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# Optimization of Phosphorus Fertilizer in Supplemental Feed-Fed Based Nile Tilapia (*Oreochromis niloticus*) Ponds

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## Abstract

An experiment was conducted in earthen ponds at the Asian Institute of Technology, Thailand to determine different phosphorus fertilizer dose effects on Nile tilapia production, water quality variables, nutrient utilization and cost-benefit under supplemental feeding. Five phosphorus fertilization rates were used as treatments e.g. 100%, 75%, 50%, 25% and 0% of 7 kg P ha week$^{-1}$. Nitrogen fertilization rate was fixed at 28 kg N ha week$^{-1}$ for all the treatments. Sex-reversed Nile tilapia were stocked at 3 fish m$^{-2}$, and 30% CP floating feed fed at 50% satiation feeding rate. Nutrient budget showed higher phosphorus fertilizer input resulted in higher phosphorus sink in the sediment. Mean weight, mean weight gain, daily weight gain and net yield were not significantly different among treatments ($P > 0.05$). Total Kjeldahl nitrogen, total phosphorus and soluble reactive phosphorus were significantly different among treatments. Economic analysis showed phosphorus fertilization resulted in positive net returns. Though the gross income was not affected by different fertilization rates, significantly lowest cost was found in the treatment using 25% phosphorus fertilizer. It can be concluded from the research that 25% phosphorus fertilization might be used as an alternative strategy of Nile tilapia pond culture in terms of economic return and nutrient loss in sediment.

**Keywords:** phosphorus fertilizer, production, water quality, nutrient, Nile tilapia

## Introduction

Nile tilapia (*Oreochromis niloticus*) is commonly produced in semi-intensive culture systems in Southeast Asia using fertilization to increase primary production (Boyd 1976; Diana, Lin & Schneeberger 1991; FAO-FIES 2008; Asano, Hayashizaki, Eda, Khonglaliang & Kurokura 2010). In many Asian countries, adding supplemental feed to fertilized ponds is becoming more and more popular for tilapia production. Supplemental feeding in fertilized ponds results in faster fish growth and higher pond yields at high stocking density compared with ponds receiving only fertilization (Hepher 1963; Tacon 1988). There is voluminous literature available on optimizing fertilization rate in fish ponds using inorganic or organic fertilizers or their combinations as the sole nutrient inputs (Boyd 1978; Olah 1986; Green, Teichert-Coddington & Phelps 1990; Diana *et al.* 1991; Khud-Hansen, McNabb & Batterson 1991; Edwards 1994; Lin, Teichert-Coddington, Green & Vevrica 1997). The natural foods in fertilized ponds increase efficiency of supplemental feeds significantly and lead to lower feed conversion ration (FCR), and feeding rate of 50% *ad libitum* was optimal in ponds fertilized at a fixed rate of 28 kg N and 7 kg P ha week$^{-1}$. Furthermore, it was observed that initiation of supplemental feeding at 50% *ad libitum* once fish reached 100 g is the most cost-effective way to produce large tilapia (Diana, Lin & Yang 1996).

The above recommended fertilization rate is appropriate when fertilizer serves as the sole nutrient input for Nile tilapia culture in the tropics (Khud-Hansen *et al.* 1991). But, nutrients may become excessive in ponds with supplemental feeding, as substantial nutrients levels are also released from feeding wastes to pond water and eventually lead to excessive phytoplankton production (Lin 1990; Lin & Diana 1995; Yi, Lin & Diana 1996, 2001; Yi & Lin 2001). It is ecologically and economically important to maintain adequate natural food production in fed ponds with balanced nutrient inputs from both external fertilization and internal wastes. To minimize nutrient waste, the rate of external fertilization needs to be adjusted according to the amount of nutrients derived from feeding waste. Such practice will result in more efficient nutrient utilization, better water quality, lower production cost and reduced nutrient load in pond effluents. Previous research has dealt with different fertilizers and feed combinations (Diana, Lin & Jaiyen 1994; Milstein, Alkon, Karplus, Kochba & Avnimelech 1995). However, almost all research to optimize supplemental feeding rate has been conducted in ponds with fixed fertilization rates, and none has been reported on optimizing fertilization regimes in fertilized ponds with supplemental feeds. Therefore, it was of interest to carry out the study to optimize external phosphorus fertilization rate for semi-intensive tilapia culture system under supplemental feeding. The purpose of the present study was to determine the phosphorus fertilization rate requirement for supplementary feed-fed Nile tilapia ponds.

## Materials and methods

The experiment was carried out at the Asian Institute of Technology (AIT), Thailand for 130 day from September 2005 to January 2006. To avoid unwanted recruitment, all sex-reversed male Nile tilapia Oreochromis niloticus (average weight 100 g) were purchased from AARM hatchery of AIT and were stocked in fifteen 200 $m^2$ earthen ponds at 3 fish $m^{-2}$. The experiment was conducted in a completely randomized block design. There were five treatments at different phosphorus fertilization rates with three replicates each. Phosphorus fertilizer (TSP- 46% $P_2O_5$) rates for the five treatments were 0%, 25%, 50%, 75% and 100% of 7 kg P ha $week^{-1}$ respectively. All ponds were fertilized with urea at 28 kg N ha $week^{-1}$. Ponds were limed according to soil pH (Boyd 1995), and after 3 days of liming, ponds were filled and the water level was maintained at 1 m for the entire experiment. Ponds were fertilized for 2 weeks prior to fish stocking.

Tilapias in all experimental treatments were fed at feeding 50% *ad libitum* with floating complete pelleted feed (30% crude protein). To determine feeding rate, fish were fed to satiation from 09:00–10:00 hours and 15:00–16:00 hours once a week, and total consumption was determined for each pond. Average consumption for each treatment was used to set the feeding rate at 50% of that level for each treatment for the remainder of the week.

