Aquaculture and Fisheries Management 1993, **24**, 483–493

The role of chicken manure in the production of Nile tilapia, *Oreochromis niloticus* (L.)

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Abstract. Two grow-out experiments were conducted to evaluate the functional role of chicken manure for Nile tilapia, *Oreochromis niloticus* (L.), production in central Thailand. Experiment 1 examined the relationship between chicken manure input and net fish yield (NFY). Experiment 2 determined the value of chicken manure in providing tilapia particulate organic carbon, and/or dissolved inorganic carbon (DIC) for stimulating algal productivity. In both experiments supplemental urea and triple superphosphate (TSP) gave all treatments total nitrogen (N) and phosphorus (P) inputs of 28·0 kg/ha/week and 7·0 kg/ha/week, respectively.

Addition of chicken manure to inorganic fertilization did not enhance production of Nile tilapia. NFY in experiment 1 increased with decreasing manure loading, which corresponded to increasing TSP input. Regression analysis suggested that chicken manure–P was about 10% effective as TSP–P at increasing NFY. NFY was linearly correlated to net primary productivity ($r^2 = 0{\cdot}62$, $P < 0{\cdot}001$), which was linearly correlated to total alkalinity ($r^2 = 0{\cdot}77$, $P < 0{\cdot}001$). Treatment differences in alkalinity, community respiration or dissolved oxygen concentrations at dawn were not related to manure input. Simple economic comparisons discourage the purchase of chicken manure as a source of soluble N and P for increasing algal productivity in Thailand.

Introduction

Organic fertilizers have a long tradition in tropical semi-intensive aquaculture. When added to ponds, they may ultimately increase fish yields through soluble and/or particulate pathways (Fig. 1). Release of soluble nitrogen (*N*) and phosphorous (*P*) stimulates algal production, which in turn can be consumed by fish directly or after intermediate processing by zooplankton or microbes (detritus formation) (Wohlfarth & Schroeder 1979; Colman & Edwards 1987). In waters with low alkalinities, manure decomposition may also provide algae with an important source of dissolved inorganic carbon (DIC) through decomposition and release of carbon dioxide (McNabb, Batterson, Premo, Knud-Hansen, Eidman, Lin, Jaiyen, Hanson & Chuenpagdee 1990). Knud-Hansen, McNabb, Batterson, Harahat, Sumatadinata & Eidman (1991) reported a nutrient limitation switch from C to N with increasing chicken manure loading rates in low alkalinity ponds in West Java, Indonesia.

Although organic fertilizers may be consumed directly or as manure-derived detritus after heterotrophic microbial activity, the role of manure or manure-derived detritus as a source of food for fish is not universally agreed upon. Several studies concluded that organic

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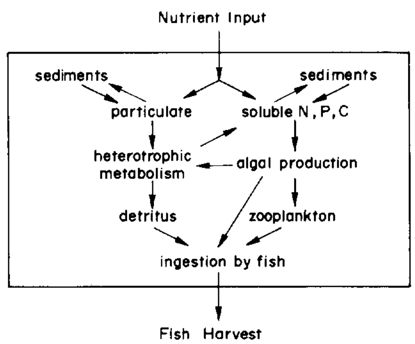

Figure 1. Schematic representation of major pathways of organic and inorganic fertilizers added to ponds to increase fish biomass.

supplements contributed to fish yield by supplying inorganic P, N and C for algal growth, and by stimulating detrital production and heterotrophic utilization (Noriega-Curtis 1979; Oláh, Sinha, Ayyappan, Purushothaman & Radheyshyam 1986; Colman & Edwards 1987; Green, Phelps & Alvararenga 1989; Knud-Hansen *et al.* 1991). Recent studies by Schroeder, Wohlfarth, Alkon, Halevy & Krueger (1990), however, suggested that organic matter from the manure contributed very little to growth of common carp, silver carp, grass carp and tilapia hybrids grown in polyculture.

