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Research article

Evaluation of oxygen budget and mechanical aeration requirements of red tilapia cage-culture in earthen ponds

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Abstract

The oxygen budget (OB) and aeration requirements were evaluated of red tilapia cage-culture in earthen ponds using two culture ponds (0.48 ha and 0.64 ha) on a commercial fish farm in Pathum Thani, Thailand. These two ponds were installed with two (3 HP) and four (2.5 HP) long-armed paddle wheel aerators, respectively. The data were collected for two consecutive crops (12 wk/crop). The results showed that the OB at night was 3.10 ± 0.08 mg/L, with 93.48 ± 0.88% total oxygen production from the aerators and 76.55 ± 2.01% of the total oxygen was consumed by fish. During the day, the oxygen budget was 10.45 ± 3.49 mg/L, with 67.08 ± 2.95 % from aerators and 91.54 ± 1.13% of the total oxygen was consumed by fish. The maximum power requirement for the aerators at night was 5.00 ± 0.20 HP/ha while during the day, no supplementary aeration was required and so the power requirement then was zero. However, the farmer used aerator power of 14.07 HP/ha for 22.5 hr/d, which exceeded the pond requirements, and the power wastage could be reduced by powering off 50 % of the aerators at night and 100% during the day unless there were a crisis. Thus, increased energy efficiency and a huge cost saving can be achieved in the production cost to farmers.

Introduction

Tilapia is one of the world's most economically viable freshwater aquaculture species, with rapid economic growth and productivity. According to Tveteras (2016), production is increasing and is expected to reach 6 million t in 2018. Among world leading producers, Thailand was reportedly able to produce more than 200,800 t of tilapia in 2016, making it the highest value among all freshwater species in the country (Department of Fisheries, 2018).

Nowadays, culture of red tilapia has increased rapidly in Thailand due to red skin color, easy cultural management, fast growth, high demand for live fish and fillet in both domestic and export markets (Pongthana et al., 2010) and also having a higher market value compared to black tilapia (Romana-Eguia and Eguia, 1999).

Based on Koranantakun and Sinchaiphanich (2006), red tilapia culture in Thailand uses mainly river cages rather than earthen ponds because of a better profit margin. However, cage culture has some disadvantages, for examples, pollution problems and fluctuating environment., Nevertheless, culturing in ponds also has some disadvantages, including needing land for building the ponds, waste

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accumulation in the pond and a high harvesting cost. To avoid the constraints of red tilapia farming in a river, farmers have tended to change to the pond-based cage-culture for several reasons, including: less pollution problems, better disease prevention, ease of harvest and less impact on the environment. Nonetheless, farmers still need more accurate management information to obtain the full benefit of high profit, especially regarding oxygen consumption and the aeration system.

Oxygen is an important factor in aquaculture and knowing the sources of oxygen production and consumption in the pond both during the day and night will enable the successful handling of aquatic animals (Tanthulwet and Pornprapha, 2001). Intensive aquaculture needs to provide aerators to produce a suitable oxygen level for all aquatic species living in the ponds. The system of raising tilapia fish in cages suspended in the earthen ponds also requires aerators and various types of aerators are used in intensive aquaculture systems, including vertical pump sprayers, propeller-aspirator-pumps, paddle wheels and diffused-air systems (Boyd, 1998b). Tanveer et al. (2018) concluded that the paddle wheel aerator is the best due to its low cost, low maintenance, ease of operation and high standard oxygen transfer rate (SOTR) as well as standard aeration efficiency (SAE) when applied in intensive pond culture systems. However, the aeration cost is the third largest cost representing about 15% of total production cost in intensive aquaculture system after post larvae and feed costs (Kumara et al., 2013). Knowledge of the oxygen budget and the mechanical aeration requirements in the pond will assist in the reduction of production costs, especially energy costs.

Therefore, this research aimed to study the oxygen budget and aeration requirements for red tilapia raised in a cage-culture in ponds.

Materials and Methods

Study area

The research was carried out in 2 red tilapia caged ponds (0.48 ha and 0.64 ha) at a commercial farm in Pathum Thani province, the central region of Thailand. In the 0.48 ha pond comprised four (7 m wide ×15 m long ×1.5 m deep) cages and initial weight stocked was 125 g with 1,600 fish/cage. Two long arm paddle wheel aerators were installed in the pond (6 HP/pond). While in the 0.64 ha pond comprised ten (5 m wide ×10 m long ×1.5 m deep) cages and initial weight stocked was 302 g with 1,000 fish/cage. Four long arm paddle wheel aerators were installed (6 HP/pond). Both ponds were fed with no less than 30% protein of pelleted feed and pH was controlled by lime solution splashing. All details are shown in Table 1 and Figs. 1(A and B). The data were collected for two consecutive crops (12 wk/crop).

