RESEARCH REPORTS
TITLE XII POND DYNAMICS/AQUACULTURE COLLABORATIVE RESEARCH SUPPORT PROGRAM

Managing Fertilizers for Fish Yield in Tropical Ponds in Asia

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ABSTRACT

The purpose of this work was to develop a strategy for fertilizer application that improved predictions of yields. Pond productivity was analyzed relative to supplies of dissolved inorganic carbon (DIC), dissolved inorganic nitrogen, and dissolved reactive phosphorus. Phosphorus did not limit pond production in any of the treatments used. Algal productivity and yield of male Nile tilapia (*Oreochromis niloticus* Trewavas) were limited by DIC when low alkalinity ponds were fertilized with chicken manure or triple superphosphate and urea. In high alkalinity ponds with adequate DIC, nitrogen limited production when chicken manure was added. This was corrected with additions of urea. Fertilizer costs per kg of yield were US$0.07 for the chicken manure treatment and US$0.06 for the chicken manure + urea treatment.

The Pond Dynamics/Aquaculture CRSP gratefully acknowledges the Asian Fisheries Society for allowing this paper to be reproduced in Research Reports. This paper originally appeared in The Second Asian Fisheries Forum, Proceedings of the Second Asian Fisheries Forum, Tokyo, Japan, 17-22 April 1989, Manila, Philippines, pp. 169-192.

Introduction

Modern variations of the ancient practice of fertilizing ponds to increase the yield of fish have been considered by Schroeder (1974), Almazan and Boyd (1978), Stickney (1979), Seymour (1980) and others. There is general agreement in this work that a significant portion of increased fish yield following the successful use of fertilizer is due to the growth of algae, and the transformation of algae to fish flesh through food webs of ponds. In this paper we examined the relationships between carbon, phosphorus, nitrogen and algae growth in fertilized ponds, and algae growth and yield of *Oreochromis niloticus*. The work was done at the Babakan Fisheries Station of Institut Pertanian Bogor in Indonesia (6.6°S 106.1°E), and the Bang Sai Station of the Royal Thai Department of Fisheries near Ayutthaya in Thailand (14.2°N 100.5°E). Our approach to obtaining predictable fish yields was to manage algal productivity and, presumably, abundance in the overall food web of fish, by using fertilizers to meet the requirements algae have for carbon, phosphorus and nitrogen in an approximate ratio of 1:7:40 by weight (Round 1973; Vallentyne 1974; Wetzel 1983).

Materials and Methods

Three sets of data are presented. Treatments in the first two sets were not conducted simultaneously. They were selected from work done with fertilizers between 1985 and 1988 in the relatively constant year-around environment of the wet tropics (McNabb et al. 1988). Treatments in the third set of data were conducted simultaneously as part of the same experiment in 1988.

There were three fertilizer treatments in the first set of data. Three ponds were used in each treatment. Chicken manure was added at a rate of 125 kg/ha/wk in one treatment, and 250 kg/ha/wk in another. In the third treatment, triple superphosphate and urea were added at rates of phosphorus and nitrogen that were equivalent to the addition of 500 kg chicken manure/ha/wk. Chicken manure averaged 2.5% phosphorus and 1.7% nitrogen by dry weight. *Oreochromis niloticus* fingerlings, weighing between 40 and 50 g each, were hand selected for males. These were planted at a density of one fish per m^2 of pond surface. Growout periods were between 147 and 149 days.

Measurements of algal productivity and amounts of inorganic carbon, dissolved reactive phosphorus and dissolved inorganic nitrogen (NH_3-N + NO_2-N + NO_3-N) were made in ponds at the beginning of treatments and every four weeks thereafter. The adequacy of supplies of phosphorous and nitrogen in ponds relative to requirements of growing algae was analyzed by the procedures of Yusoff and McNabb (1989). Ponds were drained at the end of growout periods, and fish were collected and weighed to provide data on yields.