Pond production of Nile tilapia, *Oreochromis niloticus* (L.), often utilizes manures as part of the fertilization strategy. As fish yields increase with greater fertilization rates, it becomes essential to balance the organic versus inorganic (e.g. urea and triple superphosphate (TSP)) nutrient inputs in order to maximize nutrient efficiency while minimizing the threat of deoxygenation. Two grow-out experiments were conducted to evaluate the role and utility of chicken manure for Nile tilapia production. The first experiment was designed to find the relationship between chicken manure input and tilapia yields under conditions of high inorganic inputs. Based on these results, a second experiment was conducted to determine whether DIC and/or particulate organic matter provided by chicken manure has any positive effect on tilapia yields.

Materials and methods

Research was conducted at the Bang Sai Freshwater Fisheries Station of the Royal Thai Department of Fisheries located approximately 60 km north-west of Bangkok, Thailand (14.2°N 100.5°E). A description of the site is given in Egna, Brown & Leslie (1987).

Experiments were conducted in 280-m^2 earthen ponds filled to a depth of about 0·95 m with water pumped from a nearby reservoir. Water was added to ponds periodically to compensate evaporative losses (<1 cm/day). Initial pond water characteristics for both experiments were pH = 8·4, total alkalinity = 101 mg/l $CaCO_3$, and concentrations of ammonia–N, nitrate–nitrite–N and soluble reactive phosphorus all <0·10 mg/l. Pond water temperatures during both experiments ranged from 27 to 34°C.

The first grow-out experiment, conducted from 12 October 1989 to 8 March 1990 (146 days), was designed to test the null hypothesis that under conditions of high inorganic N and P inputs, Nile tilapia NFY is not affected by the level of particulate organic matter added as layer chicken manure. Five treatments were weekly applications of 20, 60, 100, 140 and 180 kg chicken manure dry wt/ha, with urea and TSP (45% P_2O_5) added concurrently to give a total nitrogen input for all treatments equivalent to 4·0 kg N/ha/day and a N:P ratio of 4:1 by weight. Chicken manure contained very little litter, and was applied to ponds within 3 weeks of collection. All inputs were broadcast more or less evenly over each pond's surface. There were three replicates per treatment; treatment allocation to ponds was completely random. Male *O. niloticus* (about 10 g/fish), sex-reversed using 17 α-methyltestosterone (Buddle 1984), were stocked at 1·6 fish/m^2.

Experiment 2, conducted from 25 October 1990 to 21 March 1991 (147 days), was designed to test the null hypothesis that (1) chicken manure does not increase NFY by providing particulate organic carbon for consumption either directly or as manure-based detritus; and (2) chicken manure does not increase NFY by providing DIC for stimulating algal productivity. Four treatments consisted of (1) fresh layer chicken manure added at 60 kg dry wt/ha/week, (2) DIC added at 3·5 kg $NaHCO_3$/ha/week; (3) both chicken manure and $NaHCO_3$ added at the rates given in the first two treatments; and (4) no organic (chicken manure) or inorganic ($NaHCO_3$) added. Urea and TSP (45% P_2O_5) were added weekly to all ponds to give an equivalent nitrogen input of 4·0 kg N/ha/day and a N:P ratio of 4:1 by weight. In calculating loading rates it was assumed that chicken manure releases through leaching and decomposition 50% of its total carbon, 40% of total N and 20% of total P as solutes available for phytoplankton uptake. The two by two factorial design (i.e. four treatment combinations of two levels each of chicken manure and bicarbonate) allowed examination of possible interactions between different types of carbon sources on NFY. There were three replicates per treatment; treatment allocation to ponds was completely random. Male sex-reversed *O. niloticus* (about 6 g/fish) were stocked at 3·2 fish/m^2.

During the course of both experiments, chicken manure samples were analysed weekly (n= 42) for total Kjeldahl nitrogen (American Public Health Association 1985), total phosphorus using perchloric acid digestion (Yoshida, Forno, Cook & Gomez 1976), and per cent dry weight by drying at 60°C for 12 h. Per cent organic carbon was measured weekly (n = 20) using dichromate oxidation (Dewis & Freitas 1970).