Experiment 1: Evaluation of oxygen budget

The oxygen budget (OB) is the difference between oxygen production and consumption in the pond. Total oxygen available and total oxygen consumption in the earthen ponds fixed with cages stocked with red tilapia were evaluated from water quality and soil quality measurements.

Water and soil quality analysis

Biweekly sampling of water and monthly sampling of soil at the bottom of each pond were conducted to determine water and soil quality (12 wk/crop). All samples were collected from 9 am to10 am. Water temperature, dissolved oxygen (DO) and pH were measured using a YSI Professional Plus (Yellow Springs, OH, USA). Water total ammonia-nitrogen (TAN), nitrite-nitrogen (NO_2-N) and chlorophyll a (Chl-a) were measured following American Public Health Association et al. (2005). Soil organic matter, pH and total nitrogen (TN) were determined according to Jackson (1958), Chapman and Pratt (1961) and Raveh and Avnimelech (1979), respectively. Soil total phosphorus (TP) was measured using the ascorbic acid method (American Public Health Association et al., 2005) and texture was analyzed using the hydrometer method (Bouyoucos, 1961).

Oxygen budget analysis

Fish were randomly weighed and the number of individuals remaining in each cage was checked and calculated monthly until the end of the culture period (12 wk).

Table 1 Details of each commercial red tilapia earthen pond under study

Pond Management	Pond size	
	0.48 ha	0.64 ha
Number of cages in a pond	4	10
Cage dimensions by width, length, depth (m)	7×15×1.5	5×10×1.5
Initial fish size (g)	125	302
Stocking density (fish/cage)	1,600	1,000
Total number of fish (fish/ha)	13,332	15,625
Culture period (wk)	12	12
Number of aerators	2	4
Motor power (HP/pond)	6	10
Motor power (HP/ha)	12.5	15.63
Number of paddles (per aerator)	13	18
Average total biomass of fish at the harvest (kg/ha)	12,283	15,077
Protein in feed (%)	Not less than 30	Not less than 30
Number of crops before sediment removal	3	3
pH control by lime solution splashing (kg/wk/pond)	5–10	5–10

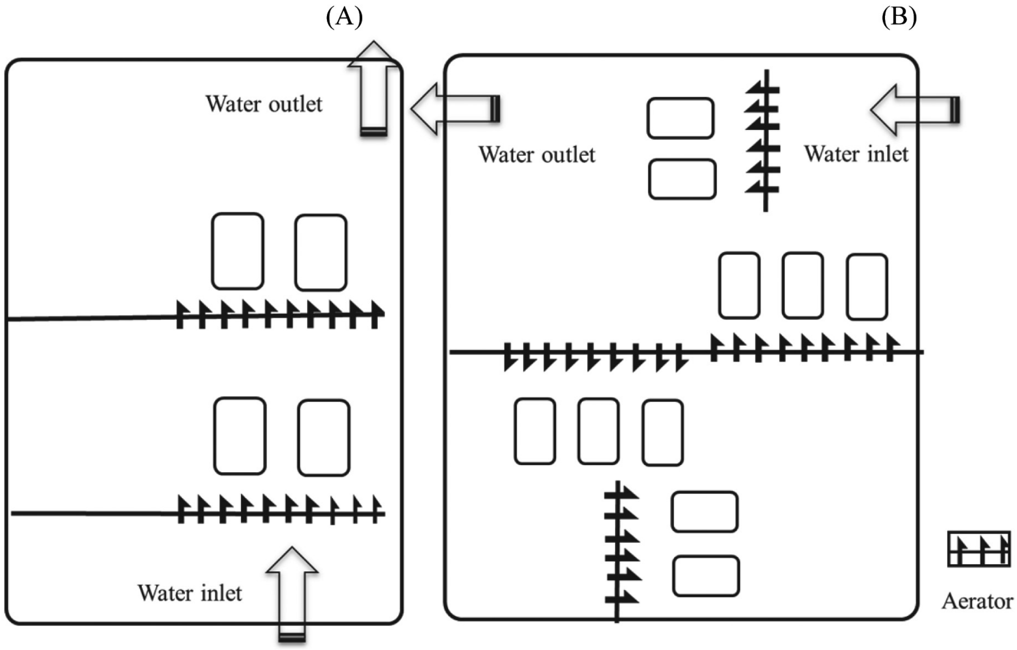

Fig. 1 A diagram showing a lay-out of cage and aerator placement in two red tilapia ponds: (A) 0.48 ha pond; (B) 0.64 ha pond

The OB in the fish ponds was determined from the difference between total oxygen production and total oxygen consumption. The OB analysis was carried out twice a day (12 hr at night, 6 pm to 6 am; and 12 hr during the day from 6 am to 6 pm) according to Equations 1 and 2, respectively:

$$OB_{(day)} = (OT + OPP + OA) – (SR + WR + FR) \quad (1)$$

$$OB_{(night)} = (OT + OA) – (SR + WR + PR + FR) \quad (2)$$

where $OB_{(day)}$ is the oxygen budget in the ponds during the day (measured in milligrams per liter); $OB_{(night)}$ is the oxygen budget in the ponds (measured in milligrams per liter during the night; OT is the oxygen transfer (measured in milligrams per liter); OA is the oxygen aerator production (measured in milligrams per liter); SR is sediment respiration (measured in milligrams per liter); WR is the water respiration (measured in milligrams per liter); PR is the plankton respiration (measured in milligrams per liter); FR is the fish respiration (measured in milligrams per liter) and OPP is the oxygen phytoplankton produced (measured in milligrams per liter).

