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A technical and economic evaluation of supplemental feeding strategies for Nile tilapia (*Oreochromis niloticus* L.) reared in lake-based cages

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Abstract

Tilapia cage farming in eutrophic lakes uses low stocking densities since tilapias can thrive mainly on natural food or minimal supplementary feeding. For semi-intensive Nile tilapia cage culture, feeding strategies to improve productivity are adopted based on technical viability and cost efficiency, as assessed in the present study. Tilapia fingerlings stocked in triplicate cages per treatment were reared in Laguna de Bay, Philippines for five months, one run each during the dry and wet seasons. The treatments were: I – UNFED or no feeding; II - FED, fish fed for the entire 155 days; III - D45, fish fed from day 45 to harvest; and IV - D75, or fish fed from day 75 to harvest. Average weight gain or AWG (153.18 g and 225.85g, for dry and wet seasons, respectively) were highest in FED. Growth parameters in all fed treatments were significantly higher ($p<0.05$) than in UNFED for both seasons. Survival rates were higher during the wet season (66-70%) compared to the dry season (35-37%). Moreover, in the wet season, when the lake's primary productivity is low, full feeding can be done without compromising lake water quality. Results showed that it favored high AWG, survival, reasonable market price, and profit.

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Introduction

This study made use of programmed or scheduled feeding in the culture of Nile tilapia in cages in Laguna de Bay, a shallow 900 km^2 eutrophic lake with a depth averaging 2.8m. Laguna de Bay (also known as Laguna Lake) is the largest lake in the Philippines. Laguna de Bay is a naturally eutrophic lake. It is highly productive due to increasing enrichment from plant nutrients, e.g., nitrogen and phosphorus, brought about by anthropogenic activities in the basin that surrounds it (Laguna Lake Development Authority, 2022). The non-occurrence of thermal overturn, which is regularly followed by bottom hypoxic conditions (2-4mgL^{-1}), indicates the lake’s eutrophic condition (Herrera and Nadaoka, 2021). These characteristics above favor primary productivity in the lake. However, primary productivity or natural food production in Laguna Lake is known to fluctuate. This is because it is highly dependent on lake processes, including saltwater intrusion, which has a preliminary clearing effect on the lake water. Such natural occurrences make the lakewater conducive for photosynthetic activity and allow plankton growth (Saguin, 2015).

The lake is a primary domestic source of milkfish, bighead carp, Nile tilapia, and several indigenous fish species obtained from aquaculture or fisheries (Santiago et al., 2005; Cuvin-Aralar et al., 2012). Adoption of supplemental feeding methods for Laguna Lake farmed fishes such as milkfish and tilapia have been limited given the availability of natural food in the lake and partly due to slightly prohibitive feed costs (Saguin, 2015). If administered wisely, meaning without seriously compromising the quality of water in the lake, complete diets given as supplemental feeds may effectively shorten the culture period for tilapias reared in the cages where farmers utilize artificial diets sparingly. The availability of feeds to the fish at a period when these are practically consumed with minimal waste would hasten the growth of tilapias that would otherwise depend mainly on the existing primary productivity in the lake. Knowing as well as when to feed farmed fish or until when fish feeding should be done for it to be still profitable, can guide the tilapia farmer in improving his production and consequently his income.

If programmed supplemental feeding is done at a suitable phase in the culture period and feeds will be utilized more efficiently, this could lead to a higher profit because of increased fish yield while incurring minimal production cost. Moreover, a well-planned supplemental feeding scheme where a feed administration schedule and good feeding practices are considered shall curb or reduce the increase in nutrient load in the lake environment caused by uneaten feeds brought about by excessive and indiscriminate feeding.

The potential of using continuous and delayed supplemental feeding schemes to increase fish yield from cages in Laguna Lake was investigated. These feeding schemes' economic viability and impact on tilapia growth, survival, and feed conversion ratio were also determined. The data generated from this study can be used in considering cost-effective feeding management protocols for sustainable semi-intensive production of tilapia in cages present in Laguna de Bay and other lake environments with similar conditions.

Materials and Methods

Similarly-sized Nile tilapia *Oreochromis niloticus* fingerlings (av. wt. = 1.63g) from the SEAFDEC/AQD hatchery were stocked in twelve 2 x 2 x 1m B-net (0.19-inch mesh size) cages at 120 fish per cage (or 30 fish m^{-3}) per run. The net pens were hung from steel frame floating modules at the SEAFDEC/AQD Binangonan Freshwater Station located in the West Bay of Laguna Lake. Fish were fed according to four feeding treatments at three replicates each. The control treatment, referred here as UNFED, had tilapia thriving mainly on natural food found in the lake. The tilapias in the three remaining treatments were given a commercial diet as follows: a) throughout the entire five-month rearing period (or FED); b) starting day 45 of the culture period onwards (or D45), and c) from day 75 onwards (or D75). The delayed feeding schemes (D45 and D75) have been included to essentially test if the tilapias can take advantage of the fish’s known capacity for compensatory growth (Cuvin-Aralar et al., 2012). Moreover, it has also been observed, albeit in semi-intensive pond culture systems, that natural food, when present, is utilized mostly by the tilapia in its early growth stages, and supplemental feeds are added at the later stages mainly for fattening (El Sayed, 2008). The same could be true for tilapia reared semi-intensively in cages in eutrophic lakes.

