration in the leachate and higher river discharge at the end of the flood season would create less environmental hazard to the surrounding water than flushing at the beginning of the rainy season.

CONCLUSIONS

1. Harrowing three times combined with three-time flushing was an appropriate measure to improve young, recently oxidized acid sulphate soils (Cai Lay). In the areas, where the soil is already improved (Tan Thanh), harrowing three times and flushing three times gave no significant effect in reducing the soluble aluminum concentration compared with one time application of each treatment. Under moderate ASS, flushing three times significantly reduces soluble aluminum compared with flushing one time, whereas harrowing one or three times gives no significant differences.

2. Soluble aluminum was effectively removed by harrowing and flushing whereas little effect of these treatments was seen on Al in the soil exchange complex.

3. Improvement of ASS by flushing is a process demanding a large quantity of good quality fresh water. Harrowing helps to increase the flushing efficiency. Without sufficient water for flushing, harrowing itself has only a very limited effect on reduction of toxic concentrations.

4. The period of flood recession is a good time for harrowing and flushing, because large quantities of fresh water are available which reduces toxic concentrations in the drain water and thus contamination of the surface water.

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Chapter 7

GENERAL DISCUSSION AND CONCLUSIONS

GENERAL DISCUSSION AND CONCLUSIONS

1. Removing toxicities out of the rootzone is essential for growing agricultural crops on ASS. This process, however, involves the transfer of toxicities to the surrounding soil and water and poses, therefore, polluting hazards to the environment. A balance between increasing agricultural productivity and protection of environment is important in reclaiming ASS in a suitable manner. Because of the importance of this balance, this study has taken an integrated approach: assessing the process of leaching ASS both from agricultural production and environmental point of view. The study focused on the effects of soil physical properties on leaching efficiency and quantified the amount of toxicity released to the surroundings. The study paid more attention to raised beds than to rice fields because the former are more problematic from an environmental point of view.

2. Soil morphological methodologies, such as staining of infiltration pattern with Blue Methylene, were used to quantify the effects of soil morphological and physical processes on the leaching process (Chapter 4). Bypass and runoff, and the corresponding aluminum concentrations, have not previously been determined under field conditions. Micro-catchment, water and solute balance concepts (Chapter 3) were devised and tested to compare the relative importance of bypass flow and runoff in the polluting process while reclaiming ASS.

3. The effectiveness of leaching soluble aluminum and the amount of aluminum released to surrounding water were strongly affected by soil physical properties, such as the hydraulic functions, infiltration rate and porosity patterns (Chapter 3 and 4). The amount of aluminum leached also depended on the chemical properties of the topsoil (Chapter 3). An interdisciplinary approach, combining chemical and physical processes when characterizing flow of water and solutes, is crucially important to obtain a realistic view of the formation and transport of solutes in and out of ASS.

4. Due to capillary rise, aluminum accumulated in the topsoil layers of ASS during the dry season. This harmful transport process can be reduced by soil management techniques like mulching and plowing. Mulching significantly reduced evaporation and, as the consequence, capillary rise. Plowing can decrease the unsaturated hydraulic conductivity of the topsoils (Chapter 2).

These positive effects of land management, however, were reduces by the first rainfall at the beginning of the rainy season which raised the ground water table and increased its aluminum concentration (Chapter 2). Aluminum moved upwards by capillary rise during dry spells in between infrequent rains during the first part of the rainy season. Lowering the water level, or applying supplementary irrigation in June could be helpful in curtailing aluminum accumulation at the soil surface at the beginning of the wet season. Downward movement of fresh irrigation water will suppress upward movement of soluble aluminum by capillary rise.

5. During the rainy season, aluminum is removed from the soil either by bypass flow or by (overland) runoff. Runoff helps remove soluble aluminum accumulated at a thin surface layer of the beds while bypass flow can remove toxicities at deeper soil layers (Chapter 3). Aluminum concentration in runoff reduced with cumulative rainfall, while aluminum concentration in bypass flow increased with cumulative rainfall (Chapter 3 and 4). The ratio of bypass flow vs. runoff and aluminum concentration in each flow component varied with the soil materials (topsoil, sulphuric or sulphidic) and methods used in forming the beds. When the bed surface is covered with a layer of sulphidic material, runoff can remove more soluble aluminum than bypass flow. The reverse is true for other cases (Chapter 3). The total aluminum (i.e. transported by bypass flow and runoff) discharged to the surroundings, however, does not differ. Increasing bypass flow may thus help to improve the agronomic soil quality without imposing higher environmental hazards.

