Soil System-Based Approach: A Tool for Fish Pond Fertilization

By Abira Banerjee, G.N. Chattopadhyay, and C.E. Boyd

To obtain maximum production of fish from any aquatic environment, it is necessary to maintain the nutrient status of the pond above critical levels in the soil-water system. This study describes an approach that achieves this goal through proper use of fertilizers and manures in fish ponds in India.

The major objective in application of fertilizers and manures to fish ponds is to encourage the growth and abundance of different fish food organisms, which in turn promotes the growth of fish (Boyd and Tucker, 1998). The aquatic environment supports various communities of living organisms which constitute the biotic load of a pond. Natural productivity is the capacity to increase this biotic load (i.e., all biomass) over time. In fish culture, which depends largely on natural foods, there is normally a close dependence of fish production on the level of primary productivity. This primary productivity in a fish pond indicates the rate of formation of organic matter due to photosynthesis, and is comprised of different groups of living communities, mainly phytoplankton, benthos, and periphyton (Chattopadhyay, 2004). These primary producers either form the natural food item to different phytophagous fishes or give rise to secondary or tertiary organisms as foods of various kinds of fishes with varying food habits **(Figure 1)**. All other environmental factors remaining favorable, nutrient concentrations determine the magnitude of primary production in a water body.

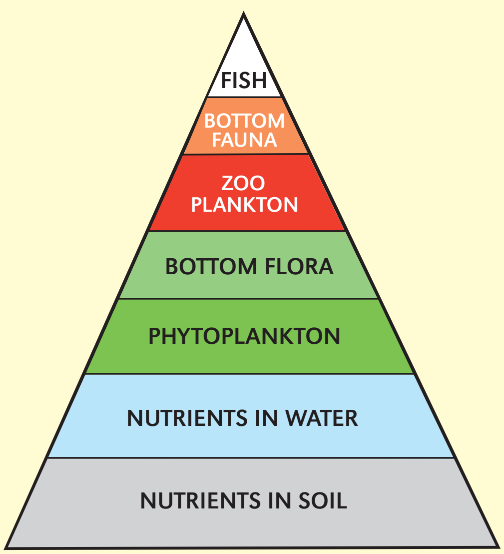

Figure 1. Food chain in fish ponds.

Mortimer and Hickling (1954) established clearly the efficiency of pond fertilizing materials in increasing the productivity of fish ponds. While Saha (1979) reported a four-fold increase in fish yield due to pond fertilization in India, positive effects of fertilization on pond productivity have been reported by many other workers from different parts of the world (Hepher, 1962: Dobbins and Boyd, 1976; Mandal and Chattopadhyay, 1992). While fertilizers and manures are applied directly to the soil through which plants derive their nutrients, in aquaculture this effect is brought about through a longer chain consisting of soil-water fertilization-bacteria-aquatic plants-zoo plankton, and zoo benthos – fish. During the course of this conversion, plant nutrients undergo various transformations in the soil and water phases. For fixing the rates and manners of use of fertilizers in fish ponds, therefore, due consideration is to be exercised to these echelons of productivity.

Abbreviations: N = nitrogen; P = phosphorus; K = potassium.
Note: US$1 is equal to approximately Rs.46

Maintenance of favorable environmental conditions in fish ponds depends largely on the bottom soil.

Soil System-Based Approach in Fish Pond Fertilization

Bottom soils play an important role in controlling such nutrient transformations, especially the behaviors of the fertilizers in fish ponds (Chattopadhyay, 2004). The significance of bottom soils in influencing availability of different nutrient elements to primary fish food organisms has been discussed in detail by Boyd and Bowman (1997). Behavior of these nutrients and also maintenance of a favorable environmental condition in any pond are controlled largely by the bottom soil of the pond where a series of chemical and biochemical reactions continuously take place. These reactions influence not only the release of inherent nutrients from soil to the water phase, but also the transformation of added fertilizers in the ponds.

Table 1. Average productivity of fish ponds in red and lateritic soil zones under two different fertilization programs.