Feeding was done twice a day (between 0800h-0900h and 1400h-1500h). UNFED tilapias did not receive any feeds or artificial diets for the whole duration of the experiments. FED fish were initially given a commercial starter floating feed. Depending on the fish size, the feeding ration and the feed type for treatments fed the commercial diet were adjusted and changed based on a phase feeding scheme, that is, beginning with the administration of starter floating feeds, followed by fingerling floating feeds, juvenile floating feeds and finally, adult floating feeds. **Table 1** shows the nutrient composition of the phase diets with the corresponding feed costs when the experiments were conducted (from February 2014 to March 2015). When administered, feeds were given based on a sliding scheme ration or 5% of fish body weight per day during the first 15 days of feeding, followed by 3% of the fish biomass for the next 44 days. For the remaining period before harvest, fish were fed at the rate of 2% of the fish biomass, specifically for treatments FED, D45, and D75.

Table 1. The nutrient composition and cost of the different phase diets used in the study.

Feed type (floating feed)	*Nutrient*					*Cost per kg (in PhP*)*
	Crude Protein	*Crude Fiber*	*Crude Fat*	*Crude Ash*	*Moisture*	
Starter	40% min	4% max	8% min	16% max	12% max	PhP 37.^{25}
Fingerling	28% min	7% max	4% min	16% max	12% max	PhP 33.^{90}
Juvenile	27% min	8% max	4% min	16% max	12% max	PhP 32.^{90}
Adult	25% min	8% max	4% min	16% max	12% max	PhP 31.^{90}

*PhP 1 = USD 45.^{52}; reference exchange rate during the study

Two feeding runs, each lasting five months, were conducted. The first trial was completed during the dry season (from 28 February 2014 to 1 August 2014), while the second run was performed during the wet season (from 20 October 2014 to 23 March 2015). It should be noted that rains occurred during the latter part of the dry season run, while precipitation during the latter half of the wet season run was not very frequent. Monthly sampling activities were carried out where fish standard length and weight measurements were taken from 30 samples per cage except during the final sampling, where individual measurements of all the experimental fish were taken. Growth parameters were computed using the following equations:

Average Weight Gain or AWG= av. final weight at harvest – av. initial stocking weight
Specific Growth Rate or SGR= (ln (final weight) – ln (initial weight))/t x 100
Feed Conversion Ratio or FCR= feed given/fish weight gain

Survival percentages were recorded from individual fish counts per cage. Survival data were then arcsine transformed before statistical analysis. Feed rations were adjusted every two weeks, based on fish's bulk weight data taken in between monthly samplings and from the monthly individual fish sampling records. The feed consumed, estimated feed conversion ratios (FCR), and the corresponding feed costs were computed. Feed management-related data were analyzed with the growth parameters to determine the technical and economic feasibility of adopting the supplemental feeding protocols. In general, a feeding efficiency financial analysis can explain how fish growth and feed input costs are analyzed to identify optimal practical feeding management protocols in fish culture (Romana-Eguia et al., 2021).

Meanwhile, cage-specific monitoring data on the primary productivity (plankton composition) and physicochemical parameters of the lake were also regularly monitored. Water quality parameters such as temperature (°C), dissolved oxygen (in mg L^{-1}), salinity (g L^{-1}), and Secchi disk transparency (cm) were monitored daily in all cages while pH using pH meter and total ammonia nitrogen (TAN in mg L^{-1}) using an ammonia test kit were recorded every week.

Growth data were checked for homogeneity using the Shapiro-Wilk test and followed a normal distribution. The comparison of growth in terms of average weight gain (AWG, in g) and specific growth rate (SGR, in % day^{-1}), estimated feed conversion ratio (FCR), and survival rate (%) were analyzed statistically through a one-way Analysis of Variance (ANOVA) at 95% confidence interval. Means were further compared via Tukey's test to identify any significant treatment differences.

Marginal cost and marginal revenue data were computed based on the following: (a) marginal cost is the change in cost from previous to present period divided by the change in quantity from previous to present period and b) marginal revenue is the change in total revenue from previous to present period divided by the change in amount gained from previous to present period. These marginal estimates were the basis for evaluating profits or losses at each feeding phase of the four feeding programs.

