ACID SULFATE SOILS AND THEIR MANAGEMENT FOR BRACKISHWATER FISHPONDS

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The major problems of fishponds built on acid sulfate soils are low pH; ionic imbalance and toxic levels of aluminum, iron, and sulfate; deficiency of phosphorus and poor response to fertilizer application; slow and poor growth of fish food organisms and fish; erosion of dikes; and in some cases fish kills. For economic operations and to remedy the problems of poor algal growth, fish kills, and low yields, the acid in the pond bottom and dikes has to be neutralized or removed. Although the acids can be neutralized by adding enormous amounts of lime at prohibitive cost, it is not necessary to neutralize them all because a large part can be removed. A repeated sequence of drying, tilling, and flushing with seawater is a cheap, fast, and effective reclamation method that can be done in one dry season. Following this method, the dry soil pH improved; exchangeable aluminum, pyritic iron, active iron, active manganese, and sulfate decreased; and available phosphorus improved. The values for alkalinity, phosphate, aluminum, iron, and sulfate in the pond water improved greatly. *Lablab* production every 2 weeks in control ponds was 32.9 g/m^2 against 112 g/m^2 in reclaimed ones. Fish production was about three-fold more in reclaimed ponds (375-510 kg/ha) compared with the control ponds (50-173 kg/ha).

INTRODUCTION

Soil is important to pond productivity because of its ability to adsorb and release the nutrients needed for the growth of algae and other microorganisms, the natural foods of milkfish. Soil is also the main and, perhaps, the only economical source of dike building materials. The quality of water in the pond is strongly affected by the nature of the soil in the pond bottom and in the dikes surrounding it. This influence of soil on pond conditions becomes clear in the case of adverse soil conditions such as acid sulfate.

In fishponds built on acid sulfate soils, a highly acidic condition develops which is detrimental to both food organisms and fish. Elements and ions like iron, aluminum, sulfate, and in some cases manganese are released to the water in toxic quantities (Singh 1982a). Likewise, acid sulfate soil renders essential nutrient phosphorus unavailable to the algae and thus, without reclamation, there is generally no response to phosphorus fertilization.

In the first 5-10 years after construction of fishponds in acid sulfate soils there are major problems precluding economic operation or even production. Growth of algae is inhibited or restricted by the low pH and the very low phosphate level of the pond water. The growth rate and condition of fish are impaired by the unfavorable ionic composition of the pond water, the periodic presence of finely dispersed ferric hydroxide, and the poor growth of fish food. Moreover, there are sudden fish kills during rains after extended dry periods owing to extremely acidic water seeping into the ponds from surrounding dikes.

After about a decade, these problems gradually recede, but fish production remains low, only on the order of 300-600 kg/ha per year. This should be compared with an average of 1.5 or, with recommended management and fertilizer levels, up to 2.5 t/ha per year in areas with non-acid coastal clays (Brinkman and Singh 1982). Although occasional fish kills are caused by acid sulfate soils in acute situations, chronic, sublethal effects that inhibit pond biota in general are probably more detrimental in the long run.

Traditional, small fish fanners dig very shallow ponds to minimize problems and limit capital costs. They survive and learn to live with the problems but do not rise above poverty within a decade, and do so slowly even after that period. Large fanners whose holdings are mainly externally financed, as well as companies developing extensive areas for fishponds, tend to abandon their efforts on this land and sell it after a few years of failure; then another victim repeats the process.

Until about a decade ago, much of this area was mangrove forest, and smaller areas were used for one poor crop of rice per year and for fishponds. In recent years, due to poor returns from rice cultivation and to other land uses, the area of fishponds has increased rapidly at the expense of mangroves and rice fields. Fishponds now appear to be the most important kind of land use in the coastal acid sulfate areas in the Philippines. Although the conversion to fishponds appears to be economically sound, this requires considerable financial resources because it is a major engineering operation; but it can result in an economically viable production system if the area is properly reclaimed and managed. However, even after reclamation, some hazards and problems remain, requiring special management methods. For successful operations, available phosphate needs to be raised above the deficiency level; potential acidity in the subsoil should be kept immobilized; and soluble iron and aluminum concentrations need to be kept low.