During the experiment, 30 fish were sampled every 2 weeks for batch weight and released back to ponds. Nutrient budget was calculated based on inputs and outputs of total nitrogen (TN) and total phosphorus (TP). At the beginning and the end of the experiment, water, fish and feed were sampled and analysed for moisture, TN and TP. Commercial inorganic fertilizers, urea (46% N) and TSP (46% $P_2O_5$) were used and not analysed for N and P content. Initial and final soil samples (top 10 cm) were collected from five locations in each pond using plastic tubes (10 cm in length and 5 cm in diameter) and were analysed for bulk density, moisture, total nitrogen and total phosphorus. Pond water samples were taken biweekly at 09:00–09:30 hours using column sampler and analysed for total alkalinity, total ammonia nitrogen (TAN), nitrite nitrogen, nitrate nitrogen, total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), chlorophyll *a*, total suspended solids (TSS) and total volatile solids (TVS) using standard methods (APHA 1985). Temperature, dissolved oxygen (DO) and pH (at 25 cm below water surface, middle and 25 cm above bottom) measured using a YSI model 58 oxygen meter, and Secchi disc visibility was measured *in situ* before collecting the water sample. In addition, monthly diurnal temperature, DO and pH were measured at 06:00, 10:00, 14:00, 18:00, 22:00 and 06:00 hours in each pond.

Growth performance of Nile tilapia was evaluated using the following calculations:

$$\text{Feed Conversion ratio(FCR)} = \frac{\text{Weight of dry feed given(g)}}{\text{Wet weight gain(g)}}$$

$$\text{Daily Weight Gain}(\text{gday}^{-1}) = \frac{\text{Mean final weight(g)} - \text{Mean initial weight(g)}}{\text{Culture period(days)}}$$

  

$$\text{Specific growth rate}(\%) = \frac{(\text{Ln}(\text{Final mean weight}) - \text{Ln}(\text{Initial mean weight})) \times 100}{\text{Culture period}(\text{days})}$$

$$\text{Net yield}(\text{kgm}^{-2}\text{per crop}) = \frac{\text{Final total weight}(\text{kg}) - \text{initial total weight}(\text{kg})}{\text{Surface areas}(\text{m}^2)}$$

$$\text{Gross yield}(\text{kgm}^{-2}\text{per crop}) = \frac{\text{Final total weight}(\text{kg})}{\text{Surface areas}(\text{m}^2)}$$

Partial budget analysis was done based on farm gate prices in Thailand for harvested fish and current local market prices expressed in US dollar (1US = 39*Baht*). Farm-gate wholesale price of Nile tilapia was fixed at 0.641 $kg^{-1}$ for 300–400 g fish. Market price for juvenile sex-reversed Nile tilapia at 0.026, urea at 0.178 $kg^{-1}$, TSP at 0.298 $kg^{-1}$, and feed at 0.48 $kg^{-1}$ were applied to the analysis. To know the effect of different doses of fertilizer and block, data were analysed for significant differences among treatments using two-way analysis of variance (ANOVA) and regression using SPSS statistical software package. The significance of difference between mean was evaluated using Fisher's least significant difference (LSD), and differences among treatments were considered significant at an alpha level of 0.05. Means were given with ± standard deviation (SD).

## Results

### Supplemental feeding and phosphorus fertilizer input effect on growth

Individual initial weight of Nile tilapia ranged from 93.2 ± 0.2 to 97.0 ± 1.2 g in all treatments. At harvest, mean tilapia weight varied from 352.0 ± 19.4 to 375.6 ± 10.1 g, with daily mean weight gains 1.97 ± 0.16–2.15 ± 0.18 g fish $day^{-1}$ (Table 1). In general, high daily weight gain was registered in all treatments during the early experimental period, and a reduced daily weight gain was observed towards the end of the experiment. Growth performance of fish was positively correlated with feed input ($r = 0.70$, $P < 0.05$) (Figs 1 and 2). Total harvested biomass was not significantly different among treatments ($P > 0.05$). Survival rates ranged from 91 to 95% in all treatments. Highest gross yield was observed in highest phosphorus fertilizer input ponds. Highest net fish yields (156.42 ± 13.29) were observed in 100% P and lowest were observed in 50% P treatment ($P > 0.05$, Table 1).

Feed conversion ratio (FCR) ranged from 1.13 ± 0.09 to 1.24 ± 0.06 in all treatments, and was not significantly different among treatments ($P > 0.05$). Specific growth rates were not significantly different among treatments ($P > 0.05$).

### Effect of fertilizers on nutrient budgets of Nile tilapia ponds

Nitrogen outputs in harvested fish and drained water were not significantly different among treatments ($P > 0.05$, Table 2). Nutrient (N and P) outputs in sediment were estimated by subtracting the total nutrient in the sediment before the experiment from total nutrients in the sediment at harvest, and thus, the gain of nutrients in the sediment in Tables 3 and 4 has been described as outputs. In all the treatments, urea fertilizer was the dominant of nitrogen source followed by feed, water and fish, whereas, feed was the main phosphorus input source followed by TSP fertilizer, stocked fish and water (Tables 3 and 4). Nitrogen outputs in sediment were significantly different between 100% P and 0% P treatments ($P < 0.05$). Lowest nitrogen deposition in sediment was observed in the treatment with 50% P. However, nitrogen output in drain water was not significantly different among the treatments. Unaccounted nitrogen was highest in the treatment with 50% P followed by 0%, 75%, 25% and 100% P ($P < 0.05$, Table 3).

Phosphorus budgets revealed in treatments with 100% P and 75% P fertilizer was the dominant input (N and P) followed by feed. Phosphorus level in the inputs was significantly different among treatments ($P < 0.05$, Table 4). Phosphorus outputs in sediment were significantly higher in the treatments with 75% and 100% P than those in treatments with 0%, 25% and 50% P ($P < 0.05$). Results showed highest phosphorus was deposited in the highest phosphorus loading rate compared with 25% P and 0% P. Nutrients recovered in