Results

Growth of caged tilapias fed supplemental diets

The production parameters for all the feeding experiments conducted during the dry and wet seasons are described below and as shown in the tabulated data (**Table 2**).

Table 2 Growth, survival and FCR during the two lake-based tilapia feeding trials

Treatment	*AWG (g)*	*SGR (%/day)*	*FCR*	*Survival (%)*
		Dry season run (late February – early August)		
I -UNFED (control)	55.85 ± 2.36^{c}	2.23 ± 0.003^{c}	n.a.*	35.0 ± 4.26^{a}
II - FED	153.18 ± 6.73^{a}	2.88 ± 0.058^{a}	1.304 ± 0.151^{a}	37.3 ± 5.37^{a}
III - D45	117.39 ± 11.13^{b}	2.71 ± 0.067^{b}	1.204 ± 0.102^{b}	36.0 ± 6.01^{a}
IV - D75	106.34 ± 5.68^{b}	2.69 ± 0.166^{b}	1.093 ± 0.051^{c}	37.0 ± 2.52^{a}
		Wet season run (late October – early March)		
I -UNFED (control)	19.15 ± 1.54^{d}	1.66 ± 0.084^{d}	n.a.*	68.0 ± 2.52^{a}
II – FED	225.85 ± 10.54^{a}	3.22 ± 0.023^{a}	0.913 ± 0.010^{a}	70.0 ± 4.16^{a}
III – D45	149.26 ± 6.27^{b}	2.98 ± 0.034^{b}	0.736 ± 0.019^{b}	67.0 ± 1.86^{a}
IV - D75	92.80 ± 2.20^{c}	2.66 ± 0.026^{c}	0.721 ± 0.011^{c}	66.0 ± 4.41^{a}

*n.a. – not applicable, no artificial feeds were given

Dry season growth experiment

Tilapias in the FED treatment had a significantly higher average weight gain or AWG (153.18g, $p<0.05$) than D45, D75 treatments, and the least, is the UNFED treatment. Specific growth rates are likewise higher for the fed treatments (FED, 2.88 % day^{-1}; D45, 2.7% day^{-1}; and D75, 2.69% day^{-1}), with all three treatments being significantly different ($p=0.000$) from the UNFED tilapias. It can be noted that the SGR remained steady for fish fed the commercial diet regardless of the number of days when feeding was delayed (45 or 75 days).

Wet season growth experiment

Fish growth responses during the wet season had the same trend as the dry season trial regardless of the parameter measured where FED tilapias significantly had the best growth (AWG = 225.85g, SGR = 3.22 % day^{-1}) compared to the other fed treatments and the UNFED treatment, based on the Tukey's test. In contrast to the results of the dry season run, all treatments differed significantly from each other in terms of AWG and SGR.

Survival rate

Survival of the stocks was not significantly different among the treatments for each of the wet and dry season runs. However, the survival rates (SR) for all the treatments were higher during the wet season (66-70%) compared to that during the dry season (35-37%).

Feed Conversion Ratio

Estimated feed conversion ratios were compared among the three fed treatments. No significant differences ($p = 0.499$) were observed in all three provided treatments during the dry season. The wet season run results showed significant differences ($p = 0.000$) both statistically and biologically in the three fed treatments. Also, during the dry season, there were no differences in the FCR of D45 and D75, but both varied significantly from the FCR of the FED treatment. In the wet season run, the FED tilapia were the only stocks that reached the domestically preferred marketable size (average body weight ~ 200g) at the end of the 155-day experiment.

Primary productivity

Natural food organisms in the lake-based cages during the entire culture period were composed of green algae, namely: *Staurastrum* sp., *Pediastrum* sp., *Spirogyra* sp., *Cladophora* sp., *Scenedesmus* sp., *Pandorina* sp., *Closterium* sp, *Cosmarium* sp, and *Ankistrodesmus* sp; blue-green algae, namely: *Lyngbya* sp., *Synechocystis* sp., *Spirulina* sp., *Microcystis* sp., and *Anabaena* sp.; dinoflagellates, namely: *Glenodinium* sp. and *Ceratium* sp.; flagellate *Euglena* sp.; and diatoms, namely: *Melosira* sp., *Cyclotella* sp., *Tabellaria* sp., *Amphora* sp., *Navicula* sp. and *Fragilaria* sp.). Other organisms that were recorded were cladocerans, copepods, ciliates, and rotifers. Of all the natural food organisms, the dominant species were *Microcystis* sp., *Pediastrum* sp., *Melosira* sp., *Cyclotella* sp, *Pandorina* sp., *Ceratium* sp., and *Closterium* sp. The blue, green algae, *Microcystis* sp., is responsible for imparting off-flavor in tilapia when found and ingested by fish in high amounts. This particular algal species was observed to have dominated the plankton community in the lake mainly during the dry months, that is, from April until July (from a minimum of 86.7 cells ml^{-1} to >511 cells ml^{-1}), while the green algae *Pandorina* sp. was the dominant species during the wet season.