In this paper the formation, properties, extent, and identification of acid sulfate soils and the problems of fishponds built on them are reviewed, and a rapid and low-cost reclamation and management method developed at the College of Fisheries, University of the Philippines in the Visayas, Iloilo — tested and verified at several privately owned fishponds — is presented.

ACID SULFATE SOILS

An acid sulfate soil has been defined as a drained soil with free as well as adsorbed sulfates having yellow mottles of jarosite and a pH less than 4 in water. A potential acid sulfate soil is a reduced and waterlogged soil that contains pyrites with pH values near neutral and that will eventually become acidic upon drainage and oxidation (Brinkman and Pons 1973, Bloomfield and Coulter 1973). Soils that develop extreme acidity upon drainage and drying occur in freshwater and brackishwater mangrove tidal swamp environments.

Acid sulfate soils are derived from marine and estuarine sediments which, upon drying and aeration, show a definite and severe acidification due to the oxidation of sulfides (mainly pyrite, FeS_2), leading to the formation of sulfuric acid. Such soils in a marine environment are generally found in estuaries, deltas, and tidal flats where sulfides have accumulated in marine sediments as a result of the bacterial reduction of seawater sulfates. In the acidic state they contain concentrations of aluminum, iron, and manganese that are toxic to both fish and other fishpond organisms. Some elements, particularly iron and aluminum, are released into the pond water in toxic quantities that render phosphorus unavailable, thus causing phosphorus deficiency in algae. Under such conditions, there is generally no response to phosphorus fertilization (Singh 1982a).

Formation of Acid Sulfate Soils

In mangrove swamps, the formation of acid sulfate soil is favored because of the abundant supply of sulfates and organic matter. The mangrove vegetation (especially dense fibrous roots) in the swamps facilitates the accumulation of inorganic and organic materials and helps in the buildup of sediments by trapping mud and therefore in controlling erosion (Van der Kevie 1973). Decomposition of organic matter in the soil depletes the oxygen, giving rise to anaerobic conditions and thus activating the sulfur-reducing bacteria. These obligate anaerobes decompose the organic materials and at the same time utilize the sulfates present in seawater for their respiratory processes, producing sulfides (Campbell and Postgate 1965).

The resulting sulfides may accumulate in the sediments as hydrogen sulfide gas or may combine with available iron to form insoluble black iron sulfide. Further transformation of the iron sulfide will produce pyrite, the mineral chiefly responsible for the formation of acid sulfate soil. Pons (1969) and Richard (1973) proposed that pyrite may be formed through the following reactions:

$$2\ CH_2O + SO_4^{=} \rightarrow HCO3 + HS + CO_2 + H_2O$$
$$H_2S + Fe \rightarrow FeS + 2\ H^+$$
$$FeS + S \rightarrow FeS_2\ \text{(pyrite)}$$

The final pH of the soil depends, however, on the amount of pyrite oxidized and on the buffering capacity of the soil. The acidity can be neutralized by bases coming from minerals, mainly calcium carbonate, and by metal cations coming from the exchange complex. Thus, soils with a low amount of bases will develop into strongly acid soils.

Processes During Drying and After Filling

Pond soil, initially reduced when flooded, contains the usual marine salts and considerable amounts of exchangeable ferrous iron. Upon oxidation, ferric hydroxide is formed and the soil may become partly aluminum-saturated. The pH drops from near neutral to a lower value. In acid sulfate soils, pyrite oxidation produces jarosites and iron hydroxide as well as sulfuric acid, which attacks the clay minerals. The pH drops to a very low value. The soil becomes largely aluminum-saturated, some free acid remains, and aluminum salts are formed (Brinkman and Singh 1982).