Water quality measurements were made biweekly at pre-dawn and 1600 h, as described by Egna *et al.* (1987). Integrated samples were collected by vertically lowering and capping a pre-rinsed 5-cm (i.d.) PVC tube. Water temperature and dissolved oxygen were measured *in situ* with a Yellow Springs dissolved oxygen (DO) meter Model 54A. Pond water pH was determined using a Suntex digital meter Model Sp-5A. Total alkalinity was analysed potentiometrically using 0·02 N HCl to titrate the sample pH 5·1 (APHA 1985). Net primary productivity (NP) was estimated from diurnal changes in DO measured before dawn (≈0600 h) and at 1600 h at pond depths of 25, 50 and 75 cm. Community respiration, and net and gross primary productivity were estimated by DO changes in pond water incubated *in situ* in light/dark bottles at pond depths of 25 cm, 50 cm and 75 cm (Egna *et al.* 1987).

ANOVA and regression analyses were done according to Steel & Torrie (1980) using the Statgraphics 4 statistical software package. Means are given with ±1 standard error (SEM) in parentheses; statistical significance is assumed at $P < 0·05$).

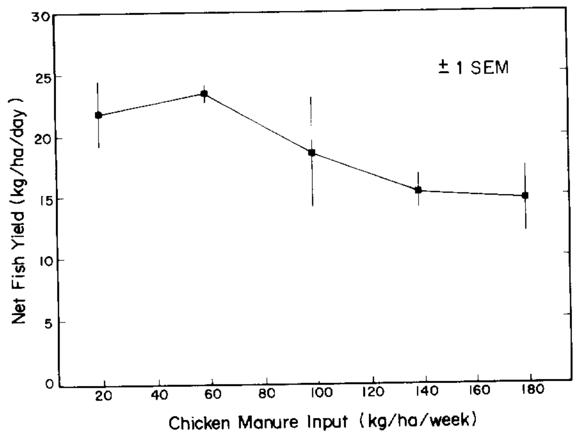

Figure 2. Relationship between chicken manure input (kg dry matter/ha/week) and mean net fish yield (NFY, kg/ha/day) (±1 SEM) in experiment 1. See text for total nutrient inputs.

Results

Concentrations of total Kjeldahl N and total P in chicken manure used to fertilize ponds averaged 2·0 (±0·1%) and 3·0% (±0·1%) of dry weight, respectively. Moisture content of the manure averaged 37·6% (±3·1%), while organic carbon averaged 18·1% (±1·0%) dry weight.

In experiment 1, final NFYs and harvest weights of fish varied considerably although all ponds received identical amounts of total N and P. Recruitment was observed in eight of 15 ponds, and included in NFY calculations. Recruitment biomass was <5% of harvest weight of adults for all treatments; there was no relationship between recruitment and manure input. Treatment means of NFY decreased from 23·6 kg/ha/day to 15·0 kg/ha/day as manure input increased from 20 to 180 kg DM/ha/week (Fig. 2). The opposite relationship was observed when NFY was plotted against TSP input, which represented from 52·8% to 95·2% of total P loading with decreasing amounts of manure (Fig. 3). A similar relationship with urea–N loading was not examined, as the percentage of N contributed by urea in the fertilization treatments had a narrow range from 87·6% to 98·6%. Variations in urea input could not logically be responsible for the relatively large treatment differences in NFY since the regression equation indicated an unreasonable NFY of 0 kg/ha/day at a fertilization rate of 3 kg N/ha/day. Harvest weight of fish decreased with increasing manure input; treatment means ranged from 168 ± 5·2 g/fish to 253 ± 10·1 g/fish. Per cent survival exhibited no relationship with treatment; treatment means ranged from 78·7% to 85·6% with an average for the experiment (n = 15) of 82·2 ± 2·7%.

In experiment 2, NFY ranged between 19·3 and 38·4 kg/ha/day for all ponds; minor recruitment (<0·5% of total harvest biomass) was noted in two ponds only. There were no significant differences in mean NFY between treatments (Table 1), however, suggesting that neither particulate organic carbon nor DIC additions benefited tilapia production. There were also no significant interactions (non-linear effects) on NFY between the two sources of carbon. Treatment means of fish weights at harvest were not significantly different from each other, ranging from 127±4·4 g/fish in the chicken manure+bicarbonate treatment to 177 ±

