

APPLICATION OF SYSTEMS MODELS FOR EVALUATION AND OPTIMIZATION OF POND MANAGEMENT PRACTICES

Eighth Work Plan, Decision Support Systems Research 1C (DSSR1C)

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INTRODUCTION

One of the primary uses of aquaculture models is for the comparison of different methods of pond management in terms of the effects on fish yields, the economic efficiency of the production system, and the efficiency of resource use. Pond aquaculture models may thus provide opportunity to optimize production technology. In this report, we discuss the application of models developed by OSU-DAST researchers relevant to PD/A CRSP fertilization strategies and the optimization of feed application rates. These two application areas of the OSU-DAST models are different in terms of the problem scope and implications of model outcomes. Therefore, each application area is discussed separately in this report.

PD/A CRSP FERTILIZATION STRATEGIES

Based on PD/A CRSP research conducted over several years, two broad categories of fertilization strategies can be identified: "fixed input" and "responsive." The "fixed input" strategy is more prevalent and involves weekly additions of fertilizers at fixed rates. Recommended fixed input rates for individual CRSP sites have typically evolved over time on the basis of successive experiments that compared different rates of nitrogen (N) and phosphorus (P) additions to ponds. The second category of PD/A CRSP fertilization guidelines, collectively referred to as "responsive" strategies, involves assessment of ambient pond water conditions prior to estimating pond nutrient needs. These strategies include fertilization guidelines generated by computer models following measurements of pond nutrient concentrations (Lannan, 1993; Nath, 1996) and bioassays (Knud-Hansen and Guttman, in prep; Hopkins and Knud-Hansen, in press).

Fixed input strategies require substantial up-front costs to experimentally determine appropriate fertilization rates (Hopkins and Knud-Hansen, in press). They may also be unreliable for estimating fertilizer requirements at geographically different locations (Lannan, 1993; Hopkins and Knud-Hansen, in press) and they do not adequately account for short- and long-term changes in aquaculture ponds (Nath, 1996). Variation in nutrient availability during a single culture period is an example of a short-term change and the accumulation of nutrients (particularly P), which may subsequently serve as a good nutrient source in pond sediment, is a long-term change.

Previous work has demonstrated that responsive strategies typically result in lower fertilization rates compared to fixed input strategies (Hopkins and Knud-Hansen, in press; Nath et al., 1997). Hopkins and Knud-Hansen (in press) also estimated fertilization efficiency in an experiment conducted in Thailand that compared Nile tilapia (*Oreochromis niloticus*) ponds managed under three different regimes. Fertilization guidelines developed from the bioassay method, PONDCLASS, and the traditional fixed input rates for that location were compared. Fertilization efficiency was evaluated in terms of the percentage of fertilizer N and P recovered in the harvested fish. This index is a useful way of comparing various fertilization strategies, because it also provides some indication of the amounts of N and P that may accumulate in the pond water and sediment. For instance, a recovery rate of 20% for P implies that roughly 80% of the P added in the form of fertilizers accumulated in the pond environment or was released (e.g., when ponds are drained for harvest). Such simple indices of production efficiency are particularly important for complex pond systems

for which the establishment of detailed nutrient budgets is tedious and expensive (because of the need for frequent water and sediment quality measurements) and, therefore, not practical under most circumstances.

Results of an experiment conducted at the Asian Institute of Technology (AIT) provide convincing evidence regarding the efficacy of responsive fertilization strategies in terms of cost and fertilizer use efficiency (Hopkins and Knud-Hansen, in press). It is not known, however, whether similar trends occur at other CRSP locations or even for other experiments in Thailand. Therefore, the focus of this study was to undertake a comparative analysis of fixed and responsive fertilization strategies for three CRSP sites, in Honduras (El Carao), the Philippines Freshwater Aquaculture Center (FAC), and Thailand (AIT).

Data Sources

Fertilizer application rates, fertilizer composition data, and fish growth information for experiments that compared fixed input rates with fertilization guidelines generated by the use of PONDCLASS were extracted from the PD/A CRSP Central Database for all three sites mentioned above. The total amounts of fertilizer N and P added to each of the two treatments (fixed input and PONDCLASS) averaged across ponds, were estimated according to their respective application rates and fertilizer compositions reported in the Database. Recovery of fertilizer N and P in fish flesh was calculated assuming a tilapia composition of 9.5% N, 2.4% P and 76% moisture (Tan, 1971 as cited by Hopkins and Knud-Hansen, in press). Cost efficiency was estimated as the cost of fertilization per kilogram of fish produced.