Lake water quality monitoring

During the dry season, DO range from 2.14– 7.19 mg $L^{-1,}$ while during the wet season, the DO ranges from 4.41-8.96 mg L^{-1}. Meanwhile, water temperatures went from 26.1°C to 33.9°C during the dry season while temperatures were lower (24.2°C to 29°C) during the rainy season. During the dry season, water was turbid from weeks 1 to 9 or days 1 – 63, with transparency readings ranging from 30-35 cm. The remaining weeks or days (days 54-155), which is the transition phase from dry to wet season or when rains start to occur, the transparency readings were slightly higher, ranging from 40-60 cm. On the other hand, during the wet season, water transparency readings had a somewhat higher lower limit (from weeks 1 – 8 or days 1 - 56) and overall readings ranging from 50-60 cm. The remaining weeks after that saw less frequent precipitation; hence the transparency readings ranged from 30-35 cm. The lake water salinity level was generally nil (0 g L^{-1}) throughout the two runs except during the dry season, specifically at weeks 14, 16, and 17 (in June) when refractometer readings ranged from 1 to 3g L^{-1}. The pH ranged from 7.2 to 8.9 for the dry season, while during the wet season, the pH levels were between 7.5 and 8.5. An ammonia test kit monitored total ammonia nitrogen (TAN) weekly. TAN levels were 0.25 to 1 mg L-1 for the dry season and 0 – 0.25 mg L^{-1} for the wet season run. The form more toxic to fish is unionized ammonia (NH_3). Actual unionized ammonia is computed from TAN using a conversion (multiplier) factor relative to the prevailing water pH and temperature at sampling. Toxicity begins from levels as low as 0.05 mg L^{-1}. In the dry season run, TAN readings of 0.5mg L^{-1} have been noted from week 14 or day 98 onwards, while the highest TAN reading of 1mg L^{-1} occurred on week 21 or a week before final sampling. At TAN of 1mg L^{-1}, NH_3 was computed at 0.011 mg L^{-1}. Although the NH_3 level could not be that toxic to the fish, its presence is a known stressor that could lead to fish mortalities. These water quality parameters were within the range that should still be favorable to tilapia farming. If at all, abrupt and prolonged fluctuations or extreme changes in the water quality parameters may cause adverse impacts on the farmed tilapias. It was observed that during the dry season, more than 60% of the total stocked fish were recorded as mortalities.

Economic Analysis

A comparative analysis of the cost of feeds used against the revenue or profit margin in the tilapia cage culture dry and wet season runs was done based on the prevailing prices and rates when the study was conducted. A summary of the estimates was tabulated (**Table 3**). The analysis accounts for the relative cost of the administration of feeds, holding all other production costs (labor, depreciation of materials, etc.) constant across treatments.

Table 3 Comparative feed cost and margin analysis, dry and wet season runs

Parameter	*Dry season run*				*Wet season run*			
	Trmt I (UNFED)	*Trmt II (FED)*	*Trmt III (D45)*	*Trmt IV (D75)*	*Trmt I (UNFED)*	*Trmt II (FED)*	*Trmt III (D45)*	*Trmt IV (D75)*
Cost* of feeds used, *PhP*	0	$285.^{00}$	$182.^{00}$	$136.^{00}$	0	$567.^{00}$	$276.^{00}$	$161.^{00}$
Total harvest, *kg*	2.4	7.0	5.3	4.7	1.7	19.2	12.1	7.5
Feed cost per kg fish, *PhP*	0	$42.^{15}$	$35.^{68}$	$29.^{85}$	0	$29.^{61}$	$22.^{94}$	$21.^{43}$
Farm gate price of fish*,*PhP* (no. of fish/kg)	$20.^{00}$ (17/kg)	$40.^{00}$ (6/kg)	$35.^{00}$ (8/kg)	$30.^{00}$ (9/kg)	$20.^{00}$ (17/kg)	$40.^{00}$ (6/kg)	$35.^{00}$ (8/kg)	$30.^{00}$ (9/kg)
Margin per kg fish,*PhP*	$20.^{00}$	$-2.^{15}$	$-0.^{68}$	$0.^{15}$	$20.^{00}$	$10.^{39}$	$12.^{06}$	$8.^{57}$
Gross margin,*PhP*	$47.^{50}$	$-14.^{99}$	$4.^{29}$	$3.^{42}$	$33.^{55}$	$201.^{24}$	$146.^{35}$	$64.^{67}$