**Table 1** Growth performance of Nile tilapia

| Parameters | Treatment 1 (100% P) | Treatment 2 (75% P) | Treatment 3 (50% P) | Treatment 4 (25% P) | Treatment 5 (0% P) |
|---|---|---|---|---|---|
| Stocking | | | | | |
| Individual mean weight (g per fish) | 93.2 ± 0.2 | 97.0 ± 1.2 | 96.0 ± 0.3 | 95.8 ± 1.4 | 95.6 ± 1.7 |
| Total weight (kg per pond) | 55.9 ± 0.2 | 58.2 ± 0.7 | 57.6 ± 0.2 | 57.5 ± 0.8 | 57.4 ± 1.0 |
| Stocking density (fish $m^{-2}$) | 3 | 3 | 3 | 3 | 3 |
| Harvest | | | | | |
| Individual mean weight (g per fish) | 372.4 ± 23.3 | 375.6 ± 10.1 | 353.7 ± 35.0 | 352.0 ± 19.4 | 355.3 ± 25.9 |
| Total weight (kg per pond) | 212.3 ± 13.4 | 205.4 ± 12.0 | 191.8 ± 11.6 | 199.1 ± 18.8 | 199.7 ± 13.1 |
| Survival rate (%) | 95 ± 3 | 91 ± 8 | 91 ± 5. | 94 ± 4 | 94 ± 2 |
| FCR | 1.13 ± 0.09 | 1.17 ± 0.10 | 1.24 ± 0.06 | 1.18 ± 0.11 | 1.21 ± 0.09 |
| Individual mean weight gain (g per fish) | 279.2 ± 23.3 | 278.5 ± 9.6 | 257.7 ± 35.0 | 256.2 ± 20.6 | 259.7 ± 27.6 |
| Daily weight gain (g fish $day^{-1}$) | 2.15 ± 0.18 | 2.14 ± 0.07 | 1.98 ± 0.27 | 1.97 ± 0.16 | 1.99 ± 0.21 |
| Specific growth rate (%) | 1.06 ± 0.05 | 1.04 ± 0.02 | 1.00 ± 0.08 | 1.00 ± 0.05 | 1.01 ± 0.07 |
| Gross yield (kg per pond per crop) | 212.3 ± 13.4 | 205.4 ± 12.0 | 191.8 ± 11.6 | 199.1 ± 18.8 | 199.7 ± 13.1 |
| Net fish yield (kg per pond per crop) | 156.42 ± 13.29 | 147.15 ± 12.36 | 134.23 ± 11.45 | 141.64 ± 19.52 | 142.35 ± 14.02 |
| Recruitment | | | | | |
| Total weight (kg per pond) | 9.7 ± 4.06 | 0.0 ± 0.0 | 2.4 ± 1.2 | 4.5 ± 3.2 | 3.0 ± 4.2 |
| Mean weight (g per fish) | 13.2 ± 5.0$^{a}$ | 0.0 ± 0.0$^{c}$ | 10.8 ± 2.6$^{ab}$ | 7.5 ± 4.8$^{ac}$ | 5.3 ± 7.4$^{bc}$ |

Values are mean ± SD ($n = 3$); mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

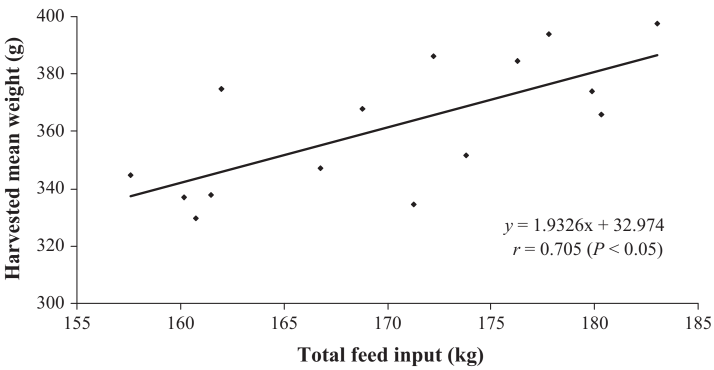


**Figure 1** Relationship between harvested mean weights with total feed input.

harvested fish biomass were 3.67 ± 0.34, 3.34 ± 0.25, 3.00 ± 0.34, 3.32 ± 0.40 and 3.33 ± 0.18 kg N and, 0.81 ± 0.12, 0.78 ± 0.06, 0.76 ± 0.22, 0.79 ± 0.11 and 0.81 ± 0.00 kg P in the treatments with 100%, 75%, 50%, 25% and 0% P, respectively, and the values were not significantly different among treatments ($P > 0.05$, Tables 3 and 4).

Fertilizer was the major nitrogen input source which accounted for 50.7–52.1% total added nitrogen in all treatments. Percentage phosphorus input through feed increased significantly with reduced phosphorus fertilization rate. Feed was the only phosphorus input source in the treatment with 0% P, which accounted for 100% total phosphorus input (Table 5).

Percentage nitrogen gain in harvested biomass was not significantly different among treatments ($P > 0.05$). However, nitrogen gained in the sediment was significantly different among treatments, and 50% P rate showed significantly lower phosphorus gained in the sediment compared with control ($P < 0.05$, Table 5). Harvested fish gained 18.5–44.9% of the total added phosphorus inputs and was significantly higher in 0% P than 25% P. Lowest phosphorus gained in biomass was observed in highest loading rate and was significantly lower than other treatments ($P < 0.05$). Nutrients trapped in sediment accounted for 34.9% to 73.7% total added nitrogen and 3.9–44.2% total added phosphorus; nitrogen percentage trapped in sediment was significantly different

  

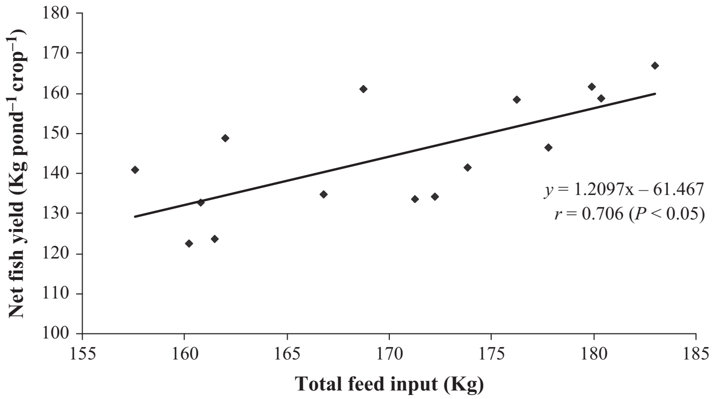


**Figure 2** Relationship between net fish yield with total feed input.

**Table 2** Total nitrogen, total phosphorus and moisture contents (%) of fish and sediment at harvest

| Parameters | (100% P) | (75% P) | (50% P) | (25% P) | (0% P) |
|---|---|---|---|---|---|
| Tilapia | | | | | |
| Moisture | 71.33 | 70.69 | 70.75 | 69.55 | 69.93 |
| TN (Dry wt) | 7.68 | 7.45 | 7.32 | 7.34 | 7.39 |
| TP (Dry wt) | 1.70 | 1.73 | 1.79 | 1.73 | 1.77 |
| Sediment | | | | | |
| Moisture | 46.61 | 43.20 | 46.83 | 46.55 | 45.70 |
| TN (Dry wt) | 0.18 | 0.18 | 0.18 | 0.17 | 0.18 |
| TP (Dry wt) | 0.11 | 0.09 | 0.08 | 0.07 | 0.09 |
| Recruitment | | | | | |
| Moisture | 77.68 | – | 77.68 | 77.68 | 77.68 |
| TN (Dry wt) | 9.26 | – | 9.26 | 9.26 | 9.26 |
| TP (Dry wt) | 1.70 | – | 1.70 | 1.70 | 1.70 |