An additional assumption in the fertilizer calculations for El Carao and AIT (where manure was used) was that only 50% of the total N and 75% of the total P in chicken manure becomes available in ponds following fertilizer application (Nath, 1992). Fertilizers used in the PONDCLASS experiments at El Carao included chicken manure (CM), urea, and diammonium phosphate (DAP), which cost 0.016, 0.28 and 0.33 US\$ kg⁻¹, respectively (Molnar et al., 1996). At AIT, available fertilizers were CM, urea, and triple superphosphate (TSP), with respective costs of 0.01, 0.27 and 0.47 US\$ kg⁻¹ (Molnar et al., 1996). At FAC, urea and a N:P:K (16-20-0) mixture were the fertilizers used in the PONDCLASS experiments, with respective costs

of 0.29 and 0.30 US\$ kg⁻¹ (Hopkins, K., personal communication).

RESULTS AND DISCUSSION

Total N and P additions, net fish yields, and fertilization efficiency in terms of nutrient recovery and costs for the fixed and responsive fertilization strategies are summarized in Table 1. Data from Hopkins and Knud-Hansen (in press) are also presented in this table for comparative purposes.

With the exception of the 1994 experiment in Thailand, responsive fertilization strategies were three to seven times more efficient in terms of P recovery compared to the corresponding fixed input strategies. This translated into P application rates that were 3.5 to 5 times lower than the commonly recommended fixed inputs at a particular location. Differences in the efficiency of N recovery were not as striking (Table 1). However, with the exception of the Honduras experiment, efficiencies of N recovery in the responsive strategies were slightly higher than, or comparable to, the fixed input strategies.

Net fish yields for the fixed input treatments were in general higher than the responsive strategies' yields (with the exception of the Philippines) (Table 1). However, in terms of practical fish production, it is the cost efficiency (i.e., fertilizer costs per unit of fish produced) and not the highest yield that is important. When this index of comparison is used (Table 1), responsive fertilization strategies were 1.5 to 3 times more efficient than fixed input strategies for the experiments conducted in the Philippines and Thailand. For Honduras, the PONDCLASS and fixed input strategies were comparable in terms of cost efficiency.

In the 14th Annual Report (Nath et al., 1997), we indicated that substantial changes had been made to the PONDCLASS fertilization model based on results of the Global Experiment for the Seventh Work Plan. This new approach has been implemented in the POND[®] software. Comparisons among the fixed input, PONDCLASS, and POND[®] fertilization guidelines were undertaken for CRSP sites in Honduras, the Philippines, and Thailand (see Nath, 1996 for details). Results for the Philippines are presented in Figure 1, where it is evident that fertilizer N recommendations obtained by the use of POND[®] are more conservative than

Table 1. A comparison of the total fertilizer inputs over the experimental period, fertilization efficiency use (i.e., fertilizer N and P recovered in fish), net fish yields (NFY), and cost efficiency for fixed and responsive fertilization strategies (PONDCLASS and Bioassay) at three different CRSP locations.

Site	Regime	Inputs (kg ha ⁻¹)		% Recovered in Fish		NFY (kg ha ⁻¹ yr ⁻¹)	Cost Efficiency (\$ per kg fish)
		N	P	N	P		
El Carao, Honduras ^a	Fixed	522	216	11.8	7.2	6975	0.19
	PONDCLASS	609	42	7.8	28.7	5425	0.20
FAC, Philippines ^a	Fixed	464	94	5.2	6.5	3168	0.51
	PONDCLASS	534	26	4.7	24.0	3259	0.35
AIT, Thailand 1992-93 ^b	Fixed	493	255	9.8	4.8	6463	0.42
	PONDCLASS	408	54	8.3	15.6	4491	0.15
	Bioassay	408	32	9.2	29.4	5022	0.20
1994 ^a	Fixed	588	147	7.7	7.8	4781	0.35
	PONDCLASS	426	141	10.4	7.9	4681	0.20

^a Data extracted from the PD/A CRSP Central Database.

^b Data from Hopkins and Knud-Hansen, in press.

those for PONDCLASS (N addition tended to be excessive). Both POND[®] and PONDCLASS generate fertilizer P recommendations that are much lower than the traditional fixed input rate used in the Philippines (Figure 1).