*Based on the prevailing prices when the study was conducted

During the dry season, although the control UNFED gave the lowest total harvest (also considering the lowest market price of PhP $20.^{\underline{00}}$ kg^{-1} or USD $0.^{44}$ for this smallest fish size), the UNFED treatment showed the highest gross margin (PhP $47.^{\underline{50}}$ or USD $1.^{04}$) compared to the fed treatments since no feed costs are incurred in this treatment. D45 ranked a distant second in terms of gross margin (PhP $4.^{\underline{29}}$ or USD $0.^{09}$) from the 5.3 kg total harvest sold at a slightly higher farmgate price relative to the fish size. However, feeding on day 45 onwards produced a higher AWG and complete harvest compared with the UNFED treatment. D75 ranked a close third in terms of gross margin. Treatment FED ranked last since feeds used from day one onwards altogether cost PhP $285.^{\underline{00}}$ or USD $6.^{30}$ with a mere 7.0 kg total harvest at a survival rate of 37%; hence feed incidence cost is PhP $42.^{\underline{15}}$ kg^{-1} (or USD $0.^{93}$ kg^{-1}) of fish produced. At an AWG of 155g, a total of PhP $14.^{\underline{99}}$ (or USD $0.^{33}$) gross margin loss is estimated when the FED treatment is used.

On the other hand, in the wet season run, the FED treatment gave the highest gross margin of PhP $201.^{\underline{24}}$ (or USD $4.^{45}$) and ranked first against the other three treatments since the total feed cost incurred per kg of fish produced is only PhP $29.^{\underline{61}}$ (or USD $0.^{65}$). D45 ranked second and obtained a PhP $146.^{\underline{35}}$ (or USD $3.^{23}$) gross margin from the sale of 12.1 kg total harvest (ABW=151 g) as it can only be sold at a lower farmgate price PhP $35.^{\underline{00}}$ kg^{-1}. D75 ranked third also in terms of gross margin (PhP $64.^{\underline{67}}$ or USD $1.^{43}$), while the control (UNFED) ranked last with only PhP $33.^{\underline{55}}$ (or USD $0.^{74}$) gross margin.

On the whole, results showed that it is best to administer feeds throughout the culture period, especially during the wet season, as was noted in the FED treatment because this feeding strategy translated mainly to a higher gross margin apart from a high volume of the total harvest, high ABW and a correspondingly high fish price in the market. However, it should be noted that the survival rate in the FED treatment was not significantly different from the other treatments. Conversely, under conditions similar to the dry season, feeding for the entire rearing duration did not translate to higher SR, the total volume of harvest, and ABW. Hence, no feeding (UNFED treatment) can give optimal results during the dry season based on the gross margin. However, the gross margin is only one-fourth of those obtained from the wet season run's FED treatment, where feeds were administered from day one onwards. However, it should be noted that the UNFED tilapias harvested during the dry season were a lot smaller, or the marketable size is not the size preferred by consumers. The next best option during the dry months would be to give tilapias feeds from day 45 onwards, although the gross margin is meager at PhP 4.$^{\underline{29}}$ (or USD 0.^{09}), or to extend the rearing period altogether to about a month or even longer.

The computation of marginal cost (MC) and marginal revenue (MR) at various feeding phases for FED treatment under both runs was made (**Table 4**). Similar computations for D45 and D75 for the two runs were not pursued because these were not optimal feeding protocol options based on the gross margin. **Figures 1a** and **1b** are graphical representations of the MR and MC estimates derived in **Table 4**. MRs are estimates of the relative increase in revenue for every feeding phase, while MCs are estimates of the relative increase in feed cost for every feeding stage. The differences between corresponding MRs and MCs represent profit or loss estimates at each feeding phase. A positive difference (MR-MC) denotes profit, while a negative difference represents a loss. Figure 1a shows that during the dry season, under cropping conditions similar to the FED treatment, harvesting can be initiated at feeding phase 11 where MR-MC = 67.$^{\underline{32}}$ where ABW=120.84 g sold at PhP 30.$^{\underline{00}}$ kg^{-1} (or USD 0.^{66} kg^{-1}) on average wholesale price. This suggests that the application of additional feeds at phase 12 will incur a loss (PhP -21.$^{\underline{24}}$ or USD -0.^{47}) and at Stage 13, with a smaller profit. In the Philippines, small fish sizes (8pcs kg^{-1}) are sought by another segment of tilapia consumers with a smaller budget or for the production of processed or dried fish locally known as '*tilanggit.'* On the other hand, Figure 1b suggests that profit is most significant during the cropping phase of the wet season represented by the FED treatment at feeding phase 12 where MR-MC = PhP 128.$^{\underline{88}}$ (or USD 2.^{85}). Application of additional feeds at phase 13 will incur a loss (PhP -15.$^{\underline{20}}$ or USD -0.^{34}) because a minimal further increase in fish biomass or size does not result in a corresponding rise in fish price. Therefore, harvesting could be initiated at feeding phase 12, where ABW=188.59 g is sold at PhP 40.$^{\underline{00}}$ kg^{-1} (or USD 0.^{88}kg^{-1}) on average wholesale price. This fish size approximates the single serving or table size preference (5 pcs kg^{-1}) of a segment of tilapia consumers in the Philippines.