between treatments with 100% P and 50% P ($P < 0.05$). There were significant differences in the phosphorus percentage trapped in sediments at 100% and 75%, which were higher than other treatments ($P < 0.05$). Lowest phosphorus was trapped in the 25% P rate.

## Effect of different phosphorus fertilizer doses on water quality parameters

Mean temperatures in all the treatments ranged from 28.6 to 28.9°C. Diurnal measurement showed mean early morning (6 am) DO in all treatments ranged from 0.79 to 0.93 mg L$^{-1}$ ($P > 0.05$) but mean DO concentrations at 9 am in all treatments ranged from 1.92 to 2.58 mg L$^{-1}$ and was significantly different among treatments ($P < 0.05$; Table 6). The value was highest in 100% P treatment and lowest was in 0% P treatment. Mean DO concentration in all treatments fluctuated between 1.00–4.70 mg L$^{-1}$ during the experiment. The highest DO concentration was recorded at the beginning of the experiment in all treatments. DO in all treatments showed declining trend with experiment progression, and dropped below 2.5 mg L$^{-1}$ on the 8$^{th}$ week. From 8$^{th}$ week onwards, DO values showed relatively small fluctuation in all treatments and ranged between 1.00–3.00 mg L$^{-1}$. pH ranged from 6.9 to 7.8 in all treatments during the experiment, and mean pH values were not significantly different among treatments ($P > 0.05$; Table 6). Diurnal fluctuation of DO showed early morning level was critically lower in all treatments and increased sharply with time of day. Diurnal DO, pH and temperature reached highest levels at 2 pm and then decreased gradually. Diurnal DO level decreased below 2 mg L$^{-1}$ at 10 pm. The fluctuation of DO, pH and temperature in all treatments were shown correlation with time of day (Fig. 3). The mean values of total alkalinity ranged from 94 to 104 mg L$^{-1}$ and its fluctuation showed a distinct but irregular trend over the experiment. Mean TAN values in all treatments

**Table 3** Total nitrogen budget (kg per pond)

| | Total nitrogen (kg) | | | | |
|---|---|---|---|---|---|
| Parameters | Treatment 1 (100% P) | Treatment 2 (75% P) | Treatment 3 (50% P) | Treatment 4 (25% P) | Treatment 5 (0% P) |
| Inputs | | | | | |
| Tilapia | 1.10 ± 0.00 | 1.15 ± 0.02 | 1.13 ± 0.01 | 1.13 ± 0.02 | 1.13 ± 0.02 |
| Feed | 9.84 ± 0.41 | 9.63 ± 0.52 | 9.35 ± 0.55 | 9.30 ± 0.69 | 9.61 ± 0.27 |
| Water | 1.00 ± 0.12 | 1.28 ± 0.42 | 1.68 ± 0.45 | 1.54 ± 0.20 | 1.91 ± 0.56 |
| Fertilizer | 10.10 ± 0.00 | 10.10 ± 0.00 | 10.10 ± 0.00 | 10.10 ± 0.00 | 10.10 ± 0.00 |
| Total | 22.04 ± 0.46 | 22.16 ± 0.87 | 22.26 ± 0.37 | 22.08 ± 0.88 | 22.75 ± 0.31 |
| Outputs | | | | | |
| Tilapia | 4.77 ± 0.34 | 4.48 ± 0.24 | 4.14 ± 0.34 | 4.45 ± 0.39 | 4.45 ± 0.17 |
| Water | 1.89 ± 0.15 | 2.04 ± 0.26 | 1.76 ± 0.28 | 2.51 ± 0.95 | 2.05 ± 0.51 |
| Sediment | 14.70 ± 1.50$^{a}$ | 12.25 ± 1.50$^{ab}$ | 6.87 ± 4.66$^{c}$ | 12.01 ± 1.84$^{ab}$ | 7.91 ± 3.02$^{bc}$ |
| Total | 21.33 ± 1.15$^{a}$ | 18.80 ± 1.67$^{ab}$ | 12.77 ± 5.11$^{c}$ | 19.00 ± 1.51$^{ab}$ | 14.40 ± 3.64$^{bc}$ |
| Gain | | | | | |
| Tilapia | 3.67 ± 0.34 | 3.34 ± 0.25 | 3.00 ± 0.34 | 3.32 ± 0.40 | 3.33 ± 0.18 |
| Water | 0.89 ± 0.13 | 0.75 ± 0.67 | 0.07 ± 0.73 | 0.97 ± 1.02 | 0.14 ± 0.72 |
| Sediment | 14.70 ± 1.50$^{a}$ | 12.25 ± 1.50$^{ab}$ | 6.87 ± 4.66$^{c}$ | 12.01 ± 1.84$^{ab}$ | 7.91 ± 3.02$^{bc}$ |
| Unaccounted | 0.68 ± 0.97$^{c}$ | 3.39 ± 2.49$^{bc}$ | 9.51 ± 4.91$^{a}$ | 3.10 ± 2.41$^{bc}$ | 8.33 ± 3.48$^{ab}$ |

Values are mean ± SD ($n = 3$); mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