Oxygen production calculation

The total oxygen production consisted of oxygen transfer, oxygen produced by photosynthesis and oxygen from aerator production.

1) Oxygen transfer (OT) is the oxygen in the water received from the air. It was determined by collecting the pond water temperature, converting the water temperature from Celsius to Fahrenheit ($^{o}F = 9/5 \times {}^{o}C + 32$), then the saturated oxygen at that temperature was calculated according to the method of Soderberg (1995), as shown in Equation 3. The percentage of saturated oxygen dissolved in water and oxygen transfer (OT) was calculated according to Boyd (1982), as shown in Equations 4 and 5, respectively:

$$DOs = 125.9/T^{0.625} \quad (3)$$

$$DOs\ (\%) = (DOs\ evening \times 100) / DO\ at\ that\ temperature\ (^{o}C) \quad (4)$$

$$OT = -0.0254\ Dos\ (\%) + 2.99 \quad (5)$$

where DOs is the saturated oxygen concentration (measured in milligrams per liter) at that temperature (in degrees Celsius); T is the water temperature (in degrees Fahrenheit); and DOs (%) is percentage of saturated dissolved oxygen in the water.

2) Oxygen produced by photosynthesis (OPP) was indirectly calculated from the chlorophyll-a content (Chl-a) according to Tanthulwet and Pornprapha (2001). This method was applied because this study was conducted in outdoor freshwater ponds where the phytoplankton in the ponds was mainly green algae (Equation 6):

$$OPP = 20.5\ mg/L \times Chl\text{-}a \times 12\ hr \quad (6)$$

where Chl-a is the chlorophyll-a content (measured in milligrams per liter).

3) Oxygen produced by aerators (OA) is the amount of oxygen produced by the paddle wheel aerators and transferred to the water at the actual water temperature during operation. The paddle wheel aerator generally used in Thailand has a standard oxygen transfer rate (SOTR) of 2.15 kg/hr and a standard aeration efficiency (SAE) of 1.6 kg/kw/hr (Tunsutaphanich et al., 2006).

The oxygen transfer rate (OTR) of the paddle wheel used at 20°C (OTR_{20}, kg/hr) was determined using the method of Santa and Vinatea (2007), as shown in Equation 7:

$$OTR_{20} = SOTR\ (Cs – Cm) / Cs \quad (7)$$

where Cs is the saturated oxygen level at 20^{o}C (SOTR20, measured in milligrams per liter); Cm is the lowest acceptable oxygen level in the pond (3 mg/L); and SOTR = 2.15 kg/hr (Tunsutaphanich et al., 2006).

Then, the OTR (measured in kilograms per hour) was adjusted to the actual water temperature (T, ^{o}C) using the method of Santa and Vinatea (2007), as shown in Equation 8:

$OTR_T = OTR_{20} \times 1.024^{T-20}$ (8)

Knowing the OTR rate at the actual water temperature, the oxygen produced from aerators (OA) can be calculated using the method of Santa and Vinatea (2007) using Equation 9:

$OA = (OTR_T) \times V \times 10^{-3} \times 12$ hr (9)

where OTR_T is the oxygen transfer rate to the actual water temperature in the pond (measured in kilograms per hour); V is total water volume in the pond (measured in cubic meters); and 10^{-3} is a conversion factor.

Oxygen consumption calculation

The total oxygen consumption consisted of sediment and water respiration, plankton respiration and fish respiration. Oxygen consumption was measured separately as followed.

1) The sediment respiration and water respiration of microorganisms were determined in the tubes, using a method adapted to aquaculture by Santa and Vinatea (2007), Boyd (1995) and Shapiro and Zur (1981). PVC tubes (6 tubes each 5 cm in diameter and 170 cm long) were set in three locations in each experimental pond. At each location, two tubes were vertically inserted 10 cm deep into the sediment, leaving 10 cm above the water surface. One tube was used to study the water respiration rate (WR tube) and the other was used to measure the sediment respiration rate (SR tube).

