Cultivation of sugarcane on acid sulphate soils in the Mekong delta

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Abstract

Sugarcane has long been a profitable crop on acid sulphate soils in the Mekong Delta. However, little attention was paid to cultural practices. Following interviews with farmers about on their normal cultural practices, soil and plant samples were taken for chemical analysis, and soil-plant relationships were analyzed.

Sugarcane can grow in pH 3.5-5 with aluminium concentrations of up to 17 cmol(+) kg^{-1} soil. Cane yields on such soils were 60-80 t ha^{-1}. Only one variety, Co 775, was planted by the farmers and it seems to possess high tolerance to aluminium toxicity. On slightly acid soil, urea (50-250 kg N ha^{-1}) and superphosphate (0-25 kg P ha^{-1}) were applied. On acid soils (Sulfic Tropaquepts), no fertilizer was applied. Aluminium concentration affected the growth of sugarcane but, with fertilizer application, cane yield was increased and aluminium concentration in the leaves was low. The presence of aluminium caused deficiency of K, Ca, Mg in the leaves of sugarcane.

Introduction

Sugarcane is an important crop in the Mekong Delta (Derevier 1991), satisfying local demand for sugar, while the by-products such as bagasse for fuel or paper making and molasses for industrial processing can bring additional income to cane growers. However, till now, little attention has been paid to improving farmers' cultivation on acid sulphate soils. In this study, farmers were interviewed on all aspects of cane cultivation, and plant and soil analyses were performed to determine the nutritional status of sugarcane on acid sulphate soils, with a view to finding optimum fertilizer applications and cultivation techniques.

Materials and methods

The study was carried out in the villages of Vi thuy, Hoa luu, Hiep hung, and Hoa an, in Hau giang province. Twenty farmers in each village were interviewed. In each of these locations, sampling sites were selected (22 in Vi thuy, 11 in Hoa luu, 22 in Hiep hung and 18 in Hoa an). At each site, one composite soil sample was taken over 1000 m^2, depth 0-20 cm. The soil samples were analyzed for pH, EC (both in 1:2.5 extract), extractable acidity and aluminium in 1N KCl extract, total N, exchangeable K, Ca, Mg in 1N ammonium acetate extract. At each corresponding location, plant growth conditions were described and plant samples were taken for analysis. The plant samples were analyzed for N, P, K, Ca, Mg, and Al after wet digestion.

Results

Cultivation techniques
Sugarcane variety Co 775 was the most widely used. It has a violet rind and is said to be resistant to attacks by insects, and tolerant of acidity and drought. The maximum yield registered was about 100 tons raw cane ha^{-1} compared with common yields of 60-120 t ha^{-1} in other soils of the Mekong Delta.

Cane is cultivated on raised beds, rarely on the natural surface. This is necessary because the land is flooded in the rainy season. The height of the beds depends on the flood level. In general, beds are 20-40 cm above the flood level. In the dry season, watertables are generally at 80-100 cm below the surface, which might result in water stress to the plants. Some farmers irrigate sugarcane by sprinkling water over the top of the raised beds by a pump or by hand. In most cases, however, irrigation is not applied, or only when cane is planted in the dry season.

Cane is mainly planted from December to February. March to April is not suitable for cane growth because the farmers must then irrigate several times during early growth. Harvesting is from September to January. Many farmers harvest whenever the price of cane is high. In the study, 2 or 3 ratoon crops are also taken, but cane is sometimes grown in rotation with rice (e.g. in Phung hiep district, Haugiang). In Thot not district (Hau giang), farmers plant sugarcane as annual crop because the flood level is high. Sugarcane is planted directly in the field without raised beds in January and is harvested in September. Then rice is planted in September and harvested in December.

Usually, special plots are cultivated for raising cuttings. Cuttings are placed close together and watered regularly. When roots develop, the cuttings are transplanted in rows. The advantages of this system are not clear – a strong root system, possibly, but time is lost this way.

Commonly, cuttings are planted end to end, one row on each raised bed which is 4-6 m wide and 50-250 m long. Some farmers plant two rows or placing the cuttings parallel. The distance between rows is 1 m. Plant density is high at about 80 000 plants ha^{-1}. This seems a waste of cuttings. In addition, double rows or dense planting leads to competition for light, limiting growth.