6. Bypass flow can be related to morphological characteristics of pore systems. Mesopores, due to their higher soil-water contact areas as compared to macropores, are more effective in leaching aluminum than macropores (Chapter 4). Soil materials used to construct the beds, land use types and the age of the beds are the most important factors determining pore-system distribution and bypass flow (Chapter 3 and 4). The amount of aluminum released by raised beds (for pineapple and yam) is about 3 to 4 times higher than for rice fields (Chapter 5). The concentration and amount of toxicities released to the surroundings are often highest at the beginning of the rainy season, i.e. in June. This period also impose the highest risk to the environment, due to very low river discharge, not allowing dilution and/or transport of the released pollution. The problem is exacerbated by the fact that

June is also the start of the growing season, when there is a high water demand for agricultural production (Chapter 5).

7. Flood water can be effectively used for flushing rice fields. The effectiveness of flushing is enhanced by proper tillage (harrowing) operations. Harrowing helps increase contact surface between soil and water (Chapter 6). Flushing at the end of the flood season helps increase rice yields. At the same time, it minimizes the environmental hazards.

8. Improving agricultural production and reducing pollution hazards are the two sides of a single coin when reclaiming acid sulphate soils. This study is the first kind to quantify the pollution risks caused by ASS leaching. It deals with the field level. Future studies are needed to quantify the mechanism of aluminum transport in canal and river networks. This is necessary to allow a prediction of aluminum concentrations in surface water on a regional basis. This should be followed by an economic assessment of pollution risk, e.g. the negative impact on fisheries and aquaculture. Only then, can the trade off between agricultural production and environment protection be properly evaluated.

SUMMARY

The objectives of this study in the Mekong delta, Vietnam, were: (1) to obtain a better understanding of the effects of soil physical properties and flow types on solute transport in ASS emphasing aluminum; (2) to quantify environmental hazards resulting from amelioration activities in acid sulphate soils (ASS); and (3) to identify measures which can increase agricultural production and reduce negative environmental side effects.

This study was conducted on ASS in the Mekong delta, Vietnam and consisted of 5 experiments starting in the dry season and ending at the end of the flood season. All experiments were carried out under field conditions. Transport of soluble aluminum was investigated for different types of water flow, which are typical for each season such as capillary rise, bypass flow and runoff.

During the dry season, soluble aluminum was accumulated in topsoil layers by capillary rise. Effects of land management methods on accumulation of aluminum was the main focus in this period: Plowing (P1) and mulching (M1), compared with non-plowing (P0) and non-mulching (M0). Experiments were conducted in lysimeters and under field conditions. In both experiments, topsoils were treated with P1M1, P1M0, P0M1, and P0M0. Three levels of ground water (GWL: 30, 60, and 90 cm below the ground surface) were maintained in the undisturbed soil columns in the lysimeters. Aluminum accumulation increased with increased evaporation. Under field conditions, where ground water levels were monitored but not controlled, mulching treatments gave a significantly lower aluminum accumulation as compared with the non-mulching treatments, whereas plowing did not result in a significant decrease of this accumulation. Rainfall during the first 3 weeks of the rainy season caused the ground water to rise rapidly while its aluminum concentration increased. This increased the soluble aluminum concentrations in the topsoils and eliminated the leaching effects of earlier land management practices.

During the rainy season, the study was focused on aluminum transport with bypass flow and runoff in and on raised beds, which are constructed by soil materials excavated from adjacent lateral ditches with the objective to avoid flooding and to enhance leaching of soil. This is a very common technique to grow upland crops in ASS. Therefore, a better understanding of leaching processes

in raised beds is needed to properly assess management options for ASS. Three types of raised beds, which are commonly constructed in the Mekong delta, were studied. In the low raised beds only topsoil material was used to construct the bed. In the high type both top soil and the jarosite layer were used. In the "traditional" raised beds, pyritic material was also found on top of the beds. The amount of runoff increased with cumulative rainfall due to a decrease of infiltration rates and saturated hydraulic conductivities. Due to surface crusting, traditional beds gave the highest runoff amounts among the three types. Concentrations of aluminum in bypass flow were consistently higher than in runoff. In low and high beds, amounts of aluminum in bypass flow were also higher than in runoff, whereas in traditional bed-types it was slightly lower. However, the negative impacts on the surrounding surface water was not significantly different for the three types of beds. Therefore, the low bed type is the most desirable from an agricultural production point of view, because less effort is needed in construction.