After inundation, the pond soil becomes reduced again. Acid is consumed by the reduction of ferric hydroxide to ferrous ions. Part of the free acid and the aluminum salts and, somewhat later, large amounts of ferrous salts diffuse from the soil into the pond water. This process appears to be speeded up by the salts in the saline or brackish water. Rain falling on previously dry dikes leaches further quantities of acid and aluminum as well as ferrous salts into the pond water, both from the surface and from the interior of the dikes. In the course of a few days, the ferrous iron is oxidized, producing more acid and finely distributed ferric hydroxide, which remains suspended in the pond water for several days. If powdered lime is used to reduce the acidity of the water, ferric hydroxide is formed more rapidly. Any phosphate that might have been present in the water is quickly trapped by the large amounts of aluminum salts or by free aluminum in the surface soil.

IDENTIFICATION AND EXTENT

Acid sulfate in pond soil can be recognized (Brinkman and Singh 1982) by the very low pH values measured in the pond water when it is flooded for the first time after drying, by the reddish iron oxide that may form on the pond bottom after flooding, by the poor growth or absence of algae, and by very low pH values (generally less than 4) measured in dry soil.

Acid sulfate in dikes can be recognized by a very low pH (generally less than 4), by the poor or spotty growth or absence of vegetation on them even several years after construction, by pieces of organic matter encrusted with whitish and pale-yellow salts, and by very acidic water seeping out of the dikes into the pond during heavy rains.

The acid sulfate soil areas in Southeast Asia (Table 1) are found extensively in coastal brackishwater as well as freshwater environments in Indonesia, Thailand, Vietnam, Malaysia, and the Philippines (Singh 1980). The extent of these areas in the Philippines seems to be less than 0.5 million ha (Brinkman and Singh 1982), and they are of the saline type. They are concentrated mostly in coastal brackishwater areas on the islands of Panay, Negros, and Bohol in the Visayas; in the provinces of Misamis Oriental and Agusan in Mindanao; and in Bicol, the Cagayan Valley, Pangasinan, Quezon, and Mindoro. Except on Panay, where they are reported to be about 20 000 ha (Singh 1982b) these areas have not been adequately surveyed.

PROBLEMS

The main problems of fishponds in acid sulfate soils are the insufficient growth of algae, the poor condition and consequent slow growth of fish, and the hazard of sudden fish kills during heavy rains after a long dry period. These are because of low pH, ionic imbalance, and toxically high levels of iron, aluminum, and sulfate; dike erosion; and deficiency of phosphorus (Singh 1980, 1982a). Even if these problems are solved, the very low efficiency of phosphate fertilizers remains (Potter 1976, Brinkman and Singh 1982).

The growth of algae is inhibited or retarded by low pH, high aluminum concentration, and low phosphate level. The low pH and high aluminum concentration may kill the fish or, in less severe cases, weaken them so that they become easy prey for diseases and parasites. The sudden influx of acid water and aluminum salts from dikes during rains causes an ionic imbalance in the fish that is commonly lethal to a large proportion of the population. Finely divided ferric hydroxide subsequently appears in the pond water and clogs the gills of the survivors, killing another contingent and weakening the remainder (Brinkman and Singh 1982). A lesser problem is the erosion of the dikes because of little or no vegetation on them, and thus those dikes remain acid-producing, at least during the first few years after construction. This further adds to the maintenance cost.

Table 1. Distribution of acid sulfate soils in South, Southeast, and East Asia.[a]

Country	Area (1000 ha)	Type
Bangladesh	700	Sulfaquents and Sulfaquepts
Burma	180	Sulfaquents
China	67	Sulfaquepts and Sulfic Haplaquepts
India	390	Highly organic Sulfaquepts and Sulfaquents
Indonesia	2000	Highly organic Sulfaquents, Sulfaquepts, and Sulfimists
Japan	21	Sulfaquepts and Sulfic Haplaquepts
Kampuchea	200	Mainly Sulfaquepts
Korea, Republic of	3	Sulfic Haplaquepts and Sulfaquepts
Malaysia	160	Mangrove acidified marshes
Philippines	7	Sulfic Tropaquepts, Sulfaquepts, and highly organic Sulfaquepts
	20	
	500	Sulfic Tropaquepts, Sulfaquents,
Thailand	670	and Sulfaquepts
		Sulfaquepts, Sulfic Tropaquepts,
Vietnam	1000	and organic Sulfaquents

[a] After Van Breemn and Pons (1977) and Singh (1980).