Results from the comparative analysis of fixed and responsive fertilization strategies clearly demonstrate that the latter are typically much more cost efficient. The higher percentage of nutrients recovered in fish flesh indicates that the use of responsive fertilization strategies will likely lead to reduced accumulations of nutrients (particularly P) in the pond environment. In terms of P application rates, it appears that CRSP ponds managed using fixed input strategies are receiving much more fertilizer P than is necessary for high algal and fish production. It is not clear whether this finding is due to P that has accumulated in pond sediments over the past few years of fertilization (and is now being returned to the water column) or whether there has always been an over-supply of P from the fixed input strategies. Both possibilities merit further investigation, because excessive nutrient addition is economically wasteful and may have undesirable environmental consequences. In any event, our analysis suggests that there is a need to re-evaluate the present rates

of N and P additions recommended for each of the sites tested. It is also necessary to conduct field experiments to test the guidelines generated by the refined POND[®] fertilization model at different CRSP locations so that the resulting information can be used to fine-tune the responsive fertilization strategy.

One drawback of responsive fertilization strategies is that they require routine (weekly or biweekly) assessment of fertilizer needs (either in the form of water collection and incubation, as in the bioassay method, or water quality analysis, as in the computerized approaches). It may also be necessary to adjust fertilizer application rates on a pond-by-pond basis. Weekly or biweekly assessments are difficult to circumvent because the very strength of responsive strategies is that they modify fertilization rates in accordance with changes in pond water quality. However, it may be possible to assess fertilizer needs on a monthly basis and use the fertilizer recommendations obtained at that point for the following four weeks (assuming that fertilizer addition occurs once a week). This can be accomplished by examining the sensitivity of responsive strategies to different time intervals of water quality assessment in an experimental setting.