**Table 4** Total phosphorus budget (kg per pond)

| | Total phosphorus (kg) | | | | |
|---|---|---|---|---|---|
| Parameters | Treatment 1 (100% P) | Treatment 2 (75% P) | Treatment 3 (50% P) | Treatment 4 (25% P) | Treatment 5 (0% P) |
| Inputs | | | | | |
| Tilapia | 0.25 ± 0.00 | 0.26 ± 0.00 | 0.26 ± 0.00 | 0.26 ± 0.00 | 0.26 ± 0.00 |
| Feed | 1.83 ± 0.08 | 1.80 ± 0.10 | 1.76 ± 0.10 | 1.75 ± 0.13 | 1.80 ± 0.05 |
| Water | 0.08 ± 0.03 | 0.07 ± 0.04 | 0.06 ± 0.01 | 0.06 ± 0.02 | 0.05 ± 0.02 |
| Fertilizer | 2.52 ± 0.00$^{a}$ | 1.91 ± 0.00$^{b}$ | 1.26 ± 0.00$^{c}$ | 0.61 ± 0.00$^{d}$ | – |
| Total | 4.67 ± 0.06$^{a}$ | 4.03 ± 0.06$^{b}$ | 3.33 ± 0.06$^{c}$ | 2.67 ± 0.12$^{d}$ | 2.10 ± 0.00$^{e}$ |
| Outputs | | | | | |
| Tilapia | 1.06 ± 0.12 | 1.04 ± 0.06 | 1.02 ± 0.23 | 1.05 ± 0.10 | 1.06 ± 0.01 |
| Water | 0.16 ± 0.05 | 0.14 ± 0.04 | 0.11 ± 0.01 | 0.12 ± 0.03 | 0.12 ± 0.03 |
| Sediment | 1.92 ± 0.13$^{a}$ | 1.48 ± 0.71$^{a}$ | 0.42 ± 0.35$^{b}$ | 0.09 ± 0.04$^{b}$ | 0.07 ± 0.04$^{b}$ |
| Total | 3.17 ± 0.06$^{a}$ | 2.67 ± 0.74$^{a}$ | 1.53 ± 0.60$^{b}$ | 1.27 ± 0.15$^{b}$ | 1.27 ± 0.06$^{b}$ |
| Gain | | | | | |
| Tilapia | 0.81 ± 0.12 | 0.78 ± 0.06 | 0.76 ± 0.22 | 0.79 ± 0.11 | 0.81 ± 0.00 |
| Water | 0.08 ± 0.03 | 0.08 ± 0.02 | 0.05 ± 0.02 | 0.06 ± 0.03 | 0.06 ± 0.02 |
| Sediment | 1.92 ± 0.13$^{a}$ | 1.48 ± 0.71$^{a}$ | 0.42 ± 0.35$^{b}$ | 0.09 ± 0.04$^{b}$ | 0.07 ± 0.04$^{b}$ |
| Unaccounted | 1.55 ± 0.11 | 1.37 ± 0.67 | 1.79 ± 0.58 | 1.41 ± 0.09 | 0.86 ± 0.07 |

Values are mean ± SD ($n = 3$); mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

were from 0.83 to 1.97 mg $L^{-1}$. The TAN concentration in 0% P treatment was higher than all other treatments during most samplings, the lowest mean was observed in highest phosphorus fertilizer ponds. Nitrate-N and nitrite-N in all treatments were from 1.43 to 1.99 mg $L^{-1}$ and 0.31 to 0.53 mg $L^{-1}$ respectively. Nitrate-N and nitrite-N fluctuated irregularly over the experiment. Mean nitrate-N and nitrite-N concentrations over the experiment were not significantly different among treatments ($P > 0.05$; Table 6). Mean TKN in all the treatments range from 3.53 to

**Table 5** Distribution (%) of TN and TP in different treatments

| Parameters | Treatment 1 (100% P) | Treatment 2 (75% P) | Treatment 3 (50% P) | Treatment 4 (25% P) | Treatment 5 (0% P) |
|---|---|---|---|---|---|
| Nitrogen | | | | | |
| Inputs | | | | | |
| Feed | 49.30 ± 1.01 | 48.77 ± 1.31 | 48.07 ± 1.42 | 47.90 ± 1.84 | 48.77 ± 0.70 |
| Fertilizer | 50.70 ± 1.01 | 51.23 ± 1.31 | 51.93 ± 1.42 | 52.10 ± 1.84 | 51.23 ± 0.70 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Gain | | | | | |
| Tilapia | 18.40 ± 1.66 | 16.90 ± 0.95 | 15.43 ± 1.50 | 17.10 ± 1.45 | 16.87 ± 0.97 |
| Water | 4.50 ± 0.75 | 3.87 ± 3.50 | 0.33 ± 3.72 | 5.07 ± 5.35 | 0.67 ± 3.61 |
| Sediment | $73.70 \pm 6.78^{a}$ | $62.23 \pm 9.16^{ab}$ | $34.90 \pm 22.68^{c}$ | $62.10 \pm 11.30^{ab}$ | $40.20 \pm 15.60^{bc}$ |
| Total | $96.60 \pm 4.99^{a}$ | $83.00 \pm 12.49^{ab}$ | $50.63 \pm 26.22^{c}$ | $84.27 \pm 11.66^{ab}$ | $57.77 \pm 17.58^{bc}$ |
| Unaccounted | $3.40 \pm 4.99^{c}$ | $17.00 \pm 12.49^{bc}$ | $49.37 \pm 26.22^{a}$ | $15.73 \pm 11.66^{bc}$ | $42.23 \pm 17.58^{ab}$ |
| Phosphorus | | | | | |
| Inputs | | | | | |
| Feed | $42.06 \pm 0.99^{e}$ | $48.51 \pm 1.34^{d}$ | $58.19 \pm 1.31^{c}$ | $74.00 \pm 1.32^{b}$ | $100.00 \pm 0.00^{a}$ |
| Fertilizer | $57.94 \pm 0.99^{a}$ | $51.49 \pm 1.34^{b}$ | $41.81 \pm 1.31^{c}$ | $26.00 \pm 1.32^{d}$ | $0.00 \pm 0.00^{e}$ |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Gain | | | | | |
| Tilapia | $18.47 \pm 2.61^{c}$ | $20.97 \pm 1.17^{c}$ | $25.17 \pm 7.27^{c}$ | $33.47 \pm 3.02^{b}$ | $44.90 \pm 1.05^{a}$ |
| Water | 1.80 ± 0.61 | 2.07 ± 0.51 | 1.60 ± 0.75 | 2.63 ± 1.37 | 3.30 ± 0.95 |
| Sediment | $44.17 \pm 3.59^{a}$ | $39.50 \pm 18.02^{a}$ | $13.77 \pm 11.68^{b}$ | $3.87 \pm 1.25^{b}$ | $4.20 \pm 2.08^{b}$ |
| Total | 64.47 ± 1.79 | 62.57 ± 18.82 | 40.53 ± 19.41 | 39.93 ± 4.63 | 52.37 ± 3.15 |
| Unaccounted | 35.53 ± 1.79 | 37.43 ± 18.82 | 59.47 ± 19.41 | 60.07 ± 4.63 | 47.63 ± 3.15 |