To determine the WR of microorganisms the pond water was passed through a 100 micron filter in the tank to remove sediment and plankton and then the PVC tube was filled with the filtered pond water and shaken well to ensure oxygen saturation in the tube. All tubes were opaque to avoid the water being exposed to light. The tubes were covered at both ends, the upper end with a cap that could be opened to insert an oxygen sensor (YSI Professional Plus). All tube water was measured for dissolved oxygen at three depth levels (30 cm from the surface, a middle depth and 20 cm from the bottom) and averaged. The difference in the average dissolved oxygen between 0 hr and 24 hr was considered as water respiration.

To determine the SR of microorganisms, the SR tube bottom was temporarily covered with aluminum foil which was torn out when the tube was pushed into the sediment and this allowed water and soil to enter the SR tube. The DO was measured as described above.

The water respiration (WR) and sediment respiration (SR) were determined using the method of Santa and Vinatea, (2007), according to Equation 10:

$R = (\Delta DO) \times H / T$ (10)

where R is the respiration rate (measured in grams per square meter per hour); ΔDO is the DO difference due to respiration (measured in grams per cubic meter); H is the height of water in the tube (measured in meters); and T is the incubation time (measured in hours).

2) Plankton respiration (PR) is the DO change due to the photosynthesis of phytoplankton. Water samples were collected at 30 cm under the surface, in the middle and at 30 cm above the pond bottom. Each sample was incubated in a clear bottle and a dark bottle for 10 hr (T) from 8 am to 6 pm. After that, the DO in all bottles was measured using the YSI Professional Plus. The difference in DO (measured in milligrams per liter) between the clear ($DO_{clear\ bottle}$) and dark ($DO_{dark\ bottle}$) bottles due to phytoplankton respiration was calculated according to the method of Boyd and Tucker (1992), using Equation 11:

$PR = (DO_{clear\ bottle} - DO_{dark\ bottle}) / T$ (11)

The PR values of the three water levels were averaged and this value represented the pond plankton respiration.

3) Fish respiration (FR) was estimated by multiplying the fish weight by the oxygen consumption per mass at an average water velocity of 30 cm/s (Is-haak et al., 2019). The average weight of the fish in each pond was estimated by randomly weighing approximately 60 fish monthly. The total biomass was calculated from the average weight multiplied by the survival rate and total number of the fish at initial stocking. All the fish were weighed at harvest.

Experiment 2: Evaluation of aeration requirement

The results from experiment 1 were used to calculate the energy requirements of the aerator in the pond using Equations 12 and 13:

Night OD = FR + WR + SR + PR – OT (12)

Day OD = FR + WR + SR – OT - OPP (13)

where WR is the water respiration rate (measured in grams of O_2 per square meter per hour); SR is the sediment respiration rate (measured in grams of O_2 per square meter per hour); PR is the plankton respiration rate (measured in grams of O_2 per square meter per hour): OT is the oxygen transfer (measured in grams of O_2 per square meter per hour); and OPP is the oxygen produced by photosynthesis (measured in grams of O_2 per square meter per hour).

Then, the total water volume in the pond was calculated for use in adjusting the oxygen demand based on Santa and Vinatea (2007), as shown in Equation 14:

$TOD = (OD) \times V \times 10^{-3}$ (14)

where TOD is the oxygen demand in the pond (measured in kilograms per hour); V is the total water volume in the pond (measured in cubic meters); and 10^{-3} is a conversion factor.

Knowing the oxygen transfer rate at the actual water temperature, the required number of aerators can be calculated using the method of Santa and Vinatea (2007) with Equation 15:

Number of aerators = TOD / OTR_T (15)

This study evaluated the aerator requirements every 4 wk up to the end of the 12 wk culture period. The average results were used to determine the energy demands for the aerators.

Data analyses

All data of the water quality parameters, SR, WR, PR, FR, OT, OPP, OTR, TOD, EP and Surplus (JPF-EP) were averaged for the two ponds for the two crops. The results were presented as the mean, SD and percentage.

Ethics Statements

This study was approved by the Ethics Committee of Kasetsart University, Bangkok, Thailand (Approval no. ACKU 61 – FIS – 056).

Results and Discussion

Experiment 1: Evaluation of oxygen budget

Water and soil quality

The results of water DO, temperature, pH, TAN, NO_2-N, Chl-a and transparency were 3.75 ± 0.62 mg/L, 29.15 ± 1.09°C, 7.30 ± 0.34, 0.88 ± 0.33 mg/L, 0.20 ± 0.10 mg/L, 59.34 ± 11.67 mg/m^3 and 33.24 ± 3.58 cm, respectively. They were the optimal condition for aquaculture, except for the total ammonia concentration, according to Boyd (1998a). Total ammonia was slightly too high for tilapia culture (0.88 ± 0.33 mg/L); however, the excessive amount of ammonia did not have a negative effect on the fish. This might have been due to the water pH throughout the culture period, which was good (7.30 ± 0.34) and the dissolved oxygen in the water, which was rather high (3.75 ± 0.62 mg/L). With these conditions, the ammonia was in the NH_4^+ form, which is non-toxic to aquatic animals (Boyd, 1982).