The second set of data dealt with potential limitation of carbon, phosphorus and nitrogen on algae growth where ponds were fertilized at the same rates with phosphorus and nitrogen. Dissolved inorganic carbon (DIC) at dawn was the independent variable in a total of five treatments. Mean alkalinities ranged from 21 to 124 mg $CaCO_3$/L. Three or four ponds were used in each treatment. Treatments varied in length from 4 to 5 months. Ponds were fertilized with chicken manure at a rate of 500 kg/ha/wk, or an equivalent mass of phosphorus and nitrogen as triple superphosphate + urea. In each case, phosphorus and nitrogen were added to ponds at rates of 12.5 and 8.5 kg/ha/wk respectively. Sampling procedures, parameters measured in ponds, and methods used for analyses were the same as those described above.

The third set of data examined the question of fertilizer loading rates needed to obtain predictable fish yields from productivity of algae and food web organisms in ponds where DIC was high and not limiting to algae. Pond size, operating depth, types of measurements, and procedures for obtaining data were as described above. Four ponds were used in each of two treatments. In the first treatment, chicken manure was applied at a rate of 500 kg/ha/wk. Chicken manure used was 4.1% phosphorus and 2.5% nitrogen by dry weight. In the second treatment, chicken manure was applied at a rate of 44 kg/ha/wk, and urea was added at 25 kg/ha/wk. Nitrogen in the chicken manure + urea equaled the nitrogen in 500 kg/ha/wk of chicken manure applied in the first treatment. Also, the amount of phosphorus in the chicken manure in the second treatment was such that the P:N ratio in fertilizers for that treatment was 1:7 by weight. *Oreochromis niloticus* male fingerlings of approximately 20 g each were planted at a density of two per m^2. A growout period of 124 days was used. A detailed economic assessment of these treatments was done. In this paper, treatments were compared in terms of fertilizer costs per unit weight of fish harvested.

Results

The first set of data is summarized in Table 1. Each of the three treatments resulted in low algal productivity and low fish harvest. DIC at dawn was also low, ranging from 5-6 g C/m^2 (alkalinity 21-28 mg $CaCO_3$/L). The nutrient analysis showed that greater amounts of both phosphorus and nitrogen were present on the average in ponds than were required to meet the daily net production needs of the algae. This result was unexpected if either phosphorus or nitrogen were limiting. The data suggest that inorganic carbon, some other nutrient, or perhaps light was limiting algae and subsequent fish production in these treatments.

Ponds in the second set of data were at five different levels of DIC. The relationship in these ponds between net algal productivity and DIC at dawn is shown in Figure 1. It is evident there that algal productivity increased linearly as DIC increased at low concentrations between about 5 and 7 g/m^2 (alkalinities between 20 and 33 mg $CaCO_3$ /L). Calculations like those in Table 1 showed that phosphorus and nitrogen were abundant in treatments I, II and III. Given this, the steep linear increase in algal productivity with increasing DIC in treatments I, II and III suggest that algal productivity was limited by inorganic carbon at low concentrations of DIC. It is also clear that algal productivity tended toward an asymptote at concentrations of DIC above 7 g/m^2. Calculations showed that phosphorus was abundant in this portion of the curve, but that nitrogen was in very short supply in treatments IV and V. We concluded that algae in ponds in treatments IV and V were limited by nitrogen.

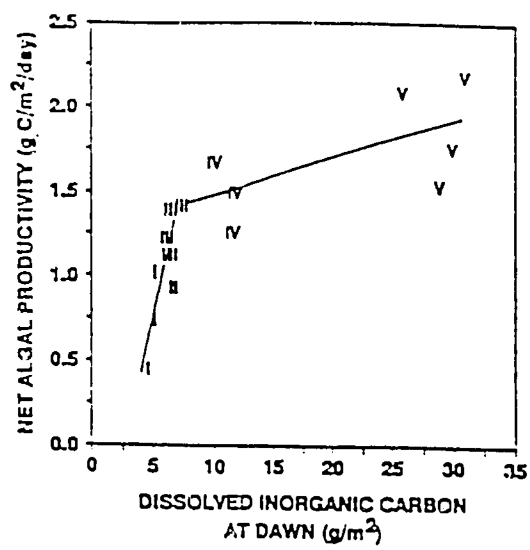

Figure 1. Relationship between inorganic carbon and net algal productivity in ponds loaded at a rate of 500 kg/ha/wk chicken manure. Roman numerals designate means for individual ponds within a treatment.

