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The role and management of bottom soils in aquaculture ponds

Soil and water management are the two basic tenants for successful land based aquaculture. Many of the negative impacts of inherent soil characteristics and changes in bottom soils resulting from aquaculture operations can be counteracted by application of management practices. These practices are outlined in Tabular form for easy reference.

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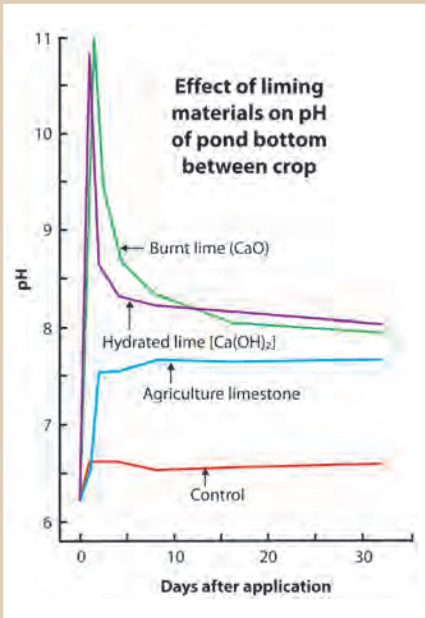
Dried bottom of a shrimp pond.

The importance of soils in pond aquaculture begins with site selection and construction. Because of their ecological significance, wetland sites usually should not be converted to other land uses and particularly to land intensive endeavours such as agriculture and aquaculture. Where soils are acceptable, their properties are important for determining permissible side-slopes of pond earthwork, degree of compaction and need for clay liners in bottoms *etc* to discuss the role and management of bottom soils in existing ponds.

The area to become the pond bottom typically is cleared of vegetation and the upper 25 to 75 cm layer of soil is removed to use as earth fill for dams or embankments. In the case of excavated ponds, an even greater depth of earth may be removed from the bottom area. In terrestrial soils, the O horizon is the top-most layer that contains recent organic matter additions such as leaves and leaf fragments. The layer below the O horizon is the A horizon that typically is the most fertile horizon. These two horizons usually are removed and the pond bottom typically lies in the B horizon or possibly in the C horizon. The B horizon is usually of relatively high clay content and both the B and C horizons are of lower fertility than the O and A horizons that were removed. The new pond bottom often is compacted to reduce the tendency for seepage. Although the original, terrestrial soil profile is greatly altered during pond construction, once the pond is filled with water and aquaculture operations initiated, formation of sediment or pond bottom soil profile begins. Dead plankton, feces of culture species, organic fertilisers and uneaten feed will settle to the pond bottom. Wave action, disturbance of the bottom by aquatic organisms, aerator-generated water currents and seine hauls to sample or harvest aquatic animals erode pond bottoms and side slopes of dams and embankments. Soil particles suspended by erosion and organic matter produced in or introduced into the pond settle to the bottom, become mixed and form a sediment layer. This sediment layer usually increases in depth most rapidly during the first 2 or 3 years in a new pond but it continues to increase in depth – typical rates of sedimentation in older ponds are 1 to 2 cm/yr. In heavily-aerated ponds, aerator-generated water currents may greatly accelerate erosion and sediment accumulation.

The typical soil profile in pond bottoms is detectable in sediment cores of new ponds within 2 or 3 years and it is well developed within 5 to 10 year where sediment is not removed regularly. Notice that the pond soil horizons are identified by different letters than used for describing terrestrial soil horizons. The most active zone of organic matter decomposition (and oxygen demand) occurs in the F and So horizons. In this aerobic zone, microorganisms use molecular oxygen to oxidise organic matter to carbon dioxide. However, dissolved oxygen movement into the sediment by diffusion and via infiltrating water is slow compared to the rate that microorganisms use oxygen in respiration and dissolved oxygen in sediment pore water usually is depleted within the upper few millimeters of the S horizon. Beneath the aerobic layer, fermentation by anaerobic microorganisms oxidises a portion of the organic matter to carbon dioxide, but much of the organic matter is converted to soluble organic compounds such as alcohols, aldehydes, ketones, and short-chain fatty acids. In absence of molecular oxygen, bacteria capable of using combined oxygen from inorganic compounds such as nitrate, iron and manganese oxides and hydroxides, sulfate and even carbon dioxide in respiration oxidise organic metabolites from fermentation. Anaerobic microbial activity produces metabolites such as gaseous nitrogen (N_2 and N_2O), ferrous iron (Fe_2^+), manganous manganese (Mn_2^+), hydrogen sulfide, and methane. Hydrogen sulfide in particular can be troublesome in aquaculture because it is highly toxic to shrimp and fish.