Pore system distribution can play a very important role in determining water flows in and on the raised beds and as a consequence, on the effectiveness of leaching toxic substances. Thus, field and laboratory studies were carried out to quantify the effects of soil physical properties and bypass flow on leaching processes of new, 1-year old and 2-year old raised beds for yam and pineapple cultivation. Water-conducting pores were characterized using Methylene Blue. Number, area, and perimeter of water-conducting pores at 10-cm depth intervals of six 1 x 1m subplots were investigated. Undisturbed 20 cm x 25 cm soil cores were subjected to three 30 mm h^{-1} rains in 30 minutes. Volume, aluminum and sulphate concentration of outflows were monitored. Due to consolidation, the area and perimeter of water-conducting pores in 2-year old pineapple beds had decreased to about one third, and bypass flow rates to about 80% of those in newly constructed beds. Consolidation, however, did not affect macropore network geometry in yam beds because they were subjected to annual tillage and yam tubers were uprooted regularly. Al and SO_4^{2-} concentrations in the outflows of newly constructed and 1-year old raised beds were higher in pineapple, while those in 2-year raised beds were higher in yam.

A side effect of leaching of ASS may be the pollution of surrounding waters. In order to obtain a proper assessment of this problem, the concentration and the amount of aluminum in water leaching from ASS during cultivation of rice, pineapple and yam were investigated. The fields have been reclaimed for 2 months, 1 and 2 years, respectively. Pineapple and yam were cultivated on raised beds. Values of pH in drainage water ranged from 2.9 to 3.9 and aluminum concentration from 3 to 13 mmol(+) l^{-1}. Mean monthly aluminum concentrations in the water discharged from pineapple and yam raised beds was about 3 times higher than from rice fields. Monthly total amount of aluminum released by the raised beds could be as high as 16,690 mol ha^{-1}, and was 3 to 5 times higher than that from rice fields. Consolidation and crust formation in pineapple beds reduced the concentration and amount of aluminum released as the beds grew older. In June, leaching from ASS was most hazardous to the environment due to a combination of highest total aluminum released to the canal network and a relatively low river discharge.

At the flood recession period, the effectiveness of flood water (in combination with harrowing) in flushing out toxic substances from the top soil of ASS was investigated. Three experimental sites with slight, moderate and strong acidity were selected. Treatments were the number of harrowings (one: H1 and three times: H3) and the number of flushings (one: F1 and three times: F3).Three times harrowing in combination with three times flushing was the most effective in leaching acid in the most acid soils. When flushing once, the number of harrowings had no effect. The quantity of aluminum adsorbed on the soil exchange complex was not affected by different harrowing and flushing treatments. F3H3 also gave a significantly higher rice yield as compared with other treatments. The flood recession period is the most appropriate moment for flushing topsoils for rice cultivation, which has a high water requirement.

SAMENVATTING

Deze studie in de Mekong Delta, Vietnam had de volgende doelstellingen: (1) het verklaren van het transport van opgelost aluminium in kattekleigronden; (2) het kwantificeren van ongunstige milieueffecten die samenhangen met de ontginning van kattekleigronden,en het uitspoelen van aluminium en (3) het identificeren van maatregelen die enerzijds de landbouwkundige productie kunnen verhogen terwijl de negatieve milieueffecten worden geminimaliseerd.

De studie werd uitgevoerd in kattekleigronden in de Mekong Delta, Vietnam, en bestond uit vijf experimenten die werden begonnen in het droge seizoen en die eindigden aan het eind van het seizoen met overstromingen. Alle experimenten werden in het veld uitgevoerd. Het transport van opgelost aluminium werd onderzocht als functie van verschillende stromingsregimes in verschillende seizoenen, zoals capillaire opstijging, "bypass flow" (het stromen van vrij water langs grote porien in een onverzadigde bodemmatrix) en oppervlakkige afstroming.

