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Application of limnology for efficient nutrient utilization in tropical pond aquaculture

C. F. Knud-Hansen, C. D. McNabb and T. R. Batterson

Introduction

Phosphorus, nitrogen and carbon have been key limiting nutrients on the forefront of eutrophication literature for more than four decades. Concepts developed by the limnological community regarding these nutrients and their cycles in aquatic environments are now becoming the basis for management of aquaculture systems, particularly those in which fertilizers are used to promote fish production. Animal wastes, with a long tradition of use in tropical aquaculture, represent an inexpensive source of organic carbon for detrital production through heterotrophic pathways, and soluble nitrogen and phosphorus for primary productivity. Depending on the species, fish will feed directly on attached or planktonic algae, detrital/fungal flocs, or smaller animals such as zooplankton and snails which feed on algae and detritus (Colman & Edwards 1987).

In most waste-fed systems, water quality degradation ultimately limits net fish yields (FY). Often as fertilization rates increase, inefficient nitrogen utilization together with daytime pHs exceeding 9.0 results in high unionized ammonia concentrations which reduce fish growth and survival (Colt & Armstrong 1981, Ruffier et al. 1981, Meade 1985). FY generally increases until high unionized ammonia concentrations and/or low morning dissolved oxygen concentrations become growth limiting (Fig. 1). For optimal fish yields, maximum food availability must be balanced with favorable pond water quality. This paper examines the role of nitrogen limitation in managing pond eutrophication in order to produce greater and more predictable fish yields.

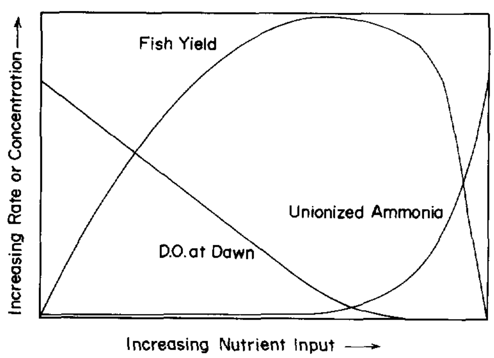

Fig. 1. Schematic representation of fish yield (FY) versus nutrient input where FY is limited by low dissolved oxygen and/or high unionized ammonia concentrations.

Methods

Nitrogen input and fish yield data utilized in this analysis came from research conducted in Indonesia and Thailand (for site description and analytical methods see Egna et al. 1987), and from other related published investigations. In all studies, Nile tilapia (*Oreochromis niloticus*), either alone or in polyculture with carp (common, silver and/or grass carp), were raised for 4–5 months in earthen ponds (surface areas of 0.02–0.04 ha, mean depths approximately 1 m) with 2 to 4 replicates per treatment. All ponds received either fresh or aged (> 1 week) chicken manure; some ponds also received inorganic N as ammonium sulphate or urea. Fertilizers were applied daily, weekly, or biweekly depending on the study. Daily mean total nitrogen loadings ranged from 0–0.70 $g \cdot m^{-2}$, except for one treatment of 1.92 $g \cdot m^{-2}$.

Results

Results showed that at nitrogen input rates below 0.2 $g \cdot m^{-2} \cdot d^{-1}$, fresh manure produced greater fish yields than aged manure (Fig. 2). As N loading from fresh manure exceeded about 0.4 $g \cdot m^{-2} \cdot d^{-1}$, FY decreased. FY surpassed 3.0 g fresh wt $\cdot m^{-2} \cdot d^{-1}$ when inorganic N was added in combination with manure at about 0.7 $g \cdot m^{-2} \cdot d^{-1}$, or about three times the yield from fresh manure alone at equivalent N input. Regression analysis gave quadratic relationships between FY versus fresh manure loading ($y = 0.72 + 3.08x - 11.01x^2$, $r^2 = 0.62$, $p < 0.1$) and manure + inorganic N ($y = 0.06 + 6.80x - 3.66x^2$, $r^2 = 0.94$, $p < 0.01$). The relationship between FY and aged manure was significantly linear ($y = 0.06 + 4.52x$,

0368-0770/91/0024-2541 $ 0.75

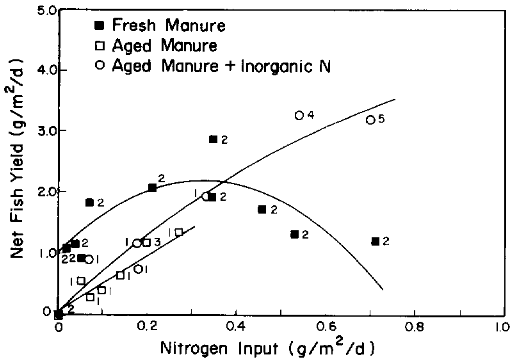

Fig. 2. Yield of Nile tilapia (and in polyculture (PC) where indicated) versus nitrogen input from chicken manure which was added fresh (■), aged (□), or aged and added with inorganic fertilizers (○). Numbers beside data points indicate source: 1 – this study; 2 – HOPKINS & CRUZ 1982 (PC); 3 – GREEN et al. 1989; 4 – MOAV et al. 1977 (PC); 5 – SCHROEDER & BUCK 1987 (PC).