Microbial action oxidises much of the fresh organic matter that settles to the pond bottom during a production cycle and converts the remainder to



a form that decomposes slowly (the refractory fraction) and has less effect on pond oxygen dynamics. Nevertheless, there is an accumulation in organic matter in sediment overtime and the concentration of labile organic matter is greatest in the F and S horizons and especially at the end of a production cycle. When ponds are drained for harvest, labile organic matter in the F horizon is removed in outflowing water, but a considerable amount remains in the S horizon. Drying of bottoms allows air to replace water in pore space in the sediment. At 20°C, 1 litre air contains 252 mg O_2 as compared to 9.07 mg in 1 litre of freshwater. More oxygen within the soil mass enhances oxidation of organic matter by bacteria as well as accelerating the chemical oxidation of ferrous iron to ferric iron (Fe_3^+), manganous manganese to manganic form (Mn_4^+), nitrite to nitrate, and sulfide to sulfate. Dry-out is beneficial because it allows most of the labile organic matter from the previous crop to be oxidised lessening the sediment oxygen demand at the beginning of the new crop. The oxidised inorganic compounds also can be used again in anaerobic respiration during the next crop. One should realise that after about 2 or 3 weeks of drying most of the labile organic fraction will have decomposed and the soil will be too dry for further microbial activity.

Pathogens, their vectors and other unwanted organisms can survive between crops in puddles of water in pond bottoms or in moist soil. Therefore, pond bottom dry-out between crops also is an excellent disinfection practice but it requires that soils be dried thoroughly enough to kill the majority of organisms through desiccation. Desiccation affects both desirable and undesirable organisms and when a pond is refilled following thorough dry-out, there will be a paucity of benthic organisms, some of which serve as food for post larvae or fingerlings. Moreover, water to fill ponds often has relatively low abundances of nutrients and plankton.

Once a pond is refilled, sediment exchanges substances with water through several processes to include dissolution of minerals, adsorption-desorption of substances by clay minerals and ion-exchange. In many cases, the equilibrium concentration of a substance in water is quite low in comparison to the concentration of the substance in the solid phase (soil minerals). For example, the concentration of soluble reactive phosphorus in the water may be only 5 to 10 µg/L, while the soil may contain 1 000 mg/kg or more phosphorus bound in insoluble forms. Certain clay minerals in soil also may fix cations, especially potassium, within their structure. Thus, depending upon the characteristics of the bottom soil, the concentrations of ions in the water added to ponds may increase, decrease or remain the same depending upon the characteristics of the bottom soil.

The soil has a pronounced influence on acid-base relationships in water. An acidic soil has low base saturation – a large percentage of acidic, exchangeable aluminum ion compared to basic, exchangeable cations (calcium magnesium, potassium, and sodium). Such soils neutralise alkalinity and lessen pH in pond water. A soil with iron pyrite will be particularly acidic because of oxidation of the pyrite and overlaying pond water may become too acidic for survival of fish and shrimp. On the other hand, a soil that contains limestone will have base saturated clay minerals and water of moderate to high alkalinity.

It is very important to maintain aerobic conditions at the soil-water interface. This thin zone acts as a barrier to the diffusion of hydrogen sulfide, nitrite and other potentially toxic metabolites of anaerobic, microbial respiration into the water column. In shallow areas of ponds benthic algal may grow on the sediment and underneath these mats of algae, microbial decomposition of dead algal cells may cause anaerobic zones. Benthic animals grow in the sediment utilising organic matter from dead algal and other pond waste as food. Benthic organisms serve as natural food for many species and especially for shrimp.

Bottom soil management between crops

Pond bottom soil management often is quite intensive in marine shrimp culture but less management is applied in most types of fish culture. The best opportunity for applying bottom soil management is during the period between crops while ponds are empty and bottoms are accessible. The length of time required to thoroughly dry-out the bottom of a pond varies with several factors and especially weather conditions (warm, dry, windy conditions favor rapid drying), soil texture (coarse texture soils

Coarsely ground agriculture limestone. Finely ground agriculture lime stone.