Values are mean ± SD ($n = 3$); mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

**Table 6** Water quality parameters measured biweekly

| Parameters | Treatment 1 (100% P) | Treatment 2 (75% P) | Treatment 3 (50% P) | Treatment 4 (25%P) | Treatment 5 (0% P) |
|---|---|---|---|---|---|
| Temperature (°C) | 28.6 ± 0.1 | 28.6 ± 0.1 | 28.9 ± 0.3 | 28.7 ± 0.2 | 28.8 ± 0.3 |
| DO at 9am (mg $L^{-1}$) | $2.58 \pm 0.28^{a}$ | $2.41 \pm 0.22^{ab}$ | $2.33 \pm 0.14^{ab}$ | $2.18 \pm 0.25^{bc}$ | $1.92 \pm 0.09^{c}$ |
| pH | 7.4 ± 0.1 | 7.4 ± 0.0 | 7.4 ± 0.0 | 7.4 ± 0.1 | 7.3 ± 0.1 |
| Secchi disc visibility (cm) | 11 ± 1 | 11 ± 3 | 11 ± 2 | 11 ± 0 | 12 ± 1 |
| Alkalinity (mg $L^{-1}$) | 76 ± 26 | 94 ± 14 | 76 ± 21 | 96 ± 4 | 104 ± 14 |
| TAN (mg $L^{-1}$) | 0.83 ± 0.58 | 1.05 ± 0.55 | 1.12 ± 0.91 | 1.35 ± 0.36 | 1.97 ± 1.07 |
| $NO_3$-N (mg $L^{-1}$) | 1.69 ± 0.84 | 1.84 ± 0.25 | 1.44 ± 0.45 | 1.99 ± 0.78 | 1.43 ± 0.70 |
| $NO_2$-N (mg $L^{-1}$) | 0.43 ± 0.05 | 0.31 ± 0.05 | 0.38 ± 0.10 | 0.52 ± 0.10 | 0.53 ± 0.11 |
| TKN (mg $L^{-1}$) | $7.30 \pm 0.84^{b}$ | $7.89 \pm 0.78^{b}$ | $7.94 \pm 1.07^{b}$ | $8.51 \pm 0.98^{ab}$ | $9.49 \pm 1.94^{a}$ |
| TP (mg $L^{-1}$) | $0.63 \pm 0.12^{a}$ | $0.61 \pm 0.16^{a}$ | $0.56 \pm 0.06^{ab}$ | $0.54 \pm 0.10^{ab}$ | $0.47 \pm 0.07^{b}$ |
| SRP (mg $L^{-1}$) | $0.03 \pm 0.02^{ab}$ | $0.03 \pm 0.01^{bc}$ | $0.03 \pm 0.02^{ab}$ | $0.04 \pm 0.01^{a}$ | $0.02 \pm 0.01^{c}$ |
| TSS (mg $L^{-1}$) | 188 ± 21 | 165 ± 52 | 149 ± 18 | 161 ± 37 | 130 ± 31 |
| TVS (mg $L^{-1}$) | 60 ± 7 | 54 ± 12 | 54 ± 5 | 57 ± 3 | 51 ± 4 |
| Chlo-*a* (μg $L^{-1}$) | 131 ± 29 | 132 ± 44 | 103 ± 31 | 114 ± 30 | 84 ± 13 |

Values are mean ± SD ($n = 3$); mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

16.03 mg $L^{-1}$. The TKN concentration in all treatments peaked around d 70 and thereafter showed a declining trend. The TKN concentration in 0% P treatment was higher than all other treatments during most sampling and was significantly different than 100%, 75% and 50% P over the experiment ($P < 0.05$; Table 6). Mean TP in all treatments ranged from 0.23 to 1.06 mg $L^{-1}$, and TP concentration in all treatments increased linearly over the experiment except decline at the end of the experiment. Mean TP concentrations were significantly ($P < 0.05$) higher in treatment 100%