Table 2 contains data from an experiment designed to test this conclusion. Four ponds with high DIC (25-29 g/m^2, alkalinities of 105 and 124 mg $CaCO_3$ /L, respectively) were used in each of two treatments. Chicken manure was applied at 500 kg/ha/wk in the first treatment. The nitrogen in that chicken manure was matched in the second treatment by weekly additions of 44 kg/ha chicken manure plus a urea supplement. This fertilization scheme resulted in a 1:7 ratio of P:N in the fertilizers added in the second treatment. Given nitrogen was indeed limiting in these ponds at rates of chicken

Table 1. Productivity and nutrients in fertilized ponds that had low amounts of dissolved inorganic carbon (DIC). NP is for net algal daytime productivity.

Treatment	NP (g C/m²/day)	Fish Harvest (kg/ha)	DIC at Dawn (g C/m²)	Nutrient Analysis* Required/Present (g P/m²)	Nutrient Analysis* Required/Present (g N/m²)
125 kg/ha/wk dry chicken manure	0.82	780	5	0.02/0.07	0.14/0.19
250 kg/ha/wk dry chicken manure	0.86	990	6	0.02/0.11	0.15/0.21
TSP and urea at P and N equal to 500 kg/ha/wk dry chicken manure	0.70	890	5	0.02/0.15	0.12/0.51

* Required is based on NP g C/m^2/day and a P:N:C algal growth requirement of 1:7:40. Present is mean concentration of dissolved phosphorus (P) and inorganic nitrogen (N) in pond water.

manure addition of 500 kg/ha/wk as previously suggested, we predicted that algal productivity and subsequent fish yield would be the same in both treatments. Data in Table 3 confirmed that prediction where mean algal productivities and fish harvest were not significantly different between treatments: $p = 0.35$ for productivities and 0.54 for fish harvests. It can also be noted in Table 2 that phosphorus and nitrogen in ponds in the second treatment were closely balanced, on the average, with needs of algae for growth. Importantly, fertilizer costs per kg of fish yield were found to be nearly the same for the two treatments: US$0.07 and US$0.06 in the first and second treatments, respectively.

Discussion

Daily requirements of algae for phosphorus and nitrogen were calculated in this paper from daily net primary productivity and a reported 1:7 ratio of these nutrients needed for growth (Round 1973; Vallentyne 1974; Wetzel 1983). Mean concentrations of dissolved reactive phosphorus and dissolved inorganic nitrogen in ponds were then compared to daily algal requirements to discriminate between conditions of abundance and nutrient limitation. This approach used those forms of both nutrients that are mostly readily taken up by algae from the pool of total phosphorus and total nitrogen present in ponds (Goldman and Horne 1983). Yusoff and McNabb (1989) used algal bioassays in conjunction with this procedure. Algal productivity was not limited in their ponds when required amounts of these nutrients were approximately equal to or greater than amounts present. Algal productivity was limited when concentrations of dissolved reactive phosphorus and dissolved inorganic nitrogen were at least four to six times less than daily requirements. From this and data in this paper, we concluded that phosphorus was not limiting in any of our treatments.

A non-limiting supply of nitrogen, as well as phosphorus, was present on the average in ponds that we used for the first set of data (Table 1). However, net algal productivities and fish yields were lower than expected for well managed ponds. They ranged from 0.70-0.86 g C/m²/day and 780-990 kg/ha with 148 day growouts respectively. For comparison, Hepher (1962) reported net algal productivity on the order of 2.9 g C/m²/day during warm summer months in Israel when pond temperatures were similar to temperatures of ponds used here (30°C). DeMaeseneer (1984) cites production of 2000 kg/ha/yr for tilapia in tropical subsistence ponds. Productivity in ponds in Indonesia used for Table 1 appeared limited by some factor other than the phosphorus or nitrogen supplied in fertilizers.

McNabb et al. (1988) assessed light as a limiting factor in tropical aquaculture ponds. Their work suggested that some factor other than light limited productivity in ponds in the first set of data. There is strong inference in our work that limitation on pond production in the first data set was due to inadequate supplies of dissolved inorganic carbon.