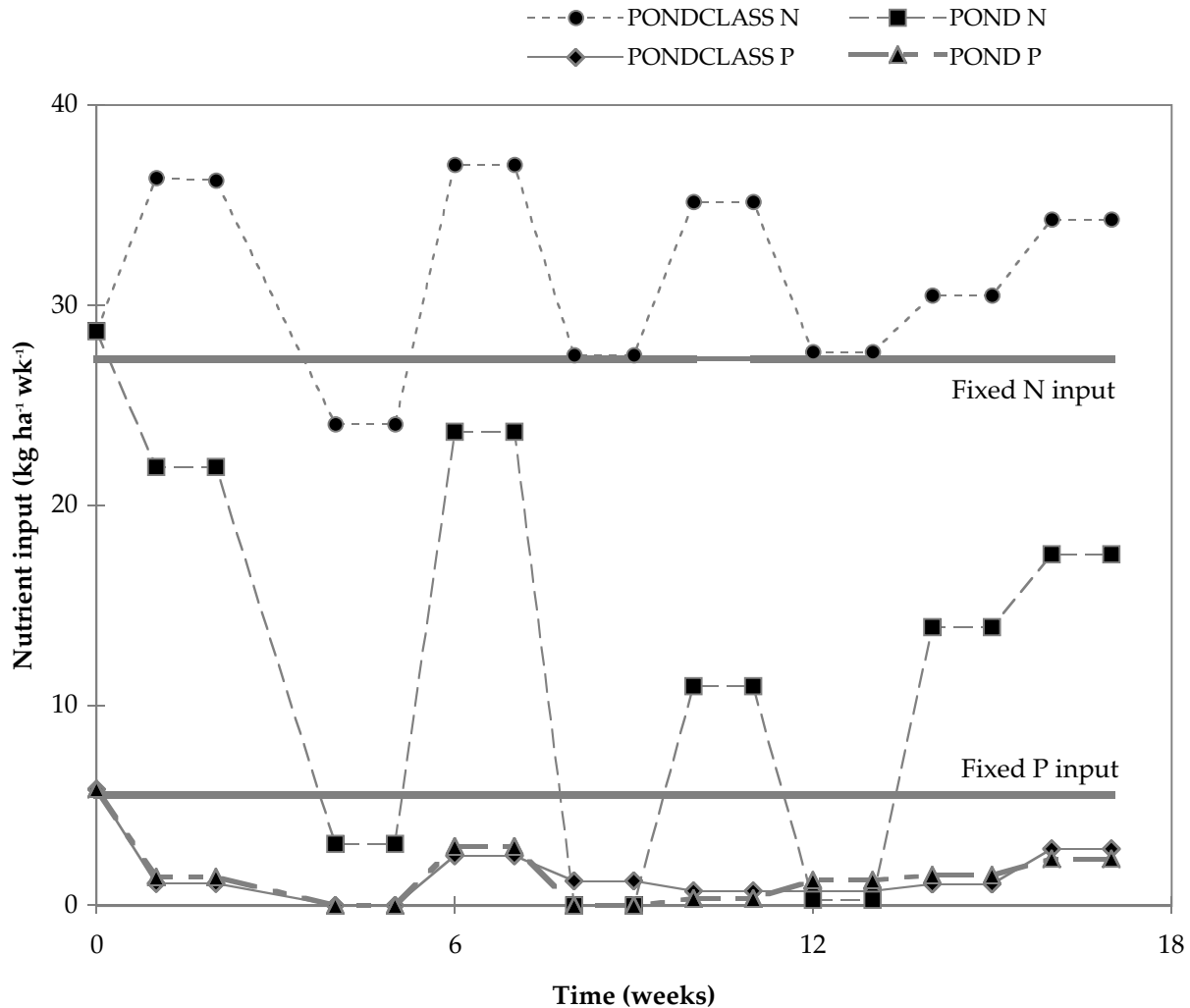


Figure 1. Weekly nutrient N and P inputs for experiments at the Freshwater Aquaculture Center (FAC) in the Philippines that correspond to fixed input (straight lines) and PONDCLASS fertilization rates. Simulated rates generated by the use of POND® are also shown.

The adjustment of fertilization application rates for individual ponds required with responsive fertilization strategies may not be a significant drawback for small, tropical ponds for which labor is relatively inexpensive and fertilizer is manually applied. However, for highly mechanized operations such as the baitfish industry in the US, this drawback assumes significant proportions because of the following reasons (Stone, N., personal communication):

- Labor costs are generally high;
- Fertilizers are typically applied by the use of mechanical devices which do not easily lend themselves to custom mixes of N and P for individual ponds; and
- The cost of fertilizers in the US is relatively low compared to other variable costs.

We are currently exploring the possibility of developing an expert system which takes into account geographical information (e.g., seasonal temperature and solar radiation profiles) and general pond characteristics (alkalinity, soil type, pond history, etc.) to generate preliminary estimates of fertilization rates in conjunction with the POND® models. These estimates can subsequently be fine-tuned under field conditions. Such an expert system may also be useful in providing estimates of the upper limit of algal productivity for different geographic locations. This information could perhaps be

used together with the bioassay technique under field conditions to predict fertilizer application rates that are appropriate for the site under consideration.

OPTIMIZATION OF FEED APPLICATION RATES

Feeds often represent the single largest component of variable costs to an aquaculture facility. Therefore, estimating the minimum amount of feed required to reach a specified target size within an acceptable period of fish culture is likely to be beneficial to pond managers, planners, and researchers.

Development of the Optimization Methodology

Bolte and Nath (1996) demonstrated the use of an adaptive, non-linear search technique (genetic algorithms or GAs) to automatically calibrate the POND® fish growth model. We are currently experimenting with GAs as an optimization tool in POND® for estimating feed requirements.

The goal of the POND® feed optimizer is essentially to generate feeding schedules (expressed on a percent satiation basis) that enable a user-specified, target fish size to be reached with the minimum amount of feed. GAs involve the evaluation of populations of solutions based on principles of natural selection (i.e., individuals with higher fitness have a higher probability of being selected into the next generation) over a specified number of generations, until a highly evolved population results (see Holland, 1975; Michalewicz, 1992 for further details). The final population consists of suitable solutions to the problem on hand.

In the POND® feed optimizer, an “individual” (feeding schedule) corresponds to a list of feeding levels that are expected to be changed every four weeks, for the entire culture period. Thus, for a culture period that lasts 28 weeks, a single “individual” in a population consists of seven monthly feeding levels. The “fitness” of an “individual” is the total amount of feed added over the culture period, with a higher fitness level corresponding to lower amounts of feed.

The search procedure consists of the following steps:

1. Create an initial population of individual feeding levels (typically 20).
2. POND® automatically executes fish growth simulations with this population.
3. Evaluate the ‘fitness’ of individuals in the population.
4. Generate a new population using ‘crossover’ (exchanging feeding levels between two individuals) and ‘mutation’ (randomly changing one or more feeding levels in an individual) operators.
5. Repeat steps two through four above until the specified number of generations is reached (typically 15). The individual with the greatest fitness represents the feeding strategy that requires the least amount of feed for fish to attain the specified target size.