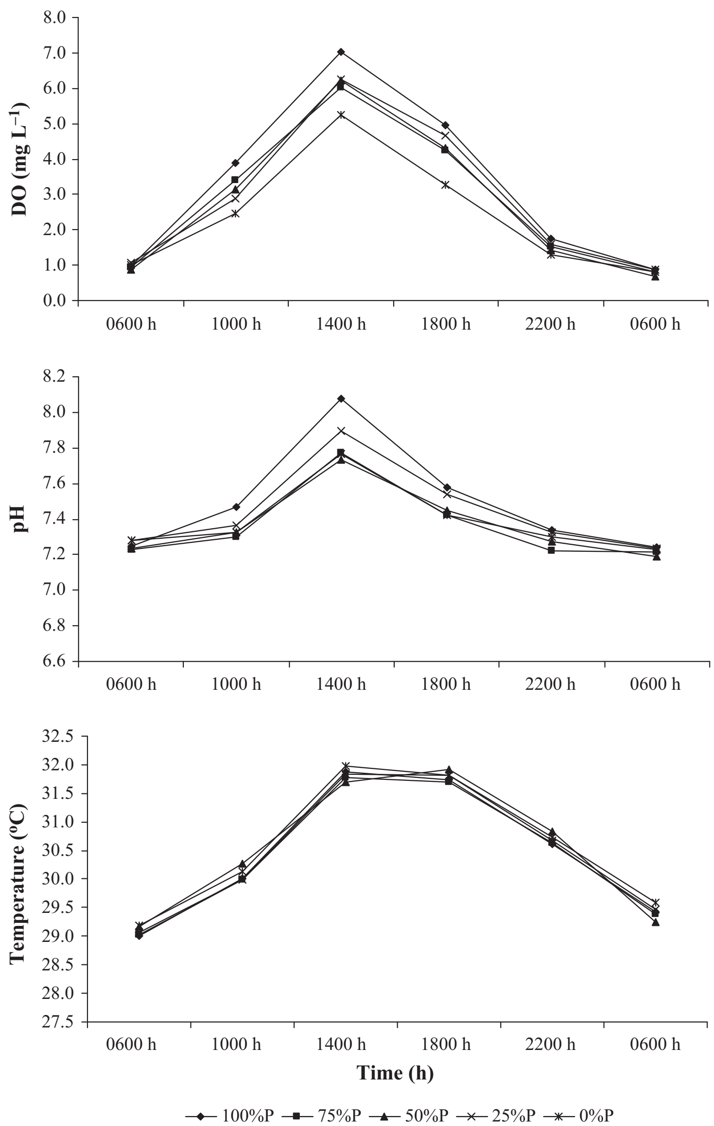


**Figure 3** Fluctuations of mean DO, pH and temperature in diurnal measurements.

P and 75% P than 0% P (Table 6), lowest value was observed in control. Soluble reactive phosphorus (SRP) concentrations in all treatments dropped throughout the experiment. There was a significant difference in mean SRP concentrations among treatments with significantly lower values found in 0% P than other treatments except 75% P ($P < 0.05$). Mean chlorophyll *a* was not significantly different among treatments ($P > 0.05$; Table 6). Chlorophyll *a* fluctuated over the experiment. The highest chlorophyll *a* (261.55 μg L$^{-1}$) concentration was observed in 100% P treatment at the end of culture, and the lowest (13.33 μg L$^{-1}$) was observed in 0% P at the beginning of culture. The lowest mean Chlorophyll *a* was observed also in 0% treatment. In general, chlorophyll *a* showed increasing trend over the culture period. Total suspended solids (TSS) and total volatile solid (TVS) increased in all treatments over the experiment. There were no significant differences in mean and final TSS and TVS values among all treatments ($P > 0.05$; Table 6). Mean and final Secchi disc depths were not significantly different among treatments. Total suspended solids (TSS) increased linearly with increasing chlorophyll *a* concentration. A positive correlation was also found between total volatile solid (TVS) and chlorophyll *a* concentration during the experiment. Secchi disc visibility decreased linearly with increasing chlorophyll *a* concentration.

  

### Partial budget analysis to compare profit in different fertilizer doses

Economic analysis indicated there were significant differences in total variable costs. The highest coast was observed in 100% P treatment and lowest was found in 25% P treatment. Gross revenue from tilapia and gross return varied among treatments. Highest cost of working capital was observed in 100% P treatments and was significantly higher than 50%, 25% and 0% P treatment. (Table 7). Comparing cost of capital, total cost and gross return 25% P treatment had comparatively higher gross returns than 75%, 50% and 0% P.

## Discussion

Results of the study showed growth was correlated with supplemental feed and in different phosphorus fertilizer doses conditions were not strongly correlated. However, it was observed supplemental feeding with lower phosphorus fertilizer dose might be better for growth and culture environment.

In the present study, some of the physical, chemical and biological variables were different among treatments, indicating all treatments might not have similar culture environments. Tilapia growth rate observed in this study is similar to those (1.74–2.15 g fish day$^{-1}$) in fed alone ponds or fertilized ponds with supplemental feeding. Results of this study are comparable to growth rate observed under similar culture conditions for different nitrogen fertilization rates with supplemental feeding. However, a higher growth rate (2.66 g fish day$^{-1}$) of Nile tilapia under continued regular pond fertilization in addition to 50% satiation feeding was also reported. Daily weight gain in all treatments fluctuated during the experiment, but, in general, showed a declining trend with culture progress. Furthermore, the relatively slower growth tilapia during the experiment corresponds to the lower dissolve oxygen concentration. This result indicates low DO concentration during night and mainly in the early morning hours in all treatments, particularly towards the latter half of culture, might have slowed Nile tilapia growth and thus, masked the treatment effects in this study might be because of the fluctuation of DO in the ponds (Tsadik & Kutty 1987).

In this study, feed conversion ratio was similar in all treatments and ranged from 1.13 to 1.24. FCR observed in this study is similar to the previous report on optimum nitrogen rates (Truc 2005). However, a lower FCR (0.87) was reported in fertilized ponds throughout culture and feeding starting from day 80 (Thakur, Yi, Diana & Lin 2004). Though there was no difference in FCR among treatments; lowest FCR was observed in the highest fertilizer treatment. Minimum fertilizer amount in supplemental feeding systems could improve water quality variables, might be feed intake in tilapia ponds was influenced by environmental factors (Zonneveld & Fadholi 1991). Final tilapia mean weights and net yield were positively correlated with total feed inputs. The results of the

**Table 7** Partial budget analysis to compare profit (US$ kg ha week$^{-1}$)

| Parameters | Treatment 1 (100% P) | Treatment 2 (75% P) | Treatment 3 (50% P) | Treatment 4 (25% P) | Treatment 5 (0% P) |
|---|---|---|---|---|---|
| Gross revenue | | | | | |
| Tilapia | 136.10 ± 8.58 | 131.63 ± 7.71 | 122.97 ± 7.44 | 127.63 ± 12.02 | 128.07 ± 8.43 |
| Variable cost | | | | | |
| Seed cost | 15.6 ± 0.0 | 15.6 ± 0.0 | 15.6 ± 0.0 | 15.6 ± 0.0 | 15.6 ± 0.0 |
| Feed cost | 91.23 ± 3.75 | 89.30 ± 4.81 | 86.80 ± 5.03 | 86.40 ± 6.36 | 89.30 ± 2.45 |
| Urea | 3.9 ± 0.0 | 3.9 ± 0.0 | 3.9 ± 0.0 | 3.9 ± 0.0 | 3.9 ± 0.0 |
| TSP | 3.80 ± 0.00$^{a}$ | 2.80 ± 0.00$^{b}$ | 1.90 ± 0.00$^{c}$ | 0.90 ± 0.00$^{d}$ | – |
| Cost of working capital | 3.27 ± 0.12$^{a}$ | 3.17 ± 0.15$^{ab}$ | 3.07 ± 0.12$^{b}$ | 3.07 ± 0.21$^{b}$ | 3.10 ± 0.10$^{b}$ |
| Total cost | 117.73 ± 3.85$^{a}$ | 114.83 ± 4.96$^{ab}$ | 111.23 ± 5.17$^{b}$ | 109.80 ± 6.53$^{b}$ | 111.90 ± 2.55$^{b}$ |
| Gross return | 18.37 ± 8.03 | 16.80 ± 7.33 | 11.73 ± 3.67 | 17.83 ± 7.41 | 16.13 ± 6.33 |
| Added cost | 5.85 | 2.93 | −0.67 | −2.07 | – |
| Added return | 2.23 | 0.69 | −4.40 | 1.68 | – |
| Added return/added cost | 0.38 | 0.24 | 6.59 | −0.81 | – |

Values are mean ± SD ($n$ = 3); mean values with different superscript letters in the same row were significantly different ($P$ < 0.05).

study indicate that under supplementary feeding conditions, growth performance of Nile tilapia was dependent on the added feed followed by the nutrient inputs.