At two, four and six months after planting, hilling up is done to stimulate the development of the root system. Simultaneously, fertilizers are applied to the rows. Most commonly, farmers apply urea or diammoniumphosphate. The quantity depends on the financial capacity of each family, varying from 50 to 250 kg N ha^{-1}. Only a few farmers apply phosphorus fertilizer. Potassium is not applied at all and farmers claim that potassium would inhibit plant growth.

Dead leaves are removed regularly, 2 or 3 times during crop growth. This is to control pests and insects. Many farmers, however, do not do this regularly, considering it to be too laborious.

Sugarcane flowers in September. Many farmers let this occur naturally. Others use chemicals such as 2,4-D to harvest their canes after 8-9 months, just before flowering, because they have observed that flowering lowers the sugar content but they were not aware that premature harvesting also gives plants with low sugar content.

Economic return

At Thot Not, on non-acid soil, total outlay for rice was VND (Vietnamese Dong) 2.5 million per ha to obtain 5 t rice ha^{-1}, giving a VND 2.5 million profit. In comparison, outlay for sugarcane was VND 6.5 million ha^{-1}, and a yield of 120 t ha^{-1}, giving a 6.75 million profit.

This calculation was based on sugarcane planting as an annual crop. If it is ratooned, the difference will be higher, because cane growers spend on land preparation only once in three years. In an acid soil such as Hoa an, there is still a relative advantage in growing sugarcane, but with higher investments (see Table 1).

Yield and yield components

On fertile soils and with sufficient water, sugarcane can tiller up to 8 plants per hill. On acid sulphate soils with little or no fertilizers applied, tillering is reduced greatly, not more than 3-5 plants per hill. This is a reason why farmers increased planting density. Maximum height of sugarcane can be 3.5-4 m at harvesting time. At Hoa an, 9-month-old cane about to be harvested was only 145 to 250 cm high. Plants also showed a low number of internodes, 18-23 per plant and internodes were between 5 to 12 cm long. These yield components reflect well the nutritional and water supply status of sugarcane (Blackburn 1984). The diameter of the plants at harvest was 2.5-3 cm. The average weight was about 1.1 kg per cane.

Soil and plant analysis

Cane yields are low on acid sulphate soils. Chemical analyses of plant and corresponding soil samples can shed some light on their relationships.

Results for the Vi thuy village showed low pH values (3.7-4.6). Extractable aluminium varied strongly from less than 1 to over 8 cmol(+) kg^{-1} soil. The soils were relatively rich in nitrogen (about 0.2 per cent) and poor in P (0.06 per cent). Exchangeable potassium was at a good level, 0.3 cmol(+)kg^{-1} soil. Plant analysis showed a particularly low content of calcium (see Table 3) of only 0.05 per cent average. Nitrogen was also low (average 1.2 compared with around 2 per cent normal). P and K were normal. Farmers only apply a small quantity of phosphorus which is, apparently, enough, but Ca is not applied. The aluminium content in leaves averaged 200 mg kg^{-1}.

Table 1 Comparison of incomes per hectare (in VN Dong) between rice and sugarcane grown in Hoa an station (1991)

Expenditures	Rice	Sugarcane
Land preparation	450 000	400 000
Planting material	200 000	800 000
Weeding, hilling up	150 000	1 000 000
Fertilizers	750 000	750 000
Insecticides	100 000	
Harvesting	200 000	500 000
Total	1 850 000	2 700 000
Income	4 000 kg rice 1 000 VNd kg^{-1}	60 tonnes cane 110 000 VNd t^{-1}
Profit	2 150 000	3 150 000

7000 VNd = U.S. $1

At Hoa an station, aluminium in soil was high 6.7-12.3 cmol(+)kg^{-1} soil. These values, although they are not a direct measure of the growth of sugarcane because they are the total content, indicate an influence on cane development. High aluminium can fix phosphorus (Clarkson 1967) and compete with calcium and magnesium outside and inside the cell wall (Siegel and Haugg 1982, Grimme 1980). Aluminium can destroy cells of roots, thereby limiting the uptake of water and nutrients. Leaf analysis showed that:

- The percentage of N varied from 0.07-1.3 per cent;
- The percentage of phosphorus varied from 0.2-0.37 per cent;
- Soil K was 0.1-1.5 cmol(+)kg^{-1}.