RECLAMATION

Acids in the pond bottom can be neutralized in two ways. They can be permanently neutralized by adding enormous quantities of lime over a period of several years, but only few farmers can afford such amounts. The acids can be made temporarily harmless by flooding the pond bottom about 3-4 weeks before stocking. During this period, the reddish iron oxides and organic matter in the soil combine to reduce the acid. However, the acid will appear again as soon as the pond bottom is dried. Acids in the dikes can also be neutralized by very large amounts of lime. It is not ordinarily possible to make them harmless by flooding because flooding of dikes to the reduced stage is usually not feasible.

It is not necessary, however, to neutralize all the acids in the pond bottom and the dikes, because a large part can be washed out and removed to the sea. Without such treatment, the pond will improve, but very slowly over a period of about 10-20 years, from almost no production to moderate levels; but most pond owners cannot afford to wait for such long periods for the natural rate of improvement. A system for rapid improvement of acid sulfate soils has been worked out at the Brackishwater Aquaculture Center of the University of the Philippines in the Visayas that can be carried out in one dry season (about 3 months) at a relatively low total cost in the range of ₱900—₱1000/ha. It has been tried in several locations in private ponds on Panay Island quite successfully. The studies conducted in developing this method include those of Poernomo (1983), Poernomo and Singh (1982), Brinkman and Singh (1982), Singh (1980; 1982a, 1982b), and Camacho (1977).

The basic concept for permanent reclamation is to remove the source of acidity by oxidizing the pyrite from the pond bottom (10-15 cm deep layer) and flushing this out of the pond to prevent further diffusion of acids, aluminum salts, and large amounts of ferrous salts from the subsoil to the upper layer and the pond water during the fish rearing period. At the same time the acid materials and other toxic elements from the relatively big dikes are also leached and removed.

The procedure involves a precisely planned sequence of drying the pond, tilling or cultivating the pond bottom by tooth harrow, filling and draining the pond, and finally broadcasting a small amount of lime (about 1 t/ha or less) on the pond soil and dikes. During the same period, the tops of the surrounding dikes are made into a series of long, narrow ponds by making small levees along their edges with soil dug out of the center of the dikes (Fig. 1); seawater or brackish water is pumped or carried into these to leach the acids from the dike soil. If the dikes are small, however, there may be no need of leaching them, or the leaching of the dikes may be restricted to those relatively big primary dikes or in some cases to secondary dikes surrounding nursery and fingerling ponds where compartment sizes are usually small. The details of this method can be seen in articles by Brinkman and Singh (1982) and Poernomo (1983). After completing the reclamation, the ponds are applied with organic and inorganic fertilizers; growing of fish food organisms and rearing of fish follow as usual.

RESULTS

The results obtained after applying this procedure at different locations in northeast Panay have been very encouraging and successful. The properties of pond and