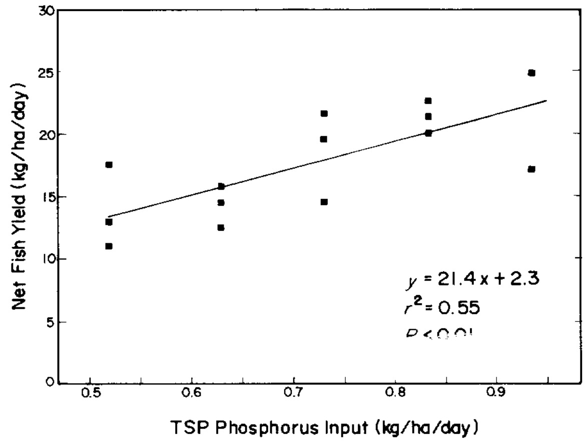

Figure 3. Relationship between triple superphosphate-phosphorus input (kg/ha/day) and net fish yield (NFY, kg/ha/day) in experiment 1. See text for total nutrient inputs.

21·1 g/fish in the bicarbonate treatment. Per cent survival was similar for all treatments; the average for the experiment ($n = 12$) was 87·5 ± 2·8%.

In neither experiment were DO concentrations at dawn or rates of community respiration related to chicken manure inputs. For all treatments, dawn DO concentrations averaged about 5 mg O_2/l during the first 2·5 months, and about 2 mg O_2/l during the second 2·5-month period. Community respiration for all ponds ($n = 27$) ranged from 5·3 to 20·9 mg O_2/l/24 h, with a mean of 12·6 ± 0·7 mg O_2/l/24 h.

Combining data from both experiments revealed a strong correlation between net primary productivity (NP) and NFY (NFY = −3·04+2·12 (net oxygen production between 0600 and 1600 h), $r^2 = 0{\cdot}62$, $P < 0{\cdot}001$) (Fig. 4). Although all ponds received similar total N and P inputs, Fig. 4 illustrates the variability observed in NP. Variations in NP were apparently due to changes in alkalinity during the course of both experiments. Initial alkalinities in all ponds were about 101 mg/l $CaCO_3$ in both experiments. By the end of the experiments alkalinities ranged from 25 to 175 mg/l $CaCO_3$ in individual ponds. There was a significant linear correlation ($r^2 = 0{\cdot}77$, $P < 0{\cdot}001$) between mean alkalinity and mean NP (Fig. 5), and in turn between mean alkalinity and NFY (Fig. 6). ANOVA indicated that alkalinity differences between ponds accounted for 44% and 77% of the observed variation in NFY and NP, respectively.

Discussion

Chicken manure as a source of particulate carbon for tilapia

Results from experiment 1 clearly indicated that at best, chicken manure-derived detritus was a minor contribution to the diet of Nile tilapia. Experiment 2 demonstrated that NFYs in ponds fertilized with the optimum manure input (60 kg DM/ha/week) indicated in experiment 1 were not significantly different from ponds fertilized at the same N and P loading but without any manure inputs (Table 1). Both experiments support conclusions of Schroeder & Buck (1987) and Schroeder *et al.* (1990).

Table 1. Treatment means and standard errors (SEM) for net fish yield (NFY, kg/ha/day), net primary productivity (NP, mg O_2/l/10h), and total alkalinity (mg/l $CaCO_3$) in experiment 2. No treatment means were significantly different from each other for each variable.

Treatment	NFY		NP		Alkalinity	
	Mean	SEM	Mean	SEM	Mean	SEM
No carbon added	30·5	1.5	11.8	0.7	98.7	22.1
Sodium bicarbonate	25.6	4.9	11.7	2.5	83.4	35.4
Chicken manure	24.3	2.0	10.1	0.5	47.3	8.0
Chicken manure+ sodium bicarbonate	30.6	5.7	13.7	1.0	99.4	18.7

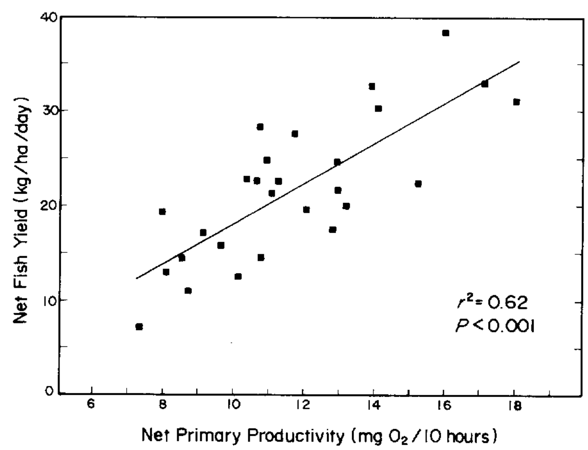

Figure 4. Relationship between net fish yield (NFY, kg/ha/day) and mean net primary productivity (diurnal changes in dissolved oxygen as mg/l/10h) for all treatments and ponds in experiments 1 and 2.