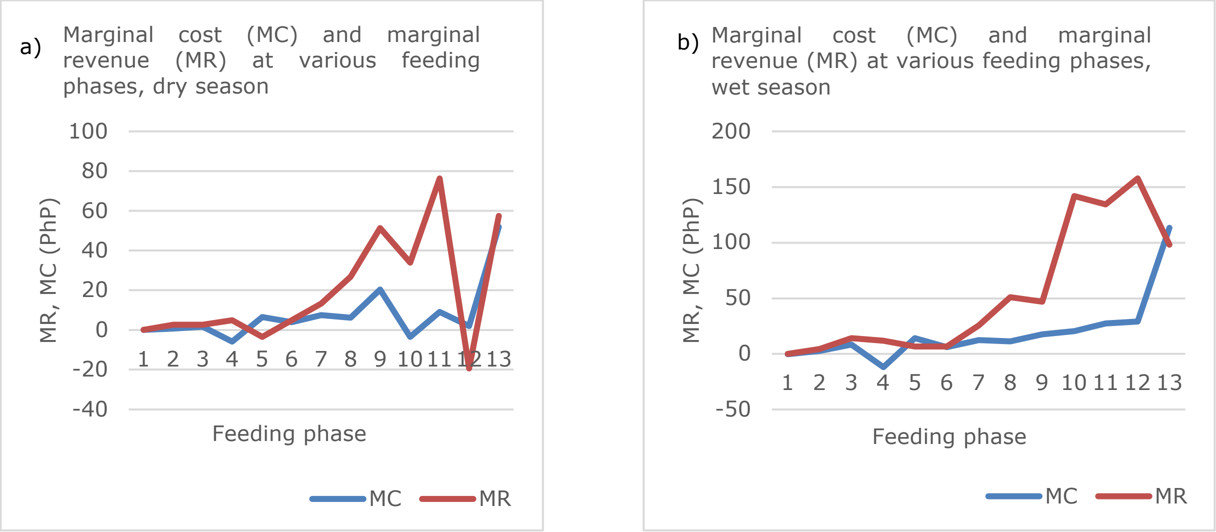

Figure 1 Marginal cost and marginal revenues at the various feeding stages using the complete feeding scheme from day 1 onwards or Treatment II (FED) for (a) the dry season and (b) the wet season.

Table 4 Computation of marginal cost (MC) and marginal revenue (MR) at the different feeding phases, (a) dry and (b) wet season runs, Treatment II (FED or feeding from day 1 onwards).