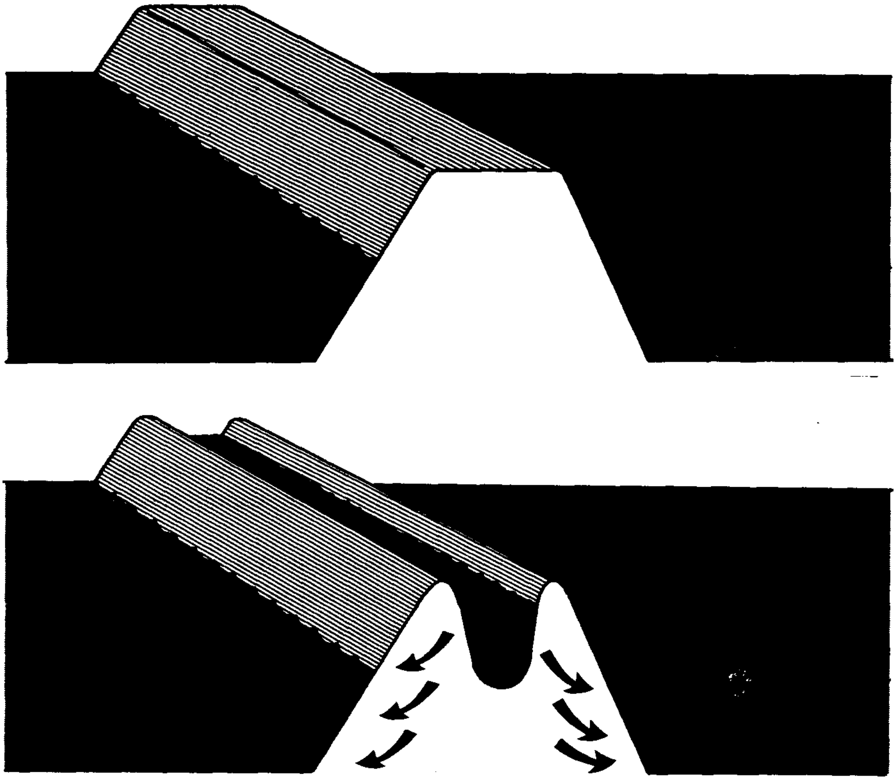

Fig. 1. Leaching of levees.

dike soil and pond water before and after reclamation and after the harvest of the first crop are shown in Tables 2,3,4, and 5. The results of *lablab* and fish production are shown in Table 6.

Soil Properties

In the beginning, the low pH combined with high concentrations of exchangeable aluminum, active iron, and acetate soluble sulfate (Table 2) indicated extremely acidic conditions. The dike soil was even more acidic than the pond bottom because of the intense oxidation of pyrites (Table 2). The concentrations of aluminum and iron in the pond soil were very high due to low pH and were far beyond the tolerable limit of most fish, which is generally about 0.5 ppm and 0.2 ppm for aluminum and iron, respectively (Nikolsky 1963). The extremely low concentration of available phosphorus in the pond bottom soil was attributed to the binding capacity of excess amounts of aluminum and iron (Table 2).

After 3 months of reclamation, the decrease in concentration of acetate soluble sulfate (5612-633 ppm) — potential acidity — coupled with decreased concentrations of aluminum (132 to 12 ppm) and iron (7607 to 3633 ppm) resulted in an

Table 2. Some physical and cbemical properties of surface soil of pond bottom and dikes in acid sulfate areas.

Properties	Pond bottom	Dikes
pH (wet)	5.8	3.6
PH (dry)	5.7	3.1
Potential acidity (meqH/100g)	23.6	24.1
Organic matter (%)	4.1	3.4
Exchangeable Al (ppm)	150.0	333.0
Active Fe (ppm)	7 845.0	9 650.0
Active Mn (ppm)	15.0	15.0
Pyritic Fe (ppm)	3 346.0	3 120.0
Acetate solution-SO_4 (ppm)	6 145.0	8 717.0
Available PO_4 (ppm)	0.25	0.39

increase (1.1 to 1.4 units) in dry soil pH in the treated ponds. The available phosphate in treated ponds increased from 0.25 to 1.03 ppm. In contrast, there was only a little change in the pH and in other properties of the control ponds (Table 3), due to washing from the rains.

The dry soil pH (4.8) attained after reclamation (Table3) was enough to maintain an ideal pH (6.8) in the wet reduced pond bottom soil and a pH of 7.0-8.5 in the pond water during *lablab* and fish growing because of continuous submergence. This situation in turn was optimal for the solubility and availability of phosphorus for *lablab* growth, since fixation of phosphorus is minimal at these pH levels (Table 3). A similar trend was also observed for dike soil (Table 4).

After fish harvest from both the ponds that were applied with 2 t of chicken manure, 48 kg N, and 60 kg P_2O_5/ha as standard operating procedure, the treated pond soils attained a higher dry pH (5.7) and had lower concentrations of aluminum (10 ppm), active and pyritic iron (2963 ppm and 1920 ppm, respectively), and sulfates (704 ppm) than the controls (Table 3). The treated ponds also had a higher level of available phosphorus (1.43 ppm). The values of aluminum, active and pyritic iron, and sulfates in control ponds were generally more than two-fold higher, registering 63 ppm, 7676 ppm, 3206 ppm, and 200 ppm, respectively.