The soil organic matter, total nitrogen and total phosphorus in the experimental ponds were quite high (3.49 ± 0.67 %, 3.80 ± 0.71 g/m^3 and 1.15 ± 0.21 g/m^3, respectively) compared to the standard reported by Boyd (1995) because the farmers did not remove pond bottom sediment every time after harvesting. Nonetheless, the soil pH was 7.15 ± 0.30, which was in the acceptable range (Boyd, 1995). The pH was stable due to the fact that in both ponds, lime solution was applied weekly (5–10 kg/wk/pond) or when the water pH was under 6.5 to control the change in pH of the water and soil throughout the culture period.

Normally, fish ponds are in the open sun, so oxygen production in the fish ponds is mainly derived from phytoplankton photosynthesis, transfer of oxygen from the air and from aerators. On the debit side, the oxygen is consumed by fish and other aquatic animals living in the pond, such as microorganisms in the bottom soil and water, and plankton (Shapiro and Zur, 1981; Santa and Vinatea, 2007).

In the current study, the rate of respiration in the ponds came from sediment, water, plankton and fish. The SR tended to increase during culturing time, which was in the range 0.12–0.18 g/m^2/hr and highest in the last week, as shown in Table 2. Usually, the respiration rate of the pond sediment microorganisms varies according to the area studied, culture systems and pond management (Santa and Vinatea, 2007). In addition, Berthelson et al. (1996) reported that the SR values measured in the same pond at different points may have different values. This may be related to the water current created by aerators, wind and feeding.

The SR detected in this study was in the range 0.01–5.3 g O_2/m^2/hr which was acceptable for intensive aquaculture ponds, as reported by Avnimelech and Ritvo (2003). The increase in SR is mainly due to the organic matter deposited on the pond bottom caused by excess feed and excretion (Yuvanatemiya and Boyd, 2006). The results of the current study were consistent with Ritvo et al. (1998) and Steeby et al. (2004), who reported that the concentration of organic matter and SR in culture ponds was likely to increase during the time of farming and increased sediment on the pond bottom.

The water and plankton respiration rates were rather constant. The WR levels during the day and night were in the range 0.08–0.11 g O_2/m^2/hr, while the PR at night was in the range 0.29–0.32 g O_2/m^2/hr, as shown in Table 2. These levels resulted from the farmer commencing changing pond water in week 3 at 10%–30% of the total volume and 1–2 times per week.

During both the day and night periods, the FR throughout the culture period was in the range 0.42–0.50 gm^2/hr, as shown in Table 2. The FR had an inverse relationship with the size, so that the FR of bigger sizes was lower than that of smaller sizes. Hoar et al. (1979) stated that under steady-state conditions smaller fish exhibit a higher overall metabolic rate than larger fish. Smaller fish have a higher metabolic rate per weight unit than larger fish (Helfman et al. 2009), as the gill surface area is associated with weight and body size and has a major effect on metabolism (Pauly, 1981; Post and Lee, 1996).

During the day, the OB showed that total oxygen production of the pond was 40.28 ± 6.42 mg/L. The main source of oxygen (67.08 ± 2.95%) was from the aerators, followed by the amount of oxygen produced by photosynthesis and the oxygen transfer between air and water at 29.10 ± 3.62 and 3.82 ± 0.67%, respectively, while the total oxygen consumption was 29.83 ± 2.93 mg/L.

Table 2 Mean fish weight (MFW), fish oxygen consumption per mass (OC), sediment respiration rate (SR), water respiration rate (WR), plankton respiration rate (PR) and fish respiration rate (FR) of the red tilapia in the earthen ponds during the day and at night

Week		MFW (g)	OC* per mass	Number of fish	Respiration rate (g O_2 m^{-2}.hr^{-1}) SR	WR	PR	FR
0	Day	213.5 ± 88.5	0.13 ± 0.01	8200 ± 1800	0.12 ± 0.008	0.08 ± 0.005	0.29 ± 0.05	0.50 ± 0.05
	Night	213.5 ± 88.5	0.13 ± 0.01	8200 ± 1800	0.12 ± 0.008	0.08 ± 0.005	0	0.50 ± 0.05
2	Day	434 ± 108	0.07 ± 0.01	8023 ± 1681	0.15 ± 0.003	0.10 ± 0.003	0.30 ± 0.06	0.47 ± 0.11
	Night	434 ± 108	0.07 ± 0.01	8023 ± 1681	0.15 ± 0.003	0.10 ± 0.003	0	0.47 ± 0.11
4	Day	614 ± 36	0.04 ± 0.01	7929 ± 1665	0.16 ± 0.003	0.11 ± 0.003	0.30 ± 0.06	0.45 ± 0.10
	Night	614 ± 36	0.04 ± 0.01	7929 ± 1665	0.16 ± 0.003	0.11 ± 0.003	0	0.45 ± 0.10
8	Day	716 ± 64	0.04 ± 0.01	7898 ± 1664	0.17 ± 0.003	0.11 ± 0.003	0.31 ± 0.06	0.43 ± 0.09
	Night	716 ± 64	0.04 ± 0.01	7898 ± 1664	0.17 ± 0.003	0.11 ± 0.003	0	0.45 ± 0.10
12	Day	985 ± 35	0.03 ± 0.01	7871 ± 1665	0.18 ± 0.003	0.11 ± 0.003	0.32 ± 0.06	0.42 ± 0.18
	Night	985 ± 35	0.03 ± 0.01	7871 ± 1665	0.18 ± 0.003	0.11 ± 0.003	0	0.42 ± 0.18