Table 2. Influence of nitrogen on productivity in fertilized ponds that had high amounts of dissolved inorganic carbon (DIC). CM in treatment column is for dry chicken manure. NP is for net algal daytime productivity.

Treatment	DIC at Dawn (g C/m²)	Nutrient Loading (kg/ha/wk) P	N	NP (g C/m²/day)	Fish Harvest (kg/ha)	P and N Relationships* Required/Present (g P/m²)	Required/Present (g N/m²)
500 kg/ha/wk CM (P:N at 1:0.6)	29	21	12	1.84	1205	0.05/0.19	0.32/0.12
44 kg/ha/wk CM	25	1.7	1	2.27	1435	0.06/0.03	0.40/0.41
+							
urea at 25 kg/ha/wk (P:N at 1:7)			11				

* Amounts of phosphorus (P) and nitrogen (N) required and present calculated as in Table 1.

In fact, carbon limitation appears to have occurred in all cases where chicken manure (2.5% phosphorus and 1.7% nitrogen), or equivalent amounts of phosphorus and nitrogen as triple superphosphate and urea, were applied at 500 kg/ha/wk or less to ponds with dissolved inorganic carbon in the range 5-7 g/m^2 at dawn (alkalinities 20-33 mg $CaCO_3$/L). Convincing evidence came from treatments I, II and III in the second set of data. At the same loading rate of chicken manure, and phosphorus and nitrogen contained therein, net algal productivity increased in a rapid, linear fashion as DIC increased from 5-7 g/m^2. The work of King (1970, 1972), King and Novak (1974), and Young and King (1980) predicts such a result in low alkalinity ponds where, as we have demonstrated, phosphorus and nitrogen were not limiting.

Manures, chicken manure included, are deficient in nitrogen relative to phosphorus and requirements algae have for these nutrients (Boyd 1982; Wetzel 1983). Addition of chicken manure to our ponds with adequate dissolved inorganic carbon promoted nitrogen deficiency because of this imbalance (Figure 1). Other manures are expected to cause the same problem. On the other hand, nitrogen in these fertilizers promoted carbon limitation in ponds with inadequate DIC. Thus, the quantity of DIC in ponds has the potential to profoundly influence growth responses of algae, food web organisms, and fish when manures are used. Data presented show that the same results are expected from triple superphosphate and urea used in proportions found in manures.

Results of the experiment in our third data set demonstrate the increased biological efficiency obtained by supplying phosphorus and nitrogen in fertilizers in a ratio appropriate for growth of organisms at the base of pond food webs. From our analysis of fertilizer costs, doing so was economical. Mean fish yield in the experiment was 1435 kg/ha using 44 kg/ha/wk chicken manure plus 25 kg/ha/wk urea. The growout period was 124 days using fingerlings averaging 20 g each at 2/m^2. We predict higher yields using the same proportions of these fertilizers at higher loading rates. Clearly, data presented show that assessments of carbon, phosphorus and nitrogen are all required to improve the level of predictability of results obtained from fertilizer applications. Reduction of inconsistencies associated with fertilizer use will result from this approach.

Acknowledgments

This research is a component of the Pond Dynamics/Aquaculture Collaborative Research Support Program (CRSP) supported by the U.S. Agency for International Development, Grant Nos. DAN-4023-G-SS-2074-00, DAN-4023-G-SS-7066-00, and DAN-4023-G-00-0031-00, and by contributions from Michigan State University, Institut Pertanian Bogor, the Royal Thai Department of Fisheries, the Asian Institute of Technology and Kasetsart University. We thank Ralph S. Beebe for his help in managing data for this paper. This is Michigan State University Experiment Station Publication No. 13154, and Pond Dynamics/Aquaculture CRSP Publication No. 91:37.

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2 December 1991 **CRSP RESEARCH REPORTS 91-37**

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RESEARCH REPORTS
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Published by the Program Management Office of the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP). The PD/A CRSP is supported by the U.S. Agency for International Development under Grant No.: DAN-4023-G-00-0031-00