Feeding phase (duration in days d, ration in % biomass)	*Biomass (kg)*	*Feed used, kg (feed type*)*	*Cost of feeds used (PhP)*	*Marginal cost (MC, PhP)*	*Average body weight, g*	*Total revenue (PhP)*	*Marginal revenue (MR, PhP)*	*MR-MC (PhP)*
A. Dry season								
1 (14d, 5%)	0.21	0.15 (SD)	$5.^{55}$		1.77	$0.^{75}$		
2 (7d, 3%)	0.44	0.19 (SD)	$6.^{31}$	$0.^{76}$	3.69	$3.^{27}$	$2.^{52}$	$1.^{76}$
3 (7d, 3%)	0.56	0.24 (FD)	$7.^{98}$	$1.^{68}$	7.13	$5.^{94}$	$2.^{67}$	$0.^{99}$
4 (14d, 3%)	1.06	0.06 (FD)	$2.^{16}$	$-5.^{83}$	13.55	$10.^{78}$	$4.^{84}$	$10.^{66}$
5 (2d, 3%)	0.77	0.25 (FD)	$8.^{63}$	$6.^{47}$	16.12	$7.^{40}$	$-3.^{37}$	$-9.^{84}$
6 (12d, 2%)	1.31	0.37 (FD)	$12.^{43}$	$3.^{80}$	18.69	$12.^{22}$	$4.^{81}$	$1.^{01}$
7 (14d, 2%)	2.11	0.59 (FD)	$20.^{03}$	$7.^{60}$	30.08	$25.^{39}$	$13.^{17}$	$5.^{57}$
8 (14d, 2%)	2.96	0.77 (FD)	$26.^{10}$	$6.^{07}$	44.08	$52.^{20}$	$26.^{81}$	$20.^{74}$
9 (13d, 2%)	4.56	1.37 (FD)	$46.^{41}$	$20.^{31}$	67.97	$103.^{38}$	$51.^{19}$	$30.^{88}$
10 (15d, 2%)	4.73	1.31 (JD)	$42.^{94}$	$-3.^{47}$	96.90	$137.^{39}$	$34.^{01}$	$37.^{48}$
11 (14d, 2%)	5.90	1.63 (AD)	$51.^{93}$	$8.^{99}$	120.84	$213.^{70}$	$76.^{31}$	$67.^{32}$
12 (14d, 2%)	6.11	1.69 (AD)	$53.^{83}$	$1.^{91}$	136.23	$194.^{36}$	$-19.^{34}$	$-21.^{24}$
13 (14d, 2%)	6.97	3.32 (AD)	$105.^{76}$	$51.^{93}$	154.95	$251.^{87}$	$57.^{51}$	$5.^{58}$
B. Wet season								
1 (14d, 5%)	0.19	0.13 (SD)	$4.^{85}$		1.55	$0.^{58}$		
2 (7d, 3%)	0.53	0.22 (SD)	$7.^{57}$	$2.^{72}$	4.43	$4.^{72}$	$4.^{14}$	$1.^{42}$
3 (7d, 3%)	1.13	0.48 (FD)	$16.^{13}$	$8.^{55}$	10.92	$18.^{56}$	$13.^{84}$	$5.^{29}$
4 (14d, 3%)	2.05	0.12 (FD)	$4.^{17}$	$-11.^{95}$	19.77	$30.^{41}$	$11.^{85}$	$23.^{81}$
5 (2d, 3%)	2.40	0.53 (FD)	$18.^{07}$	$13.^{90}$	25.68	$37.^{03}$	$6.^{62}$	$-7.^{28}$
6 (13d, 2%)	2.76	0.71 (FD)	$24.^{18}$	$6.^{11}$	31.59	$43.^{53}$	$6.^{50}$	$0.^{39}$
7 (13d, 2%)	3.88	1.09 (FD)	$36.^{81}$	$12.^{63}$	44.42	$68.^{90}$	$25.^{36}$	$12.^{74}$
8 (14d, 2%)	5.05	1.41 (FD)	$47.^{93}$	$11.^{12}$	59.27	$119.^{73}$	$50.^{83}$	$39.^{71}$
9 (14d, 2%)	6.87	1.92 (FD)	$65.^{24}$	$17.^{31}$	80.68	$166.^{38}$	$46.^{64}$	$29.^{33}$
10 (14d, 2%)	9.33	2.61 (JD)	$85.^{94}$	$20.^{70}$	110.11	$308.^{19}$	$141.^{81}$	$121.^{11}$
11 (14d, 2%)	12.69	3.55 (AD)	$113.^{34}$	$27.^{39}$	149.54	$442.^{74}$	$134.^{55}$	$107.^{16}$
12 (14d, 2%)	15.92	4.46 (AD)	$142.^{20}$	$28.^{87}$	188.59	$600.^{48}$	$157.^{75}$	$128.^{88}$
13 (14d, 2%)	19.20	8.01 (AD)	$255.^{54}$	$113.^{34}$	227.40	$698.^{62}$	$98.^{13}$	$-15.^{20}$

*SD = starter diet, PhP $37.^{25}$/kg; FD = fingerling diet, PhP $33.^{90}$/kg; JD = juvenile diet, PhP $32.^{90}$/kg; AD = adult diet, PhP $31.^{90}$/kg

Discussion

In freshwater fish culture, whether in tanks, ponds and even in natural water bodies such as lakes, it is essential to adopt optimal feeding practices (e.g., use of appropriate feed particle size, feeding time and frequency, feeding rate, etc.) apart from using nutritionally balanced diets to improve growth and increase feed efficiency (Villaroel et al., 2011). However, supplemental feeding protocols, especially in lakes, should not compromise fish yield nor cause adverse severe ecological impacts on the environment (Richter et al., 2004; Coloso, 2012). In semi-intensive tilapia culture in general, adoption of supplemental feeding strategies (delayed feeding with commercial feed), use of mixed-feeding schedule practices, reduction of feeding rates and fertilization as well as the addition of periphyton based culture, if in ponds, could help improve yield (El-Sayed, 2008).