Opgelost aluminium accumuleerde aan het bodemoppervlak in het droge seizoen. De effecten van verschillende vormen van bodembehandeling, in termen van het al of niet ploegen of mulchen, op de accumulatie van aluminium werden onderzocht in lysimeters en in het veld. De accumulatie van Al nam toe naarmate de verdamping toenam. Het mulchen had onder veldomstandigheden een duidelijk remmend effect op de accumulatie van Al, terwijl het effect van al of niet ploegen niet significant was. Regenval gedurende de eerste drie weken van de regentijd leidde tot een snelle stijging van de grondwaterstand. Door uitspoeling van Al nam ook de Al concentratie van het grondwater sterk toe. Capillaire opstijging naar de bovengrond leidde tot een toename van het Al gehalte van de bovengrond waarmee de effecten van de eerdere uitspoeling teniet werden gedaan.

Opgehoogde bedden worden veel gebruikt om gewassen te telen in gebieden met kattekleigronden in de Delta. Deze bedden worden geconstrueerd met materiaal uit de aangrenzende sloten, met als doel te voorkomen dat de gewassen onder water verdwijnen tijdens overstromingen en ook om het uitspoelen van zuren te vergemakkelijken. De rol van oppervlakkige afstroming en van "bypass flow" bij het verwijderen van Al uit drie typen bedden is onderzocht in het natte seizoen. In lage bedden is alleen materiaal vanuit de bovengrond gebruikt voor de ophoging, terwijl in de hogere bedden zowel materiaal uit de bovengrond als uit de jarosietlaag

is toegepast. In de traditionele bedden is zelfs ook pyriethoudend materiaal in de bedden aanwezig. Naarmate meer regen valt neemt de oppervlakkige afstroming toe als gevolg van een afnemende infiltratiesnelheid en hydraulische geleidbaarheid. Als gevolg van sterke oppervlakkige korstvorming werd de hoogste oppervlakkige afstroming gemeten in de traditionele bedden. Al concentraties waren steeds hoger in water dat deel uitmaakte van "bypass flow", wanneer vergeleken met concentraties in oppervlakkige afstroming. De totale uitspoeling van Al was echter niet verschillend voor de drie soorten bedden. Daarom is het lage bed het meest geschikt omdat het bij constructie de minste inspanning vereist.

De uitspoeling van Al werd gekwantificeerd voor nieuwe, een jaar en twee jaar oude bedden, die werden gebruikt voor de teelt van yam en ananas. De blauwe kleurstof methyleen blauw werd gebruikt om stromingspatronen van water zichtbaar te maken. Het aantal gekleurde porien en hun omtrek werd gemeten op horizontale bodemdoorsneden met een onderlinge afstand van 10 cm, op proefplekken van 1m x1m. Ongestoorde cylindrische monsters (20cm doorsnede x 25cm hoogte) werden beregend met drie buien met een intensiteit van 30mm per uur, binnen een periode van 30 min. Het volume van het uitstromende water en de Al en sulphaat concentraties werden gemeten. De twee jaar oude ananas-bedden hadden nog maar een derde van de gekleurde porien terwijl de "bypass rate" met 20% was gedaald. Deze verschillen konden worden verklaard door consolidatie van de structuur. In yam bedden traden deze verschijnselen niet op omdat hier elk jaar de grond wordt bewerkt en de yam knollen steeds worden uitgetrokken. Al en sulphaat concentraties waren het hoogste in nieuwe en in een jaar oude bedden bij de ananas teelt, terwijl deze het hoogst waren in de twee jaar oude bedden waar yam werd geteeld.

Gedurende het regenseizoen kan uitspoeling vanuit kattekleigronden het omringende water verontreinigen. Al concentraties werden gemeten in water dat uitspoelde vanuit bedden waarop ananas en yam werden geteeld. Rijst werd in bevloeide velden geteelt. pH waarden varieerden tussen 2.9 en 3.9 en Al concentraties tussen 3 en 13 mmol per liter. De gemiddelde maandelijkse Al concentraties in water afkomstig vanuit ananas en yam bedden was drie keer zo hoog als water afkomstig vanuit rijstvelden. De totale hoeveelheid Al per maand was maximaal 16690 mol per hectare, en dat was drie tot vijf keer zo hoog als overeenkomstige waarden voor rijstvelden. Naarmate de bedden ouder werden nam de uitspoeling af als gevolg van korstvorming aan het oppervlak. De uitspoeling van zuur vanuit kattekleigronden is het meest schadelijk in Juni omdat dan de uitspoeling relatief hoog is terwijl juist de rivieren een lage afvoer hebben.