Table 3. Some properties of pond bottom soil before and after reclamation and the harvest of first crop.

Properties	Before reclamation		After reclamation		After harvest	
	Control	Treated	Control	Treated	Control	Treated
pH (wet)	6.0	5.4	5.6	6.0	5.8	6.8
pH (dry)	3.9	3,6	3.7	4.8	3.8	5.7
Eh (mv)	2.3	220	72	10	-120	-150
Exchangeable Al (ppm)	162	135	85	12	63	10
Active Fe (ppm)	9 278	7 607	7 913	3 633	7 676	2 963
Pyritic Fe (ppm)	3 378	3 321	3 140	1 867	3 206	1 620
Active Mn (ppm)	17	16	12	18	7	0
Acetate Solution SO_4 (ppm)	6 723	5 612	2 075	633	2 000	704
Available PO_4 (ppm)	0.33	0.25	0.66	1.03	1.13	1.43

Table 4. Some properties of dike soil before and after reclamation.

Properties	Before reclamation		After reclamation	
	Control	Treated	Control	Treated
pH (wet)	3.6	3.7	3.8	4.1
pH (dry)	3.0	3.1	3.8	4.1
Eh (mv)	374	360	340	293
Exchangeable Al (ppm)	367	309	253	118
Active Fe (ppm)	9 854	8 996	9 167	5 285
Pyritic Fe (ppm)	2 330	3 215	1 767	1 362
Acetate Solution SO_4 (ppm)	9 442	8 358	2 374	1 083
Active Mn (ppm)	17	13	11	6
Available PO_4 (ppm)	0.39	0.39	0.55	0.79

Water Properties

The chemical properties of pond water before and after reclamation and after harvest of the first crop are presented in Table 5. The chemical properties of both the control and treated ponds before reclamation had similar magnitudes. The pH of the water was 3.9, alkalinity was 22 ppm, aluminum 3.5 ppm, iron9.3ppm, and sulfate 1800 ppm. Due to the low pH and the high aluminum, iron, and sulfate levels, the dissolved phosphorus in the water was essentially zero. These conditions indicate a very highly acidic and unfavorable condition for milkfish and prawns.

After the 3-month reclamation period, the pond conditions improved significantly; the pH of the water increased to 6.5, alkalinity to 47 ppm, and the levels of aluminum, iron, and sulfate decreased to 0.18 ppm, 1.35 ppm, and 773 ppm, respectively. Dissolved phosphorus improved from 0.0 to 0.02 ppm. Some improvements were also seen even in the control ponds, but these were due mainly to occasional draining of the pond water because of heavy rains during the reclamation period, and the magnitude of improvement was smaller in these ponds (Table 5). After harvest of the fish grown in control as well as treated ponds (both had received the same fertilizers and other management inputs), the water quality of the treated ponds was remarkably better than that of the controls. The levels of aluminum and iron in treated ponds decreased to negligible, sulfate decreased considerably, and pH, alkalinity, and phosphorus levels increased significantly (Table 5).

Table 5. Some properties of pond water before and after reclamation and after harvest of first crop.

	Before reclamation		After reclamation		After harvest	
Properties	Control	Treated	Control	Treated	Control	Treated
pH	3.9	3.9	4.2	6.5	6.9	8.0
Alkalinity (ppm)	20.3	23.1	23.1	47.3	48.9	98.5
Aluminum (ppm)	2.9	4.1	1.7	0.18	0.04	0.02
Iron (ppm)	9.3	9.3	3.9	1.3	0.37	0.16
Sulfates (ppm)	1 723	1 930	1 063	773	1 070	680
Phospate (ppm)	0.0	0.0	0.1	0.02	0.02	0.20

Lablab and Fish Production

The significantly lower production of *lablab* in the control ponds (Table 5) compared with that in reclaimed ones is attributed to the constantly low concentrations of available phosphorus due to the rapid fixation of phosphorus released from the fertilizer. In the reclaimed ponds, on the other hand, fixation of phosphorus by the soils seemed to be minimal. The *lablab* mat that grew evenly on the pond bottom seems to have acted as a barrier and to have prevented phosphorus fixation into the soil. Also, the soil in these ponds was no longer very acidic and therefore had lower phosphorus fixation. *Lablab* growth in all the reclaimed ponds was so thick that thinning was done to avoid the danger of sudden decomposition.