Parameter	Traditional fertilization	Soil system-based fertilization	Average increment, %
Gross primary production (Mean), mg C/m^3/hr	175 to 600 (371)	251 to 665 (480)	29.3
Net primary production (Mean), mg C/m^3/hr	75 to 425 (214)	100 to 525 (295)	37.8
Estimated fish yield (Mean), t/ha	0.92 to 2.56 (1.74)	1.25 to 3.00 (2.12)	22.1

Chattopadhyay and Banerjee, 2005.

Wudtisin and Boyd, (2005) discussed considerable variations in the results of pond fertilization under different locations and these were attributed to variations in the nature and properties of bottom soils. In view of the wide variations in the properties of bottom soils situated in different soil zones and their influence on pond productivity, it appears to be appropriate to develop a soil system-based nutrient management approach for different fish ponds. While working with fish ponds situated in red and latertic soil zones, Banerjee and Chattopadhyay (2004) studied the nature and properties of large numbers of fish pond soils with relation to their primary productivity of water and identified the major soil factors responsible for variations in gross production of primary fish food organisms in such ponds **(Figure 2)**.

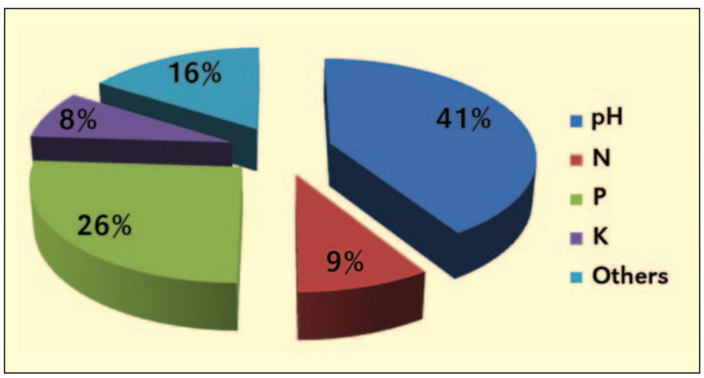

Figure 2. Percent contribution of different soil properties on gross primary productivity of fish pond water in red and lateritic soil zones.

Based on the information on the relative importance and status of the productivity-limiting plant nutrients in such pond soils, a soil system-based pond fertilization program was developed. This approach appeared to be more efficient than the traditional method of fertilizer application in fish ponds since it took into consideration the inherent nutrient supplying capacity of the pond soils along with other relevant properties of the ecosystem **(Table 1)**.

Use of Critical Levels of Nutrients for Optimizing Fertilizer Rates in Aquaculture

Fertilization rates for agricultural crops are commonly determined from the availability of nutrients in the soils. In view of the importance of bottom soils in influencing the efficiency levels of different pond fertilizing materials, it should be possible to apply the approach used in agriculture to assess the relationship between bottom soil nutrient concentrations and production of primary fish food organisms. This will also help to determine the requirements of different fertilizers for achieving economic benefits from fish pond fertilization under different soil zones. After the initial work of Cate and Nelson (1965), a large number of studies throughout the world determined the critical levels of various plant nutrients for different crops under varying soil conditions. Recently, Banerjee et al., (2009) reported a systematic study to adopt this principle in determining the critical levels of three major plant nutrients viz. N, P, and K in fish pond soils of red and lateritic soil zones and to assess the threshold levels of pond fertilizers required for attaining these critical limits.

Bottom soils were collected from different fish ponds situated in typical red and lateritic soil zones of West Bengal, India. To represent each pond, one kg of the 80 mesh sieved pond soil sample was taken into each of nine aquariums and the soils were incubated with 20 L of de-ionized water for 15 days to develop a semi-aerobic condition that simulated a typical fish pond. To determine the critical level of any nutrient, the pond soils were treated at different doses. For example, P was used at 0, 75, and 150 mg/kg/yr doses, split into 10 monthly applications. Along with the nutrient under study, the samples also received uniform doses of N and K, split as before. This was done to prevent any possibility of these two primary nutrients behaving as productivity-limiting factors. Each of the treatments were replicated three times and incubated under illuminated conditions. Soil samples were collected at weekly intervals from each of the aquariums for 3 weeks and were analyzed for gross primary productivity (GPP) of water and available P in soil. Similar studies were carried out for determining the critical limits of the other two primary nutrients.