Note: Values are expressed as the mean ± SD

* = fish oxygen consumption per mass (mg/L/hr/100g) of red tilapia in the same environment reported by Is-haak et al. (2019)

The main source of oxygen consumption was from fish respiration (91.54 ± 1.13%), followed by the respiration in sediment and water at 5.25 ± 0.70 and 3.21 ± 0.43 % of total oxygen consumption, respectively.

When the total oxygen production and the total oxygen consumption during the day were calculated and compared, it was found that the average dissolved oxygen at 6 pm was 10.45 ± 3.49 mg/L. This value differed from the average dissolved oxygen at that time, which in the pond was 7.10 ± 1.12 mg/L. This occurred because the average water temperature was about 30.15 ± 1.60°C and the saturated dissolved oxygen was 7.76 ± 0.14 mg/L, as shown in Table 3. When the dissolved oxygen in the pond water is greater than the saturation point, oxygen will diffuse to the air (Boyd, 1982). However, the data showed that the amount of oxygen produced was higher than the amount of oxygen consumed. This indicates the amount of oxygen was sufficient for fish demand during the day.

During the night, the total oxygen production in the ponds was 37.05 ± 4.20 mg/L. The main source of total oxygen production, was from the aerators (93.48 ± 0.88%) and only 6.52 ± 0.88% was transferred between the air and water. The average total oxygen consumption was 33.96 ± 4.11 mg/L. The major oxygen consumption was by fish (76.55 ± 2.01%), followed by phytoplankton and microorganisms at the bottom of the pond and in the water, at 14.53 ± 0.62, 5.53 ± 0.86 and 3.38 ± 0.53%, respectively.

When the total oxygen production and the oxygen consumption were calculated and compared, it was found that average dissolved oxygen in the pond water at 6 am was 3.10 ± 0.08 mg/L. This was the same as the value in the ponds, as shown in Table 3. This concurred with the explanation before, as under these conditions, the oxygen is not at the saturation point. Thus, the oxygen does not diffuse to the air (Boyd, 1982).

The results of the current experiment were not consistent with Garcia and Brune (1991) who examined shrimp ponds in Texas, USA. They reported that most of the oxygen production in the pond was from photosynthesis by phytoplankton and was used in phytoplankton respiration. This can be explained by the fact that the fish and shrimp cultures in Texas were traditional in style, meaning there was no aeration in the pond and therefore, the oxygen changes were mainly produced by phytoplankton. In the current study, a comparison between the amount of oxygen production and oxygen loss in the pond during the night, indicated that the oxygen produced was higher than oxygen used. This means that the amount of oxygen in the pond was sufficient to meet the needs of the fish. Boyd (1998a) states that the appropriate amount of dissolved oxygen in pond water should be at least 3 mg/L.

Experiment 2: Evaluation of aeration requirements in the pond

When the amount of oxygen required in the pond is greater than the oxygen transfer (OT), the amount of oxygen produced by the pond is not sufficient and an aerator needs to be installed in the pond. If the amount of oxygen required in the pond is less than the OT value, then an aerator is not required (Santa and Vinatea, 2007).

The assessment of TOD in this experiment evaluated the difference between the amount of oxygen required in the pond caused by the SR, WR, PR and FR from Table 2, and oxygen transfer (OT) from Table 3. The results showed that pond oxygen demand during the night from SR, WR and PR tended to increase throughout the culture period.

Table 3 Average oxygen budget (OB) in red tilapia cage-culture in earthen ponds during the day (6 am) and at night (6 pm) throughout culture period