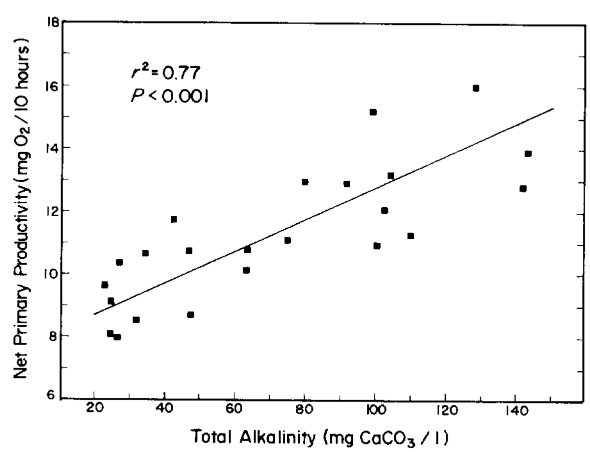

Figure 5. Relationship between mean net primary productivity (diurnal changes in dissolved oxygen as mg/l/10h) and mean total alkalinity (mg/l $CaCO_3$) for all treatments and ponds in experiments 1 and 2.

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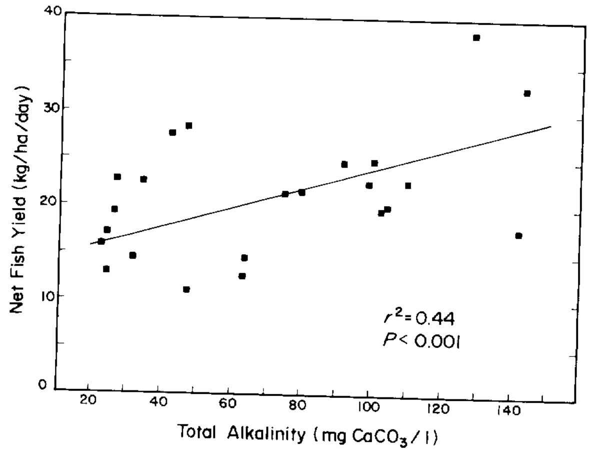

Figure 6. Relationship between net fish yield (NFY, kg/ha/day) and mean total alkalinity (mg/l $CaCO_3$) for all treatments and ponds in experiments 1 and 2.

The apparent contradiction with opposite conclusions by others (Noriega-Curtis 1979; Oláh *et al.* 1986; Colman & Edwards 1987; Green *et al.* 1989; Knud-Hansen *et al.* 1991) is probably related to algal productivity and abundance as a food source. The question is not one of autotrophic versus heterotrophic pathways, as algal-based detritus is a product of both biological processes (Fig. 1). Rather, it is a question of relative nutritive value of phytoplankton and its energetic derivatives (e.g. zooplankton and algal-based detritus) versus manure and manure-derived detritus. If tilapia prefer the former, then NFY should be related to algal productivity. Such was the case in our study, as NFY was significantly linearly correlated to primary productivity ($r^2 = 0{\cdot}62$, $P < 0{\cdot}001$) (Fig. 4). This relationship was also reported by McConnell, Lewis & Olson (1977) and Knud-Hansen *et al.* (1991). The fact that the *y*-intercept was not significantly different from zero also suggests that algal production alone was responsible for tilapia growth.

Restriction of algal production beyond dietary requirements for fish growth may force tilapia to feed on manure-derived detritus. Factors which can limit primary productivity include (1) low inorganic carbon availability, (2) reduced light penetration from inorganic turbidity (e.g. wind mixing or bioturbidation in shallow ponds), water coloration from dissolved organic matter, or algal self-shading, and (3) relatively low soluble N and P inputs. Investigations by Noriega-Curtis (1979) and Knud-Hansen *et al.* (1991) used little or no inorganic inputs, whereas Schroeder & Buck (1987) and this study applied relatively high amounts of inorganic N and P. As primary productivity increases, the importance of manure-derived detritus for tilapia production decreases.