Summary of pond bottom soil management practices	
Action	**Practice**
Empty ponds between production cycles	
Effect dry-out	• Drain ponds and let them dry for 2 to 3 weeks.
Sediment removal	• Remove sediment from areas where it is too deep to dry completely.
Correcting soil pH	• Measure pH of soil. • Apply agriculture limestone if pH < 7.5 – unless the purpose is to disinfect the soil.
Improve drying and aeration of soil	• Use a disk harrow or other tillage implements to fragment the surface soil and break up clods.
Soil disinfection	• Use lime to disinfect entire pond bottom, or apply it only at wet areas that will not dry completely. • If lime is used over entire pond for disinfection, agriculture limestone treatment usually is not needed for correcting low soil pH.
Improving natural productivity in recently-filled ponds	• Use fertilisers containing N and P to stimulate phytoplankton. • Apply plant meal or fish meal to improve zooplankton growth. • Use organic matter to encourage benthic growth.
Grow-out period	
Maintaining total alkalinity	• Lime ponds with agriculture limestone if total alkalinity falls below 50 to 60 mg/L in fish ponds or below 80 to 90 mg/L in shrimp ponds. • Use sodium bicarbonate in lined ponds.
Control decline in potassium concentration	• Apply muriate of potash fertiliser.
Minimising embankment erosion while effecting adequate oxygenation and circulation	• Install aerators in a way to avoid erosion of embankments. • Reinforce easily erodible areas of embankments with grass cover, stone, or geotextile. • Use enough aeration to provide good circulation of water over pond bottoms.
Raising redox potential of soil in un-aerated ponds	• Apply sodium nitrate or other nitrate compound.

dry faster than fine textured soils), and sediment depth (a deeper sediment layer inhibits drying). In addition, ponds may have depressions from which water does not drain sufficiently to allow the area to dry, water can seep into empty ponds from adjacent full ponds or water supply and groundwater may infiltrate into ponds constructed in low-lying areas. As a general rule, in tropical and subtropical zones, most ponds can be dried out in 2 to 3 weeks during the dry season. Tilling with a disk harrow or similar tillage implements can break up the soil mass to allow greater contact with the air and encourage evaporation, tilling is especially beneficial in drying heavy clay soils. Where sediment is over 10 to 15 cm deep, it may be impossible to dry-out ponds thoroughly. The sediment dries on the surface creating a barrier to evaporation and tilling may not be possible because the wet soil beneath the dry surface will not support the weight of the tiller. Thus, sediment removal from ponds may be necessary, there is however, no research finding to support the removal of sediment from ponds after each crop as often done in Asian shrimp farming.

The pH of pond soils should be measured on a sample of surface soil (0-5 cm layer) prepared by mixing 10 or more subsamples of soil taken randomly over the pond bottom. This sample should be thoroughly air-dried (or at 60°C in an oven) and pulverised to pass a 60 mesh sieve (0.85 mm openings). The pH should be measured in a 1:1 mixture of distilled water and pulverised soil using an electronic pH meter and glass electrode following intermittent stirring for 20 minutes. Hand-held, battery-operated soil pH testers are not accurate, especially in soils of shrimp ponds.

Ponds with a pH below 7.5 should be limed; because, as pH declines below this level, organic matter decomposition slows, phosphorus applied in fertilizers is less available, benthic productivity may decline and bottom soil acidity may cause a drop in total alkalinity. The best liming material for general purposes is agricultural limestone made by pulverising limestone to a fine particle size. There are two basic forms of agricultural limestone. One is made from calcitic or ordinary limestone that contains mostly calcium carbonate and usually a smaller proportion of magnesium carbonate; the other is made of dolomitic limestone that is essentially a 1:1 mixture of calcium carbonate and magnesium carbonate. Agricultural limestone also can be produced from marl, chalk, and seashells. There is no advantage of one of these liming materials over the others providing they have similar neutralising values; pure calcium carbonate has a neutralising value of 100 percent.