The results indicate that the sugarcane lacked nitrogen, potassium and had a low phosphorus content. No fertilizer was applied at Hoa an station. Phosphorus has a striking effect on root and shoot development of cane. In acid sulphate soils, with high aluminium, P is fixed by aluminium inside and outside of the root system (Clarkson 1967). The immobilisation of phosphorus might be prevented by addition of more phosphorus in the form of apatite or superphosphate (Mengel and Kirby 1989).

Aluminium toxicity is an important problem in sugarcane growing regions with acid soils. In our case, the range of aluminium was 6-12 cmol(+)kg^{-1} which could inhibit root growth, although we did not find any correlation between soil and leaf analysis.

Al-soil and N-leaf $r = 0.094$
Al-soil and P-leaf $r = 0.071$
Al-soil and Ca-leaf $r = 0.122$
Al-soil and Mg-leaf $r = 0.202$

Many authors (inter alia Cooke 1982) have discussed soil and leaf analysis and concluded that it is difficult to establish correlations of these parameters. But in the greenhouse, where we can control the test conditions, the correlation may be good. To tell us when to fertilize and with what element to achieve optimum yields, leaf analysis is more reliable than soil analysis.

Table 2 Comparison of some soil analysis

	Vithuy	Hoa luu	Hiep hung	Hoa an
per cent N	0.18	0.23	0.23	0.14
Total P (per cent)	0.05	0.07	0.068	0.062
Available P (mg kg^{-1})	47	56	45	–
K (cmol(+) kg^{-1})	0.3	0.3	0.3	0.1
pH (H_2O)	4.2	4.5	4.7	3.4
pH (KCl)	3.85	3.51	3.5	–
ECE ($mscm^{-1}$)	0.25	0.29	0.18	0.59
Al (cmol(+) kg^{-1})	3.9	5.7	2.2	10.3
Total acid (cmol(+) kg^{-1})	6.1	7.4	3.3	11.5
Ca (cmol(+) kg^{-1})			5.5	
Mg (cmol(+) kg^{-1})			4.8	

Table 3 Comparison of leaf analysis

	Vithuy	Hoa luu	Hiep hung	Hoa an	N level[1]	C level[2]
per cent N	1.19	1.22	1.16	1.09	2.2-2.6	< 1.8
per cent P	0.28	0.33	0.31	0.28	0.2-0.3	< 0.2
per cent K	1.76	1.19	1.13	1.12	1.0-1.6	< 0.9
per cent Ca	0.05	0.1	nd	0.13	0.2-0.45	< 0.2
per cent Mg	0.2	0.32	nd	0.17	0.15-0.32	< 0.12
Al mg kg^{-1}	200	200	130	400		
Length of 4th leaf	163.9	175	165.1	108.7		
Width of 4th leaf	5.0	5.1	5.8	3.3		

[1] Normal and [2] critical levels from Guscho and Wali 1979
nd = not determined

Comparison of 4 locations
Results presented in Table 2 show that total N was lowest on Hoa an; phosphorus varied little; K was low in all locations but especially in Hoa an.

When comparing the leaf analysis at 4 locations (Table 3) we found that the mineral composition varied little. The aluminium concentration in leaves in Vi thuy, Hoa luu and Hiep hung was lower than in Hoa an. Length and width of 4th leaves were lower in Hoa an than in other places.

Conclusions

Sugarcane tolerates the acid conditions of the Mekong Delta. However, planting techniques are often not optimal, nor is irrigation and fertilizer application.

Acceptable yields and sugar contens of cane on acid sulphate soil are feasible when attention is paid to water and nutrient requirements. With continuous cropping, especially where farmers take 2-3 ratoons without fertilizer application, soils are quickly depleted. Aluminium is limiting mineral uptake and yield of cane on acid soil.

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Recent advances in integrated land uses on acid sulphate soils

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Abstract

A first-hand account is given of land uses on acid sulphate soils in Vietnam that have not been clearly documented elsewhere. On potential acid sulphate soils, accounts of rice-fish, rice-shrimp, and rice-molting crab systems are presented. On acid sulphate soils, depending on the water regime, the land can be put under rice, upland crops, and fruit tree production. Recent advances in shallow drainage for rice cultivation are described. New findings on the low-input cultivation of Eucalyptus on annually-flooded, severely-acid soils are reported. The crucial component of management, in all cases, is appropriate water management. Soil nutritional aspects must also be well taken care of in order to ensure good yields.