Another example comes from Diana, Dettweiler & Lin (1991), who reported food limitation and decreasing NFYs of Nile tilapia with increasing stocking densities in ponds fertilized with only chicken manure (500 kg DM/ha/week). In contrast, Knud-Hansen & Lin (in press) found a completely opposite result in ponds fertilized with high levels of urea and TSP (4 and 1 kg/ha/day of N and P, respectively), where afternoon DO concentrations were often above 25 mg/l and chlorophyl *a* concentrations above 300 mg/m^3. With greater primary productivity, food constraints at higher stocking densities noted by Diana *et al.* (1991) were not indicated.

Chicken manure as a source of algal nutrients

Although data showed that chicken manure had limited utility as particulate carbon source in the production of Nile tilapia, what about its role as a source of inorganic N, P and C for algal productivity? Knud-Hansen *et al.* (1991) found through leaching experiments that about 40% of chicken manure N was released as either ammonia or nitrate-nitrite after 6 days' immersion in pond water.

Regression analysis from this study suggests that chicken manure also is not an efficient source of inorganic P. Figure 3 illustrates the significant ($r^2 = 0{\cdot}55$, $P < 0{\cdot}01$) linear relationship between TSP–P input and NFY in experiment 1. Based on the regression equation: NFY (as kg/ha/day) = 21·4 (TSP–P input as kg/ha/day)+2·3, when TSP–P input = 1·0kg/ha/day, NFY = 23·7kg/ha/day. In contrast, an input of 1·0kg/ha/day of chicken manure–P (i.e. 0·0kg/ha/day of TSP–P, since all ponds received identical inputs of 1·0kg total P/ha/day) gives a calculated NFY of 2·3kg/ha/day, or about 10% the NFY obtained with TSP–P. At 95% confidence, chicken manure–P is between 0 and 37% as effective/available as TSP–P in promoting NFY.

In order to provide available N and P at input rates used in this study, chicken manure application would exceed 750kg/ha/day. Not only would ponds fill rapidly with organic matter, tilapia as well as other species would find it difficult to survive under resulting conditions of low DO concentrations. Purchase and use of aeration devices in such highly manured ponds would significantly increase production costs. Data from this study show that high NFYs can be attained without the need for aeration with efficient N and P fertilization and little or no manure.

Although carbon inputs did not significantly influence NFY or NP in experiment 2 (Table 1), apparently DIC availability as reflected in total alkalinity did have a significant effect (Figs 5 and 6). McNabb *et al.* (1990) demonstrated that chicken manure can supplement the DIC pool increasing algal productivity in fish ponds with low alkalinities (20–30mg/l $CaCO_3$). Changes in alkalinity, however, were not related to treatment (Table 1), fertilizations from previous experiments, or spatial distribution of ponds.

A likely candidate for affecting alkalinity may be snails, which after the ponds were drained were found on sediments in varying amounts. Some ponds had only a few snails while other pond bottoms were nearly 100% covered. Although only qualitative estimates of snail biomass were made at the time, there was a distinct inverse relationship between snail coverage and pondwater alkalinity. It seems quite possible that incorporation of $CaCO_3$ into snail shells greatly influenced DIC dynamics and limited its availability for algal uptake. Although snail activity may have obscured actual beneficial effects of additional carbon inputs, further analysis did not suggest this. Treatment differences in experiment 2 explained even less variation in NFY when a second ANOVA was conducted using mean pond alkalinity as a covariate. If snails are capable of reducing DIC concentrations, then polyculture with a mulluscivore such as Chinese black carp, *Mylopharyngodon piceus* Richardson, may be a way of improving tilapia yields without increasing nutrient inputs.