The mean values of GPP of water, as well as availability of the particular nutrient in the soil, were monitored during the period of incubation under each soil-water system with different doses of fertilization for assessment of critical levels of available soil nutrients. For this purpose, Bray's percent yield (BPY) concept (Bray, 1948) was modified slightly by adopting the following formula.

$$\text{BPY} = \frac{\text{GPP with added nutrient - GPP with no added nutrient}}{\text{GPP with added nutrient}} \times 100$$

The obtained BPY values for different soil-water systems were then used for graphical determination of critical levels of the available nutrients in fish pond soils by following the principle of Cate and Nelson (1965). The studies showed the critical levels of the three nutrients to be 200, 13, and 80 mg/kg soil for N, P, and K, respectively, in red and lateritic soil zones. The necessary amount of N, P, and K fertilizers should be applied for maintaining the observed critical levels of these three nutrients in fish pond soils.

To test the effects of maintaining the critical levels of the major nutrients on productivity levels, on-farm trials were carried out in 18 ponds located on nine fish farms representing different red and lateritic soil zones. The mean effect of the three pond productivity-limiting nutrients on GPP of pond

Table 2. Estimated economic return from the inputs used in the soil system-based pond management program.

	Traditional fertilization	Soil system-based fertilization
Inputs	- - - - - - - - - - Costs, Rs./ha - - - - - - - - - -	
N fertilizer	1,000	2,000
P fertilizer	2,500	5,000
K fertilizer	-	498
Lime	1,280	640
Total cost	4,780 A	8,138 B
Return	- - - - - - - - - - Income - - - - - - - - - -	
Fish yield, kg/ha	1,758	2,153
Gross return, Rs.30/kg	52,740	64,590
Net return over fertilization cost, Rs./ha	47,960 C	56,452 D
Added cost due to soil system-based fertilization, Rs./ha		3,358 (B-A)
Added benefit due to soil system-based fertilization, Rs./ha		8,492 (D-C)
Benefit-to-cost ratio	2.53	

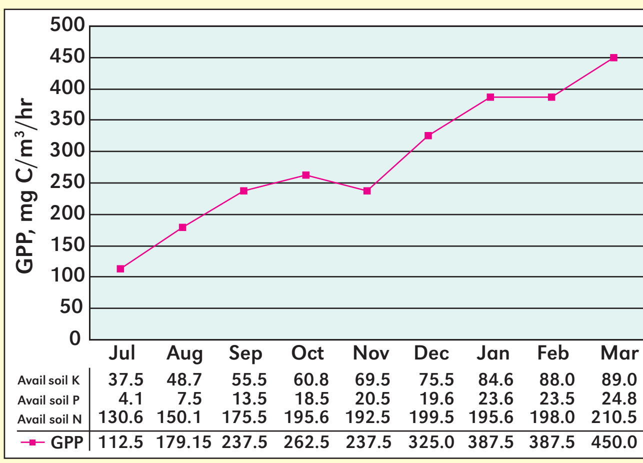

Figure 3. Variation in Gross Primary Productivity due to soil nutrient supply during the second year of study (Banerjee, 2005).

water are presented in **Figure 3**. Mean available P status attained its critical level in pond soils during September, after which the GPP values recorded an increasing trend. However, the availability of N and K were below this threshold limit during this period. Both of the nutrients neared the critical limits during November-December and GPP values exhibited a sharp increase owing to optimal presence of all the three productivity-limiting nutrients in the pond environment.

An approximate assessment of additional economic return from the proposed soil system-based pond fertilization, using local rates for different inputs and outputs, is presented in **Table 2**. Adoption of the proposed nutrient management program required an extra input cost of Rs.3,358/ha. However, this helped to produce an additional 395 kg fish/ha which under a conservative price of Rs.30/kg could fetch an ad-

Even with added input cost, an improved nutrient management program can have a very favorable benefit.

ditional income of Rs.8,492/ha of pond area. This resulted in an encouraging benefit-to-cost ratio of 2.53, supporting the developed this soil system-based pond productivity management program.

All these results show that a soil system-based approach to pond management involving identification of major productivity-limiting soil factors, determination of critical levels for relevant plant nutrients, and maintenance of those nutrients at adequate levels, may be considered as an effective proposition for increasing the productivity of fish ponds and improving the response of fertilizers in the aquatic ecosystem. BC

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