Introduction

During the past few years, advances in the reclamation of acid sulphate soils have opened new horizons to agricultural development in many countries. The dramatic increase in rice production in the Mekong Delta since 1989 has demonstrated that, as long as fresh water is made available for irrigation, farmers can grow any crop with little technical difficulty. Even the most severe acid sulphate soils in the Plain of Reeds and the Longxuyen-Hatien Quadrangle can yield 8-10 t rice ha^{-1} $year^{-1}$. Of course, the question remains whether it is economically beneficial.

The use of acid sulphate soils has been reviewed by several authors during the last decade. The most recent review, by Dent (1992), covers a large number of successful reclamation methods and includes collaborative research from Thailand, Indonesia and Vietnam that has not been reported in scientific journals. Earlier, Vo-Tong (1984), Vo-Tong et al. (1986), Dent (1986), Roelse et al. (1990), Bos (1990), and Deturck and Ponnamperuma (1991) have reported on indigenous technologies as well as research results on more profitable land uses on these problem soils. This review gives an account of the latest developments in integrated land use systems which have been applied in Vietnam but have not been reported before. The management systems are grouped according to the soil and hydrological conditions under which they operate.

Systems for potential acid sulphate soils

Many of the problems that arise from development of potential acid sulphate soils can now be solved by the use of brackish or saline water to remove soil acidity or suppress acidification. Work in Vietnam on the use of salt and brackish water on rice fields (Vo-Tong et al. 1986, Van Mensvoort et al. 1991), confirmed by Seiler (1989), has shown that a controlled, high watertable and inactivation of existing acidity, or the accelerated oxidation of pyrite by shallow drainage and subsequent leaching of acidity by salt- or brackish water, can overcome the farmers' problems.

Saline sulphidic peat and muck
Areas with peaty topsoil and daily saline tidal influence are found in defoliated and newly-cleared *Rhizophora* and *Avicennia* forests. In the Mekong Delta, polders of about 10 ha per unit have been constructed. Each polder has a network of drainage ditches. A culvert with a flap gate regulates the water level inside the polder at the depth where the sulphidic subsoil occurs.

The first crop after land clearing was pumpkin (*Cucurbita* spp.). Starting with the first rains, farmers raised pumpkins in small plots, then transplanted them into the peaty soil. Rain supplied fresh water which flushed the acid and salts from the topsoil as well as supplying the crop. During the first two years, without any fertilization, the farmers obtained an average yield of 20 t pumpkin ha^{-1}. In the third year, they constructed raised beds to plant a rotation of soybean-corn-soybean throughout the entire rainy season from May to December. Other farmers constructed ridges to plant sweet potato, intercropped with short-duration rice. The yield of 80-day soybeans was about 2 t ha^{-1}, while the rice in the furrows between ridges gave about 1 t ha^{-1}. As the peaty materials are washed away, derris replaces most of the upland crops.

Unripe saline clays and saline sulphidic clays
Areas with strong, daily tidal movement and abundant, fresh sediment are found in swamps of various species of *Acanthaceae*, *Acrosticaceae*, *Ceriop scandolleura*, and *Nipa fruticans*. Marine sediment accretion may be up to 5 cm $year^{-1}$. The reduced subsoil at depths of 20 to 40 cm contains about 0.3 to more than 1 per cent pyrite S. Several land use systems have been successful on these soils.

The rice-shrimp system
Under this integrated system, farmers can rely on a crop of rice during the rainy season, then raise shrimps during the dry season. Improvements since earlier reports (Vo-Tong 1984 and Vo-Tong et al. 1986) have been achieved during the last two years.

Polders of various sizes, but not more than 10 ha, are built. Within each polder, a network of ditches serves as drainage system during the rainy period but, in the dry season, it serves as a refuge pond for raising shrimp fry. A flapgate lets brackish or saline water into the polder in order to keep the soil wet and prevent oxidation of pyrite. The tidewater also carries into the fields shrimp fry bred naturally in the creeks. Full moon and new moon are periods for letting in shrimp fry. Grown shrimps are caught monthly until the start of the rainy season.