Het effect van overstroming met zoet water op het uitspoelen van zuur is onderzocht aan het eind van de overstromingsperiode. Op drie locaties met toenemende zuurgraad is het effect van grondbewerking in de vorm van eggen en van het doorspoelen met zoet water onderzocht. De onderzochtte varianten waren een en drie keer eggen en doorspoelen. Drie keer eggen in combinatie met drie keer doorspoelen was het meest effectief voor het uitspoelen van zuur in de meest zure bodem. Deze behandeling gaf ook de hoogste rijstopbrengst .Wanneer een keer wordt doorgespoeld maakt het geen verschil of een dan wel drie keer wordt geegd. De hoeveelheid geadsorbeerd Al werd niet beinvloed door de verschillende behandelingen.

TÓM LƯỢC

Mục tiêu của nghiên cứu này là:

1. tìm hiểu rõ hơn về ảnh hưởng của những tính chất vật lý đất và các loại hình dòng chảy lên sự vận chuyển độc chất trong đất phèn, trong đó tập trung chú ý vào độc chất nhôm
2. nghiên cứu định lượng ảnh hưởng bất lợi của việc cải tạo đất phèn lên môi trường
3. tìm những biện pháp nâng cao năng suất ít gây tác động xấu lên môi trường.

Nghiên cứu này gồm 5 thí nghiệm trên các vùng đất phèn vùng Đồng Bằng Sông Cửu Long, Việt Nam. Đây là những thí nghiệm ngoài đồng bắt đầu từ mùa khô và chấm dứt vào cuối mùa lũ. Sự chuyển vận của nhôm theo các dạng dòng chảy đặc trưng cho từng mùa khác nhau như mao dẫn, chảy trong khe rỗng lớn, chảy tràn được tìm hiểu trong đề tài này.

Trong mùa khô, mao dẫn mang nhôm hòa tan tích lũy trong tầng đất mặt. Các phương pháp làm đất có tác động đến sự vận chuyển này đã được khảo sát: cày và tủ rơm. Tổ hợp các nghiệm thức này lại, ta có: cày tủ rơm, không cày có tủ rơm, cày không tủ rơm và không cày không tủ rơm. Thí nghiệm này tiến hành trong 2 điều kiện: ngoài đồng và trong thủy tiêu kế chứa đất nguyên dạng. Trong hai trường hợp, đất mặt được chẩn bị như nhau với các cách làm đất nêu trên. Mực nước ngầm trong thủy tiêu kế được cố định ở: 30, 60, 90 cm dưới mặt đất tự nhiên. Nhôm tích lũy trong tầng mặt gia tăng rõ rệt theo lượng bốc hơi trong đất. Trong thí nghiệm ngoài đồng, mực nước ngầm được theo dõi nhưng không cố định được, tủ rơm làm giảm lượng nhôm tích lũy một cách có ý nghiã so với không tủ rơm. Trong khi đó, cày lại không cho kết quả có ý nghiã. Mưa trong 3 tuần đầu mùa mưa làm cho mực nước ngầm dâng lên rất nhanh, hàm lượng nhôm cũng tăng nhanh. Hiện tượng này làm cho tầng đất mặt bị nhiễm phèn lại và làm cho các tác động tích cực của việc làm đất trước mùa mưa bị xóa mờ.

Trong mùa mưa, nhôm vận chuyển theo nước chảy trong khe rỗng lớn và chảy tràn trên đất líp được tập trung nghiên cứu. Để tránh lũ cho cây trồng cạn, nông dân thường hay lên líp. Đây là một biện pháp canh tác rất phổ biến, do đó cần nghiên cứu kỹ hơn về loại đất này đề có biện pháp quản lý thích hợp. Có 3 loại líp phổ biến ở vùng đồng bằng sông Cửu Long: líp thấp do tầng đất mặt đắp lên, líp cao do một phần đất mặt và một phần jarosite, líp cổ điển được các vật liệu từ đất mặt cùng với jarosite và pyrite. Lượng nước chảy tràn gia tăng theo lượng mưa tích lũy do lượng

thấm rút giảm và hệ số thấm bảo hòa cũng giảm. Líp cổ điển bị đóng ván trên mặt líp do đó lượng nước chảy tràn trên loại líp này cao nhất trong ba loại líp. Hàm lượng nhôm trong nước chảy qua khe rổng luôn luôn cao hơn trong nước chảy tràn trong trường hợp líp cao và líp thấp. Trong khi đó, trên líp cổ điển nồng độ nhôm trong nước chảy qua khe rổng hơi thấp hơn trong nước chảy tràn. Tuy nhiên, tổng lượng nhôm thảy ra môi trường bên ngoài từ ba loại líp này không khác biệt. Do đó, líp thấp được khuyến cáo vì tốn ít công.