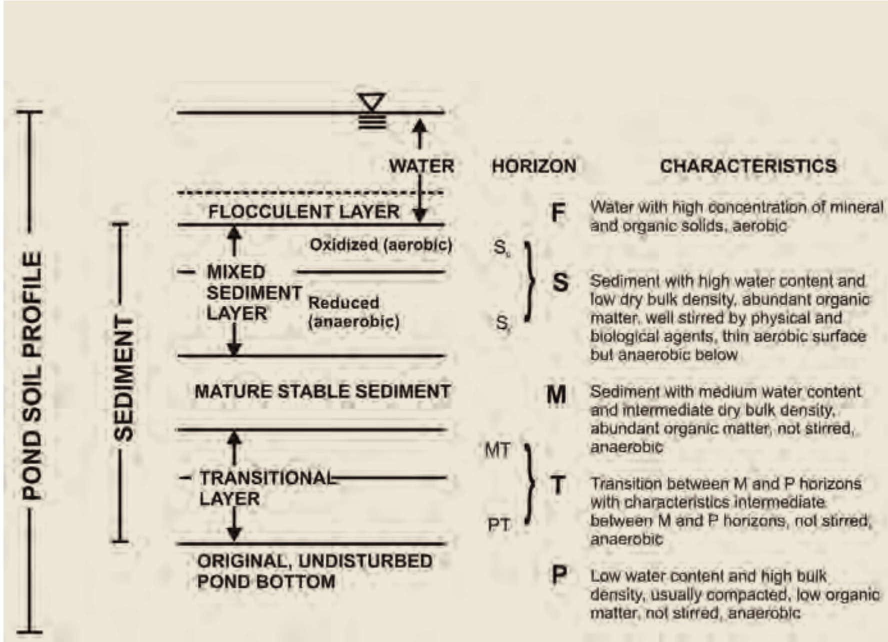
Soil testing laboratories have

procedures for determining the lime requirement of soil samples (the same sample taken for soil pH can be used). In the likely event that such a service is unavailable; the liming rate can be ascertained from soil pH and soil texture. The liming material should be spread uniformly over the bottom of the empty pond while the soil is still moist. In cases where the pond bottom is to be tilled, the liming material should be applied before tilling so that it will be mixed into the soil mass. However, it is not necessary to till the soil for liming to be beneficial.

In shrimp farming and some types of fish culture, producers commonly apply burnt lime or hydrated lime to pond bottoms to increase the pH above 10 or 11 to kill pathogenic bacteria, vectors of viral diseases and other unwanted organisms that may survive dry-out. When this practice is employed, it is not necessary to apply agricultural limestone to ponds with pH < 7.5. Burnt lime is made by incinerating limestone in a kiln at high temperature to drive off carbon dioxide; the remaining material consists of oxides of calcium and magnesium. Burnt lime can be treated with water to produce hydrated lime. When applied to ponds, either type of lime will cause a rapid increase in pH, but the pH will decline within a few days as the lime reacts with carbon dioxide. This reaction converts lime to calcium and magnesium carbonates, the same compounds in agricultural limestone.

Recent studies have shown that at least 3 000 kg/ha and up to 5 000 kg/ha of lime are needed to increase the pH of pond soils to 11 and maintain it at this level for a few hours so that most soil organisms are killed. Because of the large amount of lime needed to treat pond bottoms, the most practical way of using lime in disinfection is to treat only those areas that will not dry adequately. Of course, in the rainy season, ponds cannot be dried completely and farmers may desire to treat the entire bottom area. Lime will not be effective as a disinfectant if not applied at high rates, most farmers only use a fraction of the rate recommended above. Moreover, lime will not increase pH in dry soil, lime should be applied while the soil is still moist.

Ponds sometimes are built in organic soils that have a wide C:N ratio and



microbial respiration can be accelerated by application of nitrogen fertiliser. Urea or other nitrogen fertiliser can be applied at 200 to 400 kg/ha (20 to 40 g/m^2) to provide supplemental nitrogen for microbial activity. Urea and ammonia fertilisers should not be applied when soil pH is above 8, because much of the nitrogen will be lost to the air by ammonia volatilisation.

Some farms, particularly intensive shrimp farms, have reservoirs in which water can be held and disinfected. At small farms without reservoirs, water may be disinfected directly in ponds before stocking. The most effective disinfecting agent likely is calcium hypochlorite, often known as high test hypochlorite (HTH) but there are several other products in common use as disinfectants. A frequently recommended treatment is 10 mg/L available chlorine [15 mg/L of calcium hypochlorite (65 percent chlorine)], but a concentration of 15 to 20 mg/L available chlorine might be more generally reliable for disinfection. Many other disinfectants are used but only chlorine has been subjected to investigation and shown to be effective.