In the rainy season, the salts on the soil surface are flushed into the ditches and out of the polder through the flapgate. During high tides, the flapgate remains shut to keep out salt water. Seedlings of medium-term rice varieties, such as IR42, can be used but, nowadays, with the advent of short-duration rice varieties, farmers need not raise seedlings elsewhere; they can broadcast the seeds directly onto the fields. The rice varieties are selected so that they mature before the onset of the saline water intrusion.

After harvesting rice, while the soil is still wet, polder owners let in the saline water immediately to trap the fish *Pseudapocryptes lanceolatus* and may obtain about 150-200 kg ha^{-1} within three weeks. Then they start the shrimp culture cycle again. Shrimp yields of 300-500 kg ha^{-1} $year^{-1}$ and paddy rice of 4-5 t ha^{-1} $year^{-1}$ may be achieved. Fresh sediment deposited annually is scraped off the field onto the surrounding dike. When the raised dike becomes high enough, coconuts can be planted on it.

The rice-molting crab system

During the last two years, several farmers have quit shrimps to raise crabs instead. The market for crabs, especially molting crab, is increasingly good. Nguyen Thanh Nghiep (personal communication) describes this practice by a group of coastal farmers in Canduoc district, Longan province. The practice is similar to the rice-shrimp system, except that the dike is smaller and the trenches are smaller and shallower. After harvesting rice, farmers place the grown-up crabs in trenches excavated in the rice field. The crabs have previously been treated to initiate quick molting. Brackish water is allowed to circulate freely while the crabs are fed daily with rice bran or dried cassava chips. After three weeks, the crabs molt completely, and are ready for sale. Molting crabs fetch four times the price of ordinary crabs.

When the monsoonal rains start, the saline water in the field is drained off, ready for the following crop of traditional, transplanted rice.

Fishponds

In Asia, tidal soils are widely used for aquaculture, but the regenerating acidity of acid sulphate soils causes slow growth and poor product quality. In the Philippines, Brinkman and Singh (1982) and Singh (1987) found that rapid pyrite oxidation of the pond bottom, followed by adequate flushing of the toxic substances from the pond using saline water, and, finally, liming could create favourable conditions for fish and shrimp growth.

Systems for actual acid sulphate soils

On empoldered coastal ridges and thick marine deposits with severely acid horizons deeper than 80 cm, farmers should take great care of their dikes to prevent salt water intrusion. This is in contrast with the rice-shrimp system. The farmers start land preparation by early ploughing, immediately after harvesting the main wet season traditional rice crop. The turned-over soil clods are thus left fallow until monsoon rains are about to start. Previously, after a few rains which softened the soil, farmers broadcast rice seeds of medium-term varieties. Nowadays, short-duration HY rices are broadcast on the dry soil for the first cropping season, before the normal crop of transplanted, medium-term varieties. The 'dry seeding method' has become an important technology for the rainfed lowland rice cultivation. By double cropping, yields of 6 to 9 t ha^{-1} $year^{-1}$ can be obtained with rain as the sole source of water.

Raw acid sulphate mucks in empoldered coastal backswamps

In these areas, tidal movement is slight and the surface often becomes dry during the dry season. Jarosite occurs at 10 to 50 cm depth.

The most profitable practice is shallow drainage to grow one crop of a medium-term rice (Vo-Tong et al. 1982). This system consists of shallow ditches (30-60 cm deep, 60-100 cm wide and 9 m apart) excavated by hand. The excavated slices of soil are spread evenly on the 9 m strips, forming slightly-raised beds. The ditches are connected to a deeper drainage canal running to a flapgate in the main dike. With the first heavy rain, normally in April, rainwater flushes the acid soil on the ridges and removes toxic substances which are collected in the shallow ditches and in the drainage canals. The outlet gates remain closed until the drainage water is level with the surface of the raised beds. Then, with the next rains, the accumulated water is allowed to run through the canals and out to the river at low tide. The cycle is repeated 2 or 3 times before the entire region is naturally flooded and drainage is no longer possible.

Seedlings, 45 to 60 days old (about 80 to 100 cm tall) are transplanted on to the raised beds which are by then submerged under 10 to 40 cm of water. Traditional, medium-term rice varieties such as Tai Nguyen, Lun Can, Trang Mot Buoi and Trang Tep are commonly used. Yields of 2.5 to 3.8 t ha^{-1} were obtained compared to 0.2 to 0.5 t ha^{-1} on undrained soils.