Whether a farmer should use organic and/or inorganic fertilizers depends on relative environmental and economic efficiencies of transferring soluble and particulate nutrients into fish biomass. Combining chicken manure data and the above analyses with current market prices in Thailand indicates that it is economically unsound for a farmer to purchase chicken manure for the purpose of turning ponds green (Table 2). Although urea and TSP are over 10

Table 2. Economic comparison of different fertilizers with respect to available nitrogen (N), phosphorus (P), and carbon (C) (US$ = 25 baht)

Fertilizer	Cost (baht/50 g)	Available N (baht/kg)	Available P (baht/kg)	Available C (baht/kg)
Chicken manure	20[a]	76[b]	194[c]	7[d]
Urea	240	10	–	24
TSP	450	–	45	–
$NaHCO_3$	1000	–	–	140

[a] Wet weight.
[b] Assumes 40% dry weight of total N is available (Knud-Hansen *et al.* 1991).
[c] Assumes 10% dry weight of total P is available (this study).
[d] Assumes 50% dry weight of organic C oxidizes to DIC.

and 20 times more expensive than chicken manure, respectively, the cost per kilogram of available N is over seven times less expensive with urea and the cost of available P is about one quarter with TSP. In addition, 1 kg urea and TSP yields equivalent N and P as about 90 and 100 kg chicken manure (wet weight), respectively. So when secondary costs such as transportation and manual labour are included, urea and TSP become even more attractive.

Possible benefits of chicken manure fertilization

Table 2 shows that chicken manure is a cheaper source of C than urea or sodium bicarbonate in Thailand. However, the usefulness of chicken manure as source of DIC is still unclear. Neither experiment indicated any positive relationship between chicken manure application and DIC availability. Nevertheless, more research should be completed before any definitive conclusions are drawn.

Organic inputs also may have a beneficial impact on pond bottoms. Although pond sediments can effectively remove P from the water column (Boyd 1971; Boyd & Musig 1981), sedimentation of organic matter and accumulation on pond substrates may also improve P availability for phytoplankton. This may occur for two reasons. First, colloidal organic matter does not adsorb P as readily as clay substrates, thus keeping more P soluble in the water column (Hepher 1958; Boyd 1971). And second, desorption of P is enhanced under anoxic conditions with low oxidation-reduction potentials (Nakanishi, Ukita & Kawai 1986; Redshaw, Mason, Haynes & Roberts 1990), an environment commonly found in sediments of ponds fertilized with manures. The positive effect of accumulation of organic inputs in sediments can be seen in improved fish yields in ponds with historically greater manure fertilizations (Boyd 1971). Previous TSP inputs, however, were found to be more effective than chicken manure at increasing P availability and therefore NP and NFY (Knud-Hansen 1992).

Perhaps chicken manure's greatest potential contribution to tilapia production is found in integrated farming systems, where chicken coops are placed over ponds. There are no costs for manure or its transportation. Fresh manure is of higher quality than older manure sold by chicken farmers, as relatively nutrient-rich soluble excreta also enters the pond (Knud-Hansen, McNabb & Batterson 1991). In addition, fish below benefit from spilled chicken feed.

Results clearly indicate that chicken manure is neither a preferred source of particulate organic matter for Nile tilapia, nor in non-integrated systems an economically wise choice of fertilizer to provide N and P for production of natural foods. This is very useful to the farmer in that adding manure to ponds can degrade water quality, fill in ponds, and be labour intensive. Some benefits of chicken manure fertilization, including release of inorganic carbon and improving sediment P mobility, may be obtained without subjecting fish to dangerously low DO concentrations by adding manure to ponds about a week prior to stocking. During grow-out, relatively cost-efficient fertilizers with high solubility and low oxygen demand, such as urea and TSP, should be used to supply N and P to stimulate natural food production and increase fish yields.

Acknowledgments

The research was conducted jointly by Michigan State University (USA), National Inland Fisheries Institute (Thailand), and the Asian Institute of Technology (Thailand) as a part of the Pond Dynamics/Aquaculture Collaborative Research Support Program (CRSP) supported by the US Agency for International Development, Grant No. DAN-4023-G-OO-0031-00 and by contributions from the participating institutions. This will be Pond Dynamics/Aquaculture CRSP publication No. 1063. Acknowledgment is also made to the Michigan Agricultural Experiment Station for its support of this research. The AIT aquaculture laboratory staff are gratefully acknowledged for their technical assistance, and P. Edwards and two anonymous reviewers for their comments and review of the manuscript.

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