Currently, the feed optimizer in POND® is being tested and evaluated. Preliminary trials were conducted wherein feed requirements were estimated for the culture of the African catfish (*Clarias gariepinus*) under two conditions: feeding to full satiation and feeding according to the optimal schedule generated by the use of the GA-based optimizer. In the latter, it was assumed that acceptable feeding levels ranged from 75 to 100% satiation. Stocking densities were two fish m⁻² and fish weight was 50 g. Fish were assumed to be stocked on January 1 and harvested no later than April 30. The target fish weight was set at 400 g. Daily mortality was assumed to be 0.1%. Feed composition was assumed to be as follows: moisture content (10%), gross energy (3.6 kcal g⁻¹), and protein level (30% on a dry matter basis).

Optimization Results and Discussion

Under simulation conditions of satiation feeding, the target fish weight was attained in a 100-d culture period, whereas feeding at rates suggested by the GA-based feed optimizer resulted in the target weight being reached in 117 d. Production parameters are summarized in Table 2. Net fish yield under satiation feeding was predicted to be higher than that for fish fed according to the schedule generated by the GA. This is because the number of fish at harvest as predicted by POND® was higher for satiation feeding (Table 2), a result of the shorter culture period and the assumption of a uniform daily fish loss due to mortality.

Feeding rates (expressed as % satiation) corresponding to the best feeding solution obtained by the GA (Figure 2) indicate that the optimizer recommended rates that increased according to fish weight. The rate of increase also

Table 2. A summary of African catfish (*Clarias gariepinus*) production parameters for POND® simulations wherein fish were fed to satiation and according to the “optimal” feeding schedule generated by the GA.

Feeding Schedule	Culture Duration (d)	Net Fish Yield (kg ha ⁻¹)	Feed Requirements (kg ha ⁻¹)	Food Conversion Ratio
Satiation	100	6103	9400	1.55
Optimal	117	5905	8857	1.49

increased with time. Because comparative results under actual pond management conditions are not available, it is difficult to judge whether such results are realistic. More likely than not, it would appear that the use of very high feeding rates at high fish biomass levels would adversely affect growth because of the effects on water quality. These effects are not captured in the present version of the feed optimizer, but it may be possible to introduce them in the form of ‘penalty functions’ which reduce the fitness of individuals that require high feeding rates when fish biomass is high. The effect of such penalty

functions would reduce the probability that these individuals enter a new generation of the GA-based optimizer.

Overall feed requirements generated by the GA-based optimizer were about 550 kg less than those predicted under satiation feeding conditions (Table 2). Although this difference potentially represents substantial savings (depending on local feed costs), model outputs must also be evaluated in terms of the operating costs that are required to hold fish for the additional 17 days and the value

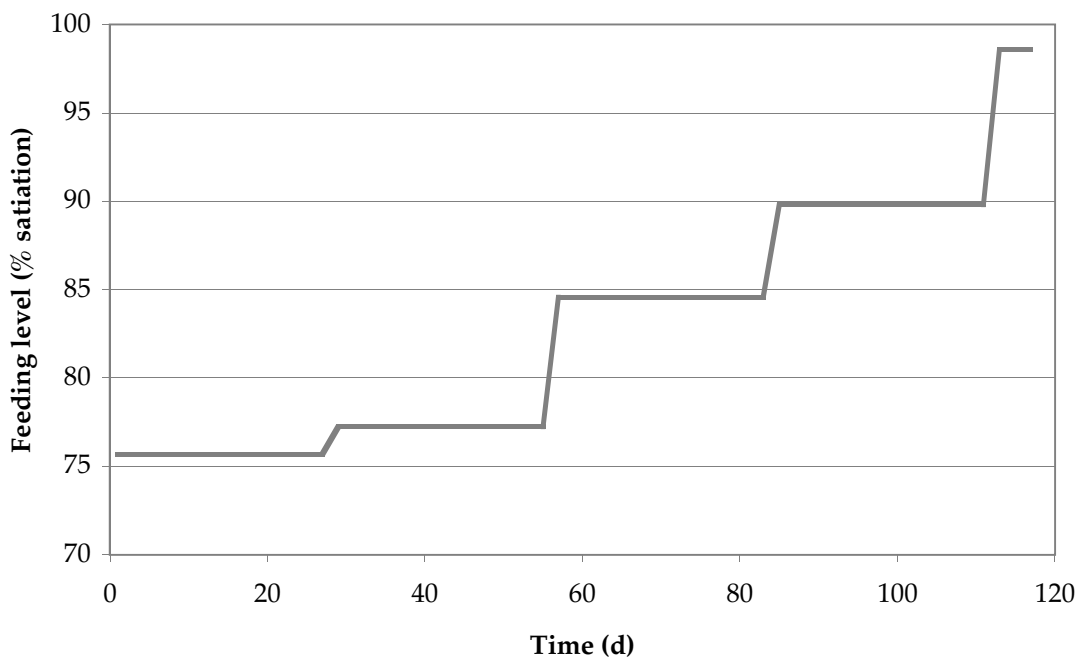


Figure 2. Feeding levels for the optimal solution generated by the GA-based feed optimizer in POND®. The levels reflect feeding rates that are fixed for four week intervals.