During the last two years, we have seen a major change in the practice of shallow drainage. Instead of dredging the old trenches after the third year, new trenches are excavated starting from the middle of the raised beds. The excavated earth is used to cover the old trenches. Short-duration HY rice is dry-seeded on the new raised beds. To conserve precious fresh water from the last rainy season and to avoid capillary rise of toxic substances during the dry season, the soil surface may be covered with straw mulch, about 5 cm thick (Gora Beye 1973).

These practices add another dimension to rainfed rice cultivation. Varietal screening and water management for rice on acid sulphate soils have received attention in India (Singh and Mongia 1987). The principle of keeping the acid or sulphidic subsoil flooded for as long as possible has proved successful elsewhere though, admittedly, usually where the acid layer is much deeper below the surface, for example Bloomfield and Powlson (1977) and Chew et al. (1984) in Malaysia, and Sudjadi (1984), Bos (1990) and Roelse et al. (1990) in Indonesia for a variety of crops.

Raw acid sulphate clays with a thin, peaty topsoil: Medium to deeply flooded, high groundwater during the dry season

On low sites along the rivers Vaico East and Vaico West, during the low flow period in the dry season, water management by gravity with brackish water is possible. Farmers have constructed polders of various sizes, each having a culvert fitted with a flapgate to regulate water inside the polder. Within the polders, raised beds of 5 to 8 m wide separated by ditches of various depths (30 to 60 cm) and widths (50 to 100 cm), depending on the depth to jarosite, have been constructed. The raised beds are planted with cassava, kenaf, jute or yams.

Cassava *(Manihot esculenta)*

Usually, the entire polder is flooded from September to November. When water recedes, the farmers till the soil on the raised beds and plant cassava which grows during the dry season and is harvested in May. To supress acidification of the topsoil, river water is let the polder up to the top of the jarositic layer. After three years of upland crops, rice can be grown on the same beds.

Kenaf *(Hibiscus cannabis)* and jute *Corchorus spp)*

The jute or kenaf germinates and grows with the residual moisture in the soil to a height of about 50 cm when the soil becomes totally dry. It survives the drought through the dry season and resumes growth again when the rains come. The crop is harvested in August, yielding about 1.5 t fibre ha^{-1}. After three years, the land can be planted to rice, with moderate yield at first (2-2.5 t ha^{-1}) increasing (to 3-4 t ha^{-1}) over a couple of years.

Yam *(Dioscorea esculanta)*

To plant yams, farmers construct high ridges before the first rains and leave them unplanted throughout the rainy season. The ridges are gradually submerged in the flood. This is a good method of leaching toxic substances. As the flood subsides, the ridges are tilled and yam cuttings are planted. Harvesting is in April, before the next rainy season starts, and the whole cycle starts again. Several farmers, in the fifth year, instead of continuing with yam, planted high-yielding rice on levelled fields. Rice yield was about 4 t ha^{-1}.

Raw acid sulphate clays with medium to deep groundwater during the dry season

In areas that are flooded to a depth of less than 60 cm during the rainy season, farmers grow pineapple or sugarcane quite successfully. First, they construct polders of different sizes, depending on their land tenure. Then raised beds are built 4 to 5 m wide and about 60 cm higher than the original land surface. The width of the resulting excavated ditches between the raised beds varies according to the amount of soil needed to build the beds. Care should be taken not to excavate pyritic material and not to expose jarosite layers on top of the beds. Ideally, the excavated topsoil should be set aside first, then the excavated jarositic subsoil deposited on the bed and, finally, the excavated topsoil is spread evenly over the top of the bed. The beds are left to be leached by rainwater through one whole wet season before planting pineapple or sugarcane. The beds can be irrigated with impounded ditchwater even if it is acidic.

Yields of pineapple are usually from 6 to 8 t ha^{-1}, and sugarcane from 30 to 60 t ha^{-1}. Truong Thi Nga et al. (1993) found that, although both sugarcane and pineapple can tolerate acid sulphate soil pH from 3 to 5, it is essential that these crops be supplied with adequate water, K and Ca.

Raw acid sulphate clays and unripe sulphidic clays on deeply flooded floodplain, high watertable in the dry season

Depressed areas where it is always wet are dominated by the grass *Ischaemum* sp., which can elongate during high flood. Farmers have long been using these areas as pastures for cows and water buffalo, and in this marshy environment, fresh water fish grow abundantly. If it dries out, the soil becomes extremely acidic, there will be no more fish, nor *Ischaemum* grass, and no water buffalo or cow can graze.