Pond bottoms and waters often are essentially sterile following dry-out and other disinfecting efforts, and fertilisation to promote benthic organisms and plankton for natural food organisms before stocking culture animals is advisable. Organic matter may be applied to pond bottoms at rates of 250 to 500 kg/ha to encourage benthic organisms. Chemical fertiliser may be applied to the water to promote phytoplankton blooms. An N: P_2O_5 ratio of 1:2 or 1:3 in fertilisers is acceptable, but the nitrogen input should not exceed 8 kg/ha. There are, however, many opinions about the optimum fertilisation rate. Zooplankton growth typically lags phytoplankton growth and plant meal or fish meal can be applied over the water surface at 10 to 20 kg/ha to encourage rapid development of zooplankton communities.

Once an adequate plankton bloom has been established, post larvae or fingerlings may be stocked. It is not a good practice to stock small animals in clear water ponds even where feed is offered. Natural food organisms are an important supplement to the diet of post larvae and fingerlings that cannot use manufactured feed as efficiently as can older and larger animals. Of course, care must be taken to avoid excessive phytoplankton growth in ponds that could lead to stressfully low dissolved oxygen concentrations at night.

Bottom soil management during grow-out

During the grow-out period, there are fewer opportunities to manage pond soils. In areas with highly acidic soils, especially acid-sulfate soils, total alkalinity may decline gradually and it should be measured occasionally. If the concentration is below 50 to 60 mg/L in fish ponds or 80 to 90 mg/L in crustacean ponds, agricultural limestone should be applied.

Aerators should be positioned in ponds so that they do not damage earthwork by erosion and suspend large amounts of soil particles. However, aerator-generated water currents should be adequate to thoroughly circulate pond water and provide a continuous movement of oxygenated water across the sediment-water interface to maintain a So horizon that serves as a barrier to the diffusion of reduced substances from the Sr horizon into the water column.

Some shrimp producers apply sodium nitrate to ponds for the purpose of poising the redox potential at the soil-water interface to lessen the possibility of hydrogen sulfide and other metabolites of anaerobic, microbial respiration entering the water column. Nitrate is used by denitrifying bacteria in the sediment and as long as nitrate is present, the redox potential will not fall low enough for the existence of anaerobic microbial metabolites and especially hydrogen sulfide at the sediment-water interface. This practice probably is beneficial in some un-aerated ponds.

During inland culture of shrimp or other marine organisms in low-salinity water, potassium in water of some ponds may decline to an unacceptably low concentration, because it is removed from water by cation exchange with bottom soil and by fixation within certain clay minerals. Muriate of potash fertiliser (potassium chloride) must be applied periodically to such ponds to maintain adequate potassium for good survival and growth of the cultured species. The treatment rate usually is calculated to raise potassium concentration to the level that would occur in normal seawater diluted to the salinity of the culture system. The target potassium concentration in milligrams per liter can be estimated by multiplying the salinity in the culture system (in ppt) by 10.7, the ratio of potassium concentration to salinity in seawater. Each unit of muriate of potash is equal to about 0.5 units of potassium.

In intensive aquaculture, it is becoming increasingly popular to line pond bottoms with impermeable plastic liners. In ponds that are completely lined, phosphorus is not removed from water by bottom soils, and the potential for dense phytoplankton blooms increases. Large amounts of dead plankton and other wastes accumulate in the bottoms of such ponds, and some producers use suction devices to remove this material and discharge it outside ponds. This practice lessens the oxygen demand of organic matter in ponds and allows more of the dissolved oxygen supplied by aeration to be used by the aquaculture crop. Of course, the oxygen demand is exported to the surrounding environment.

Lined ponds often are operated without water exchange and there is no contact of water with bottom soil. Thus, when ammoniacal nitrogen from the cultured species is oxidised by nitrifying bacteria creating acidity, alkalinity declines because there is no input of replacement alkalinity in incoming water or from dissolution of carbonate minerals in pond bottoms. Alkalinity should be checked regularly in lined ponds and liming materials applied to maintain the desired concentration. Because of the limited solubility of traditional liming materials, sodium bicarbonate that dissolves quickly and completely is an excellent alternative. The amount of sodium bicarbonate needed to neutralise acidity is around 45 g/kg of feed. However, the application rate usually is made at frequent intervals to maintain a relatively stable alkalinity. Each milligram per liter of sodium bicarbonate is equivalent to 0.60 mg/L of total alkalinity (expressed in terms of calcium carbonate).

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