In the Philippines, feeds comprise 50-70% of the total variable costs in Nile tilapia (*Oreochromis niloticus* L.) farming (Borski et al., 2011; Romana-Eguia et al., 2013; Coloso, 2015). Several feeding management technologies such as alternate-day feeding (Bolivar et al., 2006), 25%, 50%, 75%, and 100% supplemental feeding (Yi et al., 2003), 45-day and 75-day delayed feeding, 67% sub-satiation feeding (Brown et al., 2000), 50% reduction of daily feed ration (Bolivar et al., 2010), have been applied in semi-intensive pond systems and have efficiently cut feed costs without a significant decrease in fish yield. Hypothetically, reduction in feed costs without a decline in fish yield can result from more efficient feed consumption (minimal waste or uneaten feeds), better feed utilization efficiency (low feed conversion ratio, FCR), or both. Meanwhile, feeding caged fish indiscriminately in eutrophic lakes has been shown to contribute to environmental pollution as evidenced by mass fish kills, etc. Feeding regimes, especially in tilapia cage farming, should be planned. The ration should be measured ahead of use to enable the fish to attain optimum growth and the best possible FCR (El-Sayed, 2013). However, using cost-effective, low polluting diets and automatic feeders, promoting optimized feeding schedules, and adopting good feeding management schemes could minimize the unwanted impacts of administering supplemental artificial feeds (Cuvin-Aralar et al., 2012).

When skipping feeding versus daily feeding were assessed in cages in selected lakes in the Philippines, no statistically significant differences were noted, especially when tried on tilapia farmed in Laguna de Bay cages (Cuvin-Aralar et al., 2012). Cost-effective feeding management schemes have likewise been tried on tilapia reared together with prawns for co-culture in Laguna de Bay net cages (Romana-Eguia et al., 2021), where daily feeding favored better growth in the farmed tilapias reared either alone or in co-culture, especially during the wet season. In this present study, it appears that daily feeding using floating feeds and following a sliding scheme ration for the entire tilapia cage rearing operations were both technically and economically feasible. Floating feeds were used to allow the farmer or technician to observe the fish's response to the meal, hence minimizing feed wastage (Prabu et al., 2018). This is particularly true for the FED tilapias reared during the wet season when natural food items were not enough for the fish to thrive, especially during the early stages.

Although mainly herbivorous, tilapias utilize natural food organisms when abundant and supplementary diets such as feed ingredients like rice bran or complete commercial diets (Romana-Eguia et al., 2020). In the present study, regardless of the season, it can be surmised that growth of the unfed stocks is due primarily to the fishes' utilization of higher amounts of natural food irrespective of whether what was abundant was mainly the blue-green algae. Tilapias are known to digest 30-60% of the protein in planktonic algae as these fish are generally herbivorous but are detritus feeders (Shelton and Popma, 2006; Prabu et al., 2018; Temesgen et al., 2022). Blue-green algal species (*Microcystis* sp*.*) abundant during the dry season could have been digested mainly by the UNFED tilapias more efficiently than green algae. It is believed that in eutrophic lakes, Nile tilapias can ingest and digest large quantities of *Microcystis*. In fact, in some countries like China, one study revealed that stocking Nile tilapia had been found to effectively control algal blooms in eutrophic waters, particularly in lakes where grazing by zooplankton cannot effectively manage phytoplankton production (Lu et al., 2006). In this present study, although it can be said that the availability of natural food organisms has somehow benefitted the tilapias that were reared in the lake during the dry season, an overabundance of the same, especially that of the *Microcystis* sp*.*, could also lead to massive fish deaths. Based on the primary productivity data collected during the dry season, *Microcystis* sp*.* was the predominant species in the cages from mid-April until the end of the culture period when rains have started to occur. However, despite the presence of natural food in the cages, it should be noted that low water transparency and occasional low dissolved oxygen conditions, high/fluctuating temperature in the rearing water in the first nine weeks of the dry season could have also adversely affected tilapia feeding behavior, growth (mainly seen in the slow-growing FED and D45 treatments) and survival in all the fed treatments during the dry season. Furthermore, since rains occurred during the latter part of the dry season (July to August), water overturn may have contributed to the high fish mortality.

It is evident in this study that indeed, in tilapia cage farming, fish growth and survival are influenced primarily by water quality, feeds, and feeding management (Schmittou, 2006; Romana-Eguia et al., 2010). Another generally accepted impact is stock quality, or when several farmed stocks with different genetic attributes or backgrounds are used (Romana-Eguia et al., 2010). However, only one type of tilapia stock was used in the present study. Moreover, in terms of feeding management, it was shown through this study that feeding fish with commercial diets and introducing these feeds at specific phases of their life cycle helped enhance growth in contrast to when these were unfed. The use of a programmed feed management scheme was shown to be still cost-effective, as evidenced by the high gross margin obtained from the wet season run (despite the high cost of the feeds consumed). Hence, the most practical scheme for farmers in rearing tilapias in a eutrophic lake such as the Laguna de Bay is to feed tilapias supplemental diets when primary productivity in the lake is low. Likewise, when fed throughout the culture period, one should provide the tilapias a good quality diet at the correct quantity (Prabu et al., 2018) and harvest them following the scheme when the potential profit earned is at its highest estimated potential value.

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