Nutrient budgets revealed feed and fertilizer were the greatest nitrogen sources and phosphorus inputs. Supplemental feeds and fertilizers are the predominant nutrient inputs among various sources in closed ponds (Edwards 1992; Lin, Yi & Diana 1997).

The nutrient recovery harvested fish (15.43–18.40%) in the present study was similar to those (15.45–20.04%) reported previously (Lin, Teichert-Coddington, Green & Vevirica 1996). However, higher nitrogen recovery (19.26–37.14%) was observed in harvested fish in an experiment on optimum nitrogen rates (Truc 2005). Phosphorus recovery percentage (18.47–44.90%) in fish harvested in the present study was higher than those (10.02–15.10%) reported previously (Lin *et al.* 1996). Nitrogen budgets showed a large portion of the total nitrogen inputs (34.90–73.70% N) went to the sediment. In the case of phosphorus, highest phosphorus in fish body was recovered in treatment 25% P and lowest in 100% P treatment. However, a large proportion of total nutrient inputs (35.53–60.07% P) went unaccounted. The unaccounted phosphorus might have resulted from mud adsorption, as mud has strong attraction for phosphorus (Boyd 1985). Higher proportion of total phosphorus outputs in sediment was observed in the treatments with 100% and 75% P than the other treatments, and lowest was observed in 25% P treatment. This result indicates increased phosphorus fertilization rate resulted in higher phosphorus accumulation in the sediment. Similar findings showed that much phosphorus fertilizer is not used in the pond, rather than accumulated in the sediment (Masuda & Boyd 1994). Nitrogen fertilizer not removed in fish was incorporated in sediment as organic nitrogen or lost to the atmosphere through denitrification and ammonia volatilization (Gross, Boyd & Wood 2000). In the present study, nutrients contained in sediment were higher than those in the effluent water. The results are in agreement with the previous observation where they found that sediment layer of few centimetres deep contains more nutrient than the water column (Avnimelech, McHenry & Ross 1984). Unnecessary fertilizer can be harmful as well as increase production costs. It was observed from this experiment that using of 25% P fertilizer was the optimum dose for supplemental feed based earthen Nile tilapia ponds.

Water temperature during the experiment was suitable for tilapia feeding and growth (Chervinski 1982). Mean morning DO concentrations observed in this study were much higher than those reported previously (Truc 2005). The highest value was observed in the highest fertilizer loading treatment. The lowest was observed in 0% P fertilizer treatment indicating phosphorus fertilizer is correlated with pond ecosystem nutrient dynamics. Moreover, low growth of tilapia in this study, observed during the latter half of culture, was correspondent with the low DO concentrations. It was also reported that when fish fed *ad libitum*, the weight gain and feed consumption decline with decreasing dissolved oxygen level (Boyd 1990). The TP and SRP were significantly lower in 0% P treatment ($P < 0.05$). On the other hand, TKN was significantly higher in the same treatment. This indicates without phosphorus fertilizer, nitrogen fertilizer cannot be fully utilized by the pond ecosystem dynamics. Combination of both nitrogen and phosphorus in appropriate doses is the best for fish culture ponds.

However, other water quality variables were not significantly different among the treatments. In the present study, phosphorus concentration in water was not high even in the pond with the highest fertilizer rate. There was no significant difference in phosphorus concentration using lower phosphorus fertilizer dose compared with the highest dose ($P > 0.05$). The results showed higher phosphorus fertilizer rates do not necessarily result in higher phosphorus content in water column as the added phosphorous is removed from the water column by other processes; possibly sequestered in bottom sediment. Recently, in a study on bluegill, also observed higher rates of fertilizer had no effect on concentration of total nitrogen and phosphorus in pond water (Wudtisin & Boyd 2005). Aquaculture ponds receiving feeds often have total phosphorus concentrations above 0.5 mg $L^{-1}$ and total nitrogen concentrations of 2 or 3 mg $L^{-1}$ (Boyd & Tucker 1998). Total phosphorus and nitrogen concentrations in water in the present study during most of the sampling remained 0.5 mg $L^{-1}$ and 4 mg $L^{-1}$ respectively. Mean chlorophyll *a* concentration in all treatments increased gradually over the experiment. Similar types of changes in primary production were previously observed when fertilization and feeding were done (Green

  

1992). Total suspended solids (TSS) and total volatile solids (TVS) were positively correlated with the chlorophyll *a* concentration. The secchi disc visibility negatively correlated with chlorophyll *a* concentration, indicating the number of phytoplankton increased with the time of experiment. The results in this study, indicate the majority of the pond turbidity is from phytoplankton and not from clay turbidity.

The economic analysis showed positive gross return was found in all treatments. Production of treatment 25% P was higher than the treatment 50% P and 75% P. It was reported that net revenue reached \$5,029 ha year$^{-1}$ when fish were fed at 50% satiation, starting feeding at 100 g in fertilized ponds, which was highest net revenue compared with fertilized ponds and feed alone ponds (Yi, Lin & Diana 2002). Feed costs as a per cent of total costs averaged 77.49% to 79.80% for all treatments. Total production costs for the 100% P was higher than 50% P, 25% P and 0% P treatments. In this experiment, income from the sale of harvested fish was similar for all treatments. Among all treatments, 25% P of standard phosphorus application (7 kg P ha week$^{-1}$) showed feed and fertilizer costs about 78.69% and 4.37%, respectively of total production costs, which was the lowest among the treatments. It can be concluded from the research using 25% P together with nitrogen fertilizer is suitable for supplemental feed-fed based Nile tilapia ponds.

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