of the higher yield predicted under satiation feeding conditions. In other words, optimizing feed usage *per se* may not generate outcomes that are economically optimal for the overall enterprise. This suggests that similar types of model-based optimization studies should perhaps take into account the overall costs and benefits of production. This can be accomplished within the GA-based optimization framework by modifying the 'fitness' function to reflect such costs and benefits. As an example, minimization of the variable cost of producing one unit of fish may be an alternative fitness function. Our future work will focus on this area of facility-level optimization.

The other area of research that we believe would be beneficial to the overall CRSP effort of developing efficient pond aquaculture systems is to continue to more closely link modeling with field research efforts. The benefits of comparing model-recommended guidelines to those traditionally used at the three different CRSP sites are clearly demonstrated for fertilized systems in this report. Similar benefits can be expected if the newer POND® models/optimization techniques and their outputs are subjected to comprehensive testing in the field.

ANTICIPATED BENEFITS

Optimization of feed and fertilizer additions supporting pond aquaculture production enhances the profitability of pond facilities and reduces excess resource consumption. Models such as POND® perform a rational analysis of feed and fertilization strategies to determine the effect of different management strategies which consequently lead to the development of optimal management regimes. Such analyses benefit producers and planners in developing management regimes which provide the maximum benefit to the facility, in terms of enhanced profitability, and to the environment, in terms of reduced effluent discharge of unutilized production inputs.

LITERATURE CITED

- Bolte, J.P. and S.S. Nath, 1996. Decision support for pond aquaculture: Parameter estimation techniques for simulation models. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report 1995, Pond Dynamics/ Aquaculture Collaborative Research Support Program, Office of International Research and Development, Oregon State University, Corvallis, Oregon, pp. 62-67.
- Holland, J.H., 1975. *Adaptation in Natural and Artificial Systems*. University of Michigan Press, Ann Arbor, 183 pp.
- Hopkins, K.D. and C.F. Knud-Hansen, in press. Comparison of three fertilization strategies: algal assay, nutrient concentration and fixed input. *J. World Aqua. Soc.*
- Knud-Hansen, C.F. and H. Guttman, in prep. An algal bioassay method for pond fertilization.
- Lannan, J.E., 1993. *Users Guide to PONDCLASS: Guidelines for Fertilizing Aquaculture Ponds*. Pond Dynamics/ Aquaculture Collaborative Research Support Program, Office of International Research and Development, Oregon State University, Corvallis, 60 pp.
- Michalewicz, Z., 1992. *Genetic Algorithms + Data Structures = Evolution Programs*. Springer-Verlag, Berlin, 250 pp.
- Molnar, J.J., T.R. Hanson, and L.L. Lovshin, 1996. Social, economic and institutional impacts of aquacultural research on tilapia: The PD/A CRSP in Rwanda, Honduras, the Philippines, and Thailand. Research and Development Series No. 40, International Center for Aquaculture and Aquatic Environments, Alabama Experimental Station, Auburn University, Alabama, USA, 72 pp.
- Nath, S.S., 1992. Total and available nutrients in manures for pond aquaculture. M.S. Thesis, Oregon State University, Corvallis, Oregon, USA, 67 pp.
- Nath, S.S., 1996. Development of a decision support system for pond aquaculture. Ph.D. dissertation, Oregon State University, Corvallis, Oregon, USA, 273 pp.
- Nath, S.S., J.P. Bolte, and D.E. Ernst, 1997. Applications of POND® as a tool for analysis and planning. In: D. Burke, B. Goetze, D. Clair, and H. Egna (Editors), Fourteenth Annual Technical Report 1996, Pond Dynamics/ Aquaculture Collaborative

Research Support Program, Office of International Research and Development, Oregon State University, Corvallis, Oregon, pp. 38-54.

Tan, Y.T., 1971. Proximate composition of freshwater fish—grass carp, *Puntius goniotus* and Tilapia. *Hydrobiologia*, 37:361-366.