Parameter	Day		Night	
	mg/L	%	mg/L	%
Pond size (ha)	0.56 ± 0.11		0.56 ± 0.11	
Number of fish per pond	8,103 ± 1,897		8,103 ± 1,897	
Average fish weight (g)	544 ± 269		544 ± 269	
Oxygen production				
Oxygen concentration transfer from the air	1.50 ± 0.03	3.82 ± 0.67	2.00 ± 0.05	6.52 ± 0.88
Oxygen concentration produced from photosynthesis	11.96 ± 3.33	29.10 ± 3.62	0	0
Oxygen concentration produced from aerators	26.83 ± 3.12	67.08 ± 2.95	35.05 ± 4.24	93.48 ± 0.88
Total oxygen production	40.28 ± 6.42	100.00 ± 0.00	37.05 ± 4.20	100.00 ± 0.00
Oxygen consumption				
Fish respiration	27.34 ± 3.02	91.54 ± 1.13	26.06 ± 3.83	76.55 ± 2.01
Sediment respiration	1.55 ± 0.06	5.25 ± 0.70	1.85 ± 0.07	5.53 ± 0.86
Plankton respiration	-	-	4.91 ± 0.39	14.53 ± 0.62
Water respiration	0.95 ± 0.04	3.21 ± 0.43	1.13 ± 0.05	3.38 ± 0.53
Total oxygen consumption	29.83 ± 2.93	100.00 ± 0.00	33.96 ± 4.11	100.00 ± 0.00
Calculated OB Oxygen	10.45 ± 3.49		3.10 ± 0.08	
Oxygen saturated	7.76 ± 0.14		-	
Oxygen measured	7.10 ± 1.12		3.10 ± 0.08	

Note: Values are expressed as the mean ± SD

This was due to the intensive culture system which needed more feed input and thus, may cause more waste accumulation (leftover feed and fish excretion) in the pond, followed by microorganism growth and plankton bloom which needs more oxygen. Fish respiration was the major oxygen consumer in the pond, and it increased with time and growth. This was similar to several studies by Boyd (1998b), Brune et al. (2003) and Vinatea et al. (2011), who carried out experiments in white shrimp ponds. The oxygen source in the pond was obtained from the OT, which was constant throughout the culture period (0.13 g O_2/m^2/hr) because the water temperature within the pond did not change much throughout the culture period. The TOD during the night, as shown in Table 4, was positive and increased continuously over time in the range 4.74–5.22 kg/hr, resulting in increasing EP in the ponds. The EP values were in the range 4.38–5.00 HP/ha, and the highest value was in week 12 (5.00 ± 0.20 HP/ha).

However, the farmer turned on all aerators, which resulted in the ponds having an average OTR increase to 14.07 ± 1.57 HP/ha. This used more power than was necessary to aerate the ponds, by up to 9.06–9.69 HP/ha, as shown in Table 4.

During the day, the second main source of oxygen was from phytoplankton (OPP) and it increased during the day in the range 1.07–1.52 g O_2/m^2/hr, or five times that of OT (0.12 g O_2/m^2/hr), which was constant throughout the culture period because of phytoplankton blooms during the day, resulting in more photosynthesis and increasing oxygen production, corresponding to Boyd (2001) who studied channel catfish (*I. punctatus*) ponds and reported that the source of oxygen in the pond during the day was photosynthesis from phytoplankton.

The TOD during the day throughout the culture period was in the range of -3.08 to -5.43 kg/hr. The EP was in the range -2.59 to -4.68 HP/ha and increased negatively indicating that the ponds did not need energy from the aerator. However, the farmer still operated the aerators throughout the culture period with an OTR of 14.07 HP/ha, resulting in energy usage to generate oxygenation that exceeded the needs of the pond throughout the culture period. The excessive values were in the range 16.66–18.75 HP/ha as shown in Table 4, which introduced waste and added to the cost.

The current study confirmed that using this culture system, the farmers did not need to turn on the aerators during the day and thus could reduce their energy costs.

In conclusion, using cage culture in an earthen pond system, the oxygen budget during the night was 3.10 ± 0.08 mg/L, with 93.48 ± 0.88% of total oxygen production from aerators and 76.55 ± 2.01 % of the total oxygen was consumed by fish. During the day, the oxygen budget was 10.45 ± 3.49 mg/L, with 67.08 ± 2.95 % from aerators and 91.54 ± 1.13 % of the total oxygen was consumed by fish.

The maximum required aerator output during the night was 5.00 ± 0.20 HP/ha and during the day no aerator operation was required. Regardless, the farmer used power (14.07 HP/ha) to operate the aerators for 22.5 hr/d, which exceeded the requirements of the pond, resulting in wasted power from 50% of the aerators during the night and from 100% during the day, unless there were some crisis situation.