Sự phân bố hệ thống khe rổng đóng vai trò rất quan trọng quyết định lượng nước chảy vào và chảy trên mặt líp, từ đó quyết định đến hiệu suất rửa độc chất trong đất. Thí nghiệm ngoài đồng và trong phòng thí nghiệm xác định các tính chất vật lý của líp đồng thời cũng xác định lượng nước chảy trong khe rổng và vai trò của nó trong việc rửa nhôm trong đất. Thí nghiệm được thực hiện trên các loại líp trồng khóm và khoai mở: vừa mới trồng, líp một tuổi và líp hai tuổi. Các khe rổng dẫn nước được đánh dấu bằng Xanh Methyl. Số lượng, diện tích và chu vi của khe rổng dẫn nước ở các lát cắt trên tầng đất cách nhau 10 cm được đo. Mẫu đất nguyên dạng 20 cm X 25 cm được phun mưa nhân tạo với cường độ là 30 mm h^{-1} trong 30 phút. Lượng nước chảy ra, nồng độ nhôm và sulphate được đo. Diện tích và chu vi của các khe rổng của líp kho1m hai tuổi thấp hơn líp mới đắp khoảng 3 lần và lượng nước chảy qua khe rổng giảm đi 80 % do líp hai tuổi bị lún. Líp khoai mở không bị hiện tượng này vì khoai mở được thu hoạch và làm đất hàng năm. Nồng độ nhôm và sulphate trong nước chảy qua khe rổng của líp khóm mới và líp một năm cao hơn líp hai năm. Trong khi đó líp khoai hai năm cho nừng độ này cao nhất.

Cải tạo đất phèn có thể dẫn tới ô nhiễm môi trường nước các vùng lân cận. Để có thể đánh giá đúng mức vấn đề này, nồng độ nhôm trong nước tiêu từ vùng đất phèn canh tác lúa, khóm và khoai mở được đo. Các lô đất này có tuổi là: 2 tháng, 1 năm và 2 năm. Khóm và khoai mở được trồng trên líp. Giá trị pH đo được từ 2.9 đến 3.9 và nồng độ nhôm từ 3 đến 13 mmol(+) l^{-1}. Nồng độ nhôm bình quân tháng trong nước tiêu từ lô trồng khóm và trồng khoai mở cao hơn lúa 3 lần. Tổng lượng nhôm phóng thích từ các líp lên đến 16.690 mol(+) ha^{-1} và cao hơn lúa từ 3 đến 5 lần. Hiện tượng lún và đóng ván trên líp khóm làm cho nồng độ nhôm trong nước giảm theo thời gian. Tháng sáu hàm lượng nhôm ra môi trường bên ngoài cao nhất do lượng nhôm phóng thích cao cùng với lưu lượng nước sông rạch bên ngoài thấp.

Vào cuối mùa lũ, hiệu suất của việc dùng nước lũ để rửa đất cùng với việc cày trục đất được nghiên cứu. Ba điểm thí nghiệm với ba mức độ phèn khác nhau được dùng cho nghiên cứu này. Các nghiệm thức là số lần trục (trục một lần:H1, trục ba lần:

H3) và số lần rửa (rửa một lần:F1, rửa ba lần: F3). H3F3là cách rửa hữu hiệu nhất trên hầu hết loại đất phèn. Khi rửa một lần, ba lần đánh bùn không mang lại hiệu quả. Lượng nhôm trao đổi trong đất không bị ảnh hưởng bởi các cách làm đất nói trên. H3F3 cũng là nghiệm thức cho năng suất lúa cao nhất. Tnhời gian lũ rút là thời gian thích hợp nhất để sửa soạn đất trồng lúa.

CURRICULUM VITAE

Le Quang Minh was born 28 July 1953 at Dong Thap province, Vietnam. After obtaining B. Sc. degree specialized in Agronomy from Can Tho University in 1978, he has worked for the faculty of Water Management of the same university till this very day. In 1980, as a research assistant, he jointed VH 10 project. This was a collaboration project between Wageningen Agricultural University and Cantho university in research of acid sulphate soils. After completing his M. Sc. degree in Agrohydrology in Wageningen Agricultural University in 1985, he was promoted the head of Water Management department. At present time, he is the dean of faculty of technology.