Fish production in the treated ponds (375-510 kg/ha) was significantly higher than in the control ponds (50-173 kg/ha), although both had received same management inputs (Table 6). Twice in the control ponds there were mortalities, which resulted in only 43% survival. Survival in the treated ponds was 93%. Ideally, the weight gain

Table 6. *Lablab* and milkfish yield in a culture period of 90 days.

	Lablab		Milkfish		
	Ash free dry weight (g/m^2)				
Treatment	Total	Per two weeks	Survival (%)	Weight (gain/fish)	Yield[a] (kg/ha)
Control	230.1	32.9	43	107.6	50-173
Treated	783.4	112.0	93	124.1	374-510

[a] The range in yield indicates the difference among sites used.

in the control ponds should have been higher than in the treated ones because of the smaller number of fish, but the results were otherwise; the fish in the treated ponds had a higher weight gain (124.1 g) than those in the control (107.6 g). This indicates that the food supply in the control ponds was not sufficient and the water quality not optimal. This was further confirmed by length-weight analysis. Fish production in both treatments was significantly correlated with *lablab* growth.

Although there may be no significant difference between ponds with and without dike leaching in terms of *lablab* and fish production, there were more acids and other toxic elements in the dikes without leaching. The results of leaching indicate that more acids were washed and removed from the leached dikes compared to the unleached ones. The leached dikes pose a smaller hazard of acid water seeping out than the unleached and thus have more potential for fish kills. In other words, the effect of dike leaching on *lablab* and fish production may be undetectable in the first season of rearing fish, but it could be more pronounced in subsequent growing seasons, especially during rainy months.

Other methods of improving acid sulfate soils include liming; covering the acidic soil with a more suitable material like neutral clay, river bottom mud, or filter mud press; covering pond dikes with vegetation to check erosion; and lining the dikes with limestone.

CONCLUSIONS AND RECOMMENDATIONS

Based on the studies cited in this paper, the following conclusions and recommendations are drawn:

1. The development of fishponds in mangrove areas should be undertaken with caution, and prior to any development a detailed soil survey must be conducted.
2. Though acid sulfate soils are undoubtedly detrimental if they are developed into fishponds, they can be rapidly improved into productive soils following a proper method of reclamation (Singh and Poernomo 1983).
3. A repeated sequence of drying, tilling, and flushing the pond with seawater and leaching of relatively big dikes, preferably during the dry season, is a cheap and fast method of reclamation (Singh 1980, Brinkman and Singh 1982, Poernomo and Singh 1982, and Poernomo 1983).
4. A moderate amount and low rate of application of powdered lime (500 kg/ha) broadcast on the pond bottom immediately after reclamation or during pond preparation for fish rearing helps speed up soil reduction; suppresses the concentrations of aluminum, iron, and acids that may be released into the pond water; and reduces the phosphorus fixation into the soil. The application of waste materials like mud press from sugar mills and burnt rice hulls on the wet pond bottom is also effective in reducing the phosphorus fixation in the soil (Singh 1982b).
5. To further avoid excessive phosphorus fixation by pond bottom soil, small weekly dressings of preferably slow release fertilizers are recommended (Singh 1982a).
6. Instead of prefingerlings, the postfingerling size of milkfish or of other hardy fish should be used for stocking in the first or second year after reclamation. Prawns should be tried afterwards in polyculture with milkfish on an experimental basis before embarking on intensive commercial prawn monoculture after several years (Singh 1982b).

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