$r^2 = 0.91$, $p < 0.01$) because fertilization rates were still relatively low. The regression equation for chicken manure plus inorganic N suggested that maximum fish productivity may reach over $4.0\,g \cdot m^{-2} \cdot d^{-1}$ when total nitrogen input is about $0.7-0.8\,g \cdot m^{-2} \cdot d^{-1}$. In 2 of the 4 ponds receiving $1.92\,gN \cdot m^{-2} \cdot d^{-1}$ unionized ammonia-N levels surpassed $2\,mg \cdot l^{-1}$, and all the fish died after three months; this treatment was not included in the regression.

Discussion

Higher FY observed with fresh versus aged manure at lower fertilization rates probably resulted from the higher percentage of soluble N in fresh manure. Diminished FY at higher fresh manure loading rates coincided with low dissolved oxygen concentrations at dawn, and increased manure-derived turbidity which limited primary productivity and caused high concentrations of unionized ammonia from reduced algal utilization (HOPKINS & CRUZ 1982).

In organically fertilized systems, detritus from manure decomposition may be an important dietary component for Nile tilapia (NORIEGA-CURTIS 1979, GREEN et al. 1989). But by substituting much of the manure-N with inorganic N, photosynthetic production was increased. Ponds were generally quite green (chlorophyll *a* concentrations exceeding $400\,mg \cdot m^{-3}$), and self-shading probably limited algal productivity. Based on the regression equation, maximum FY would be 4.1(± 0.3, 1 SE) $g \cdot m^{-2} \cdot d^{-1}$ at N loading rate of $1.15\,g \cdot m^{-2} \cdot d^{-1}$. Light limitation from high algal densities, however, would probably prevent complete N utilization at such high N input rates. At fertilization rates of at least $1.9\,gN \cdot m^{-2} \cdot d^{-1}$, water quality degradation may result in high and unpredictable fish mortalities.

Because efficient ammonia utilization reduces the risk of high unionized ammonia concentrations, nitrogen limitation is desirable. Tropical freshwaters, often naturally limited by nitrogen alone or nitrogen in combination with phosphorus (MOSS 1969, ZARET et al. 1981, MELACK et al. 1982, SETARO & MELACK 1984), can be made more nitrogen limited by the addition of manures (Table 1), which generally have N:P ratios well below the 7:1 ratio by weight required by algae (REDFIELD et al. 1963). When P fertilization exceeds algal requirements, additional nitrogen input can increase fish yields (BOYD 1976). Additional P input is necessary to maintain N limitation in ponds built in acid sulphate soils, common in the tropics, because of the soil's P sequestering capabilities (GAVIRIA, 1986, unpubl. data). FY of $5\,g \cdot m^{-2} \cdot d^{-1}$ or greater may be possible by increasing organic and inorganic N input while maintaining N limitation through effective addition of other nutrients like P. Pond aeration to reduce nocturnal oxygen deficits may further promote fish yields.

In many tropical Asian countries, where fish represent over 50 % of the total animal protein consumed and yields of wild fish are dwindling from overfishing and environmental degradation, increasing food production through fish cultivation is the primary strategy for managing aquatic resources (EDWARDS 1983). 1985 data from Thailand show that 36,500 pond/paddy fish farms totalling 13,000 ha produced 46,000 metric tons with a commercial value of US $50.8 million (Dept. of Fisheries 1987). Better understanding of limnological processes such as nutrient cycling, sediment/water interactions and trophic dynamics

Table 1. Representative nitrogen (N) and phosphorus (P) concentrations (as dry wt) of different manures used for pond fertilization.

Manure	% N	% P	N:P ratio	Source
Chicken	1.4	2.2	0.6:1	This study
Cow	1.5	0.6	2.5:1	GREEN et al. 1989
Duck	4.4	1.1	4.0:1	A. I. T. 1986
Buffalo	1.4	0.2	7.0:1	A. I. T. 1986

should help determine optimal fertilization and waste recycling schemes, thereby aiding developing nations to produce food with greater ecological and financial efficiency.

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Authors' addresses:

C. F. Knud-Hansen, Asian Institute of Technology, Agr. and Food Engineering, G. P.O. Box 2754, Bangkok 10501, Thailand.
C. D. McNabb and T. R. Batterson, Department of Fisheries and Wildlife, Michigan State University, East Landing, Michigan 48824, USA.