Raw acid sulphate clay and ripe acid sulphate clay with peaty topsoil, low groundwater table in the dry season

These strongly acid soils are typical of the Plain of Reeds and the Plain of Hatien. Soil variability is so great that even within 50 m more than two different types of acid sulphate soils are found. Studies from the Philippines showed that these soils can be used for biomass energy plantations (Koffa 1991). In Vietnam, based on careful surveys through years of experience, farmers planted *Melaleuca leucodendron* or *Eucalyptus* spp.

Melaleuca

Melaleuca planting is simple. If the supernatant water is cloudy, seedlings 1 m tall are transplanted. The best way is to drive a deep hole into the soil and insert carefully the root of a seedling without packing the soil afterwards. In those places where supernatant, acidic water is clear, the soil is usually ploughed while still dry, then farmers wait until August or September when field water level is about knee-high. They go out in sampan boats to broadcast *Melaleuca* seeds, which have been mixed with burned rice husk. The seeds sink to the bottom and start to germinate and grow while submerged. As water level increases gradually to 1-1.5 m, the young plants increase in height in water. After the flood water recedes, the plants keep on growing in dry soil. The water regime has little influence on plant growth.

An average *Melaleuca* forest can yield about 100 to 120 m^3 ha^{-1} after five years. Once planted, regrowth is by dropped seeds. However, measures should be taken to avoid forest fires during the dry season: shallow canals 4 to 5 m wide and about 1.5 m deep are dug, and the whole area must be empoldered so that floodwater can be retained inside after the flood subsides. Fish from the flood are thus trapped inside too. Flowers of *Melaleuca* have long been recognized as good feed for honeybees, so honey production can be integrated with *Melaleuca* production. The lowest areas can be used for integrated lotus-fish production.

Eucalyptus

Several *Eucalyptus* spp. have been tested with different planting methods during the last four years (Tran Duy Phat 1991). It has been found that, instead of raising costly high beds to avoid flooding, inexpensive land preparation using a mouldboard plough to make ridges and furrows is adequate. *Eucalyptus* is transplanted into the ridges. It can survive inundation for two months without harm. This is another low-input development of the severe acid sulphate soils.

Reed mace

Reed mace is a good raw material for handicraft production such as weaving sacks, shopping bags, hats, sleeping mats, etc. In very severe acid sulphate soils where *Eleocharis* spp. dominate, it can be eradicated by using reed mace as a biological method of weed control. Seedlings of reed mace, with 2-3 tillers, are transplanted at a distance of 1 m apart in the *Eleocharis* field. At each transplant site, a small area should be cleared of *Eleocharis* by uprooting. The reed mace will tiller and expand into the surrounding area and will shade the *Eleocharis*. Within one year, the field produces reed mace.

Deeply flooded acid sulphate clays with jarosite deep in the profile

Floating rice

In areas annually flooded to more than 1 m in the wet season, followed by low water table during the dry season, floating rice is grown in rotation with water melon, sesame, or mung bean. If, however, fresh water can be made available cheaply, an early-maturing high-yielding rice crop can be broadcasted when the flood is about to recede. In the Mekong Delta this is often called 'acid-avoidance rice cultivation'.

Water melon
Another profitable practice by some advanced farmers was observed in the My lam village in the Mekong Delta. Land preparation is similar to that for yams. Ridges are established before the onset of the monsoon rains and the annual flood; left to soak during the entire flood season; then, as the water recedes and the tops of the ridges are just exposed, water melon seedlings are transplanted. For the next 80 days, water melon can grow well with residual water in the furrows.

Conclusion

Although there are still problems to be solved, it appears that existing technologies for the development of the various acid sulphate soils can bring higher income for farmers. The essential component of these systems is appropriate water management, and this can be decided only by precise land evaluation and planning.

Polders should be of appropriate sizes. If fresh water is available at all time, even high-yielding production can be achieved. When production depends solely on rainfall and natural flooding, there are ways to cope. For integrated agroforestry-aquaculture development on these soils, early land preparation should be done immediately after the end of the rainy season to avoid upward flux of toxic substances during the dry period. Suitable crops or animals can be introduced at an appropriate time.

Of course, development depends on the market and the ability of the farmers or local government to invest.

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