Table 4 Average red tilapia fish weight (MFW), pond total oxygen demands (TOD), estimated aeration power (EP) and power use at the Jittiporn farm (JPF) during the day and at night throughout the culture period (12 wk)

Week	Time	MFW (g)	Number of fish	Water temperature (°C)	OT (g O_2/m^2/hr)	OPP (g O_2/m^2/hr)	TOD (kg/hr)	EP (HP/ha)	OTR (JPF) (HP/ha)	Surplus (JPF-EP) (HP/ha)
Initial	Day	213.5±88.5	8200 ± 1800	31.30 ± 0.20	0.12 ± 0.00	1.18 ± 0.17	-3.65 ± 1.95	-3.04 ± 1.62	14.07 ± 1.57	+17.10 ± 3.18
	Night	213.5±88.5	8200 ± 1800	27.05 ± 0.25	0.13 ± 0.01	0	4.74 ± 0.10	4.38 ± 0.06	14.07 ± 1.57	+9.69 ± 1.50
2	Day	434±108	8023 ± 1681	30.80 ± 0.20	0.12 ± 0.00	1.07 ± 0.15	-3.08 ± 1.84	-2.59 ± 1.54	14.07 ± 1.57	+16.66 ± 3.10
	Night	434±108	8023 ± 1681	26.65 ± 0.15	0.13 ± 0.00	0	4.80 ± 0.08	4.48 ± 0.07	14.07 ± 1.57	+9.59 ± 1.53
4	Day	614±36	7929 ± 1665	30.50 ± 0.10	0.12 ± 0.00	1.20 ± 0.17	-3.68 ± 1.95	-3.12 ± 1.65	14.07 ± 1.57	+17.19 ± 3.22
	Night	614±36	7929 ± 1665	26.40 ± 0.10	0.13 ± 0.00	0	4.84 ± 0.04	4.54 ± 0.02	14.07 ± 1.57	+9.52 ± 1.54
8	Day	716±64	7898 ± 1664	30.15 ± 0.15	0.12 ± 0.00	1.35 ± 0.19	-4.72 ± 2.32	-4.03 ± 1.97	14.07 ± 1.57	+18.10 ± 3.53
	Night	716±64	7898 ± 1664	25.85 ± 0.15	0.13 ± 0.00	0	4.85 ± 0.06	4.61 ± 0.05	14.07 ± 1.57	+9.46 ± 1.52
12	Day	985±35	7871 ± 1665	29.75 ± 0.25	0.12 ± 0.00	1.52 ± 0.22	-5.43 ± 2.62	-4.68 ± 2.23	14.07 ± 1.57	+18.75 ± 3.79
	Night	985±35	7871 ± 1665	25.40 ± 0.20	0.13 ± 0.00	0	5.22 ± 0.17	5.00 ± 0.20	14.07 ± 1.57	+9.06 ± 1.76

Note: Values are expressed as the mean ± SD

Conflict of Interest

The authors declare that they have no conflicts of interest.

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References

American Public Health Association, American Water Works Association and Water Pollution Control Federation. 2005. Standard Methods of the Examination of Water and Wastewater, 22th ed. United Books Press. Columbia, MD, USA.

Avnimelech, Y., Ritvo, G. 2003. Shrimp and fish pond soils: Processes and management. Aquaculture. 220: 549–569.

Berthelson, C.R., Cathcart, T.P., Pote, J.W. 1996. *In situ* measurement of sediment oxygen demand in catfish ponds. Aquacult. Eng. 15: 261–271.

Bouyoucos, G.J. 1961. Hydrometer method improved for making particle size analyses of soils. Agron. J. 54: 464–465.

Boyd, C.E. 1982. Water Quality Management for Pond Fish Culture. Elsevier Scientific Publishing Company. Amsterdam, the Netherlands.

Boyd, C.E. 1995. Bottom Soils, Sediment and Pond Aquaculture. Chapman and Hall. New York, NY, USA.

Boyd, C.E. 1998a. Water Quality in Pond for Aquaculture. International Center for Aquaculture and Aquatic Environments, Alabama Agricultural Experiment Station, Auburn University. Auburn, AL, USA.

Boyd, C.E. 1998b. Pond water aeration systems. Aquacult. Eng. 18: 9–40.

Boyd, C.E., Tucker, C.S. 1992.Water Quality and Pond Soil Analyses for Aquaculture. Alabama Agricultural Experiment Station. Auburn University, Auburn, AL, USA.

Brune, D., Schwartz, G., Eversole, A., Collier, J. Schwedler, T. 2003. Intensification of pond aquaculture in high rate photosynthetic systems. Aquacult. Eng. 28: 65–86.

Chapman, H.D., Pratt, P.F. 1961. Methods of Analysis for Soils, Plants, and Water. Univ. California, Berkeley, CA, USA.

Department of Fisheries. 2018. Fisheries Statistics of Thailand 2016. Department of Fisheries. Bangkok, Thailand.

Garcia, A., Brune, D.E. 1991. Transport limitation of oxygen in shrimp culture ponds. Aquacult. Eng. 10: 269–279.

Hoar, W.S., Randall, D.J., Brett, J.R. 1979. Fish Physiology. Volume 8. Bioenergetic andGrowth. Academic Press, Inc, New York, NY, USA.

Helfman, S.G., Collette B.B., Facey, D.E., Bowen, B.W. 2009. The Diversity of Fishes: Biology, Evolution and Ecology, 2nd ed. Wiley-Blackwell Publishing. Hoboken, NJ, USA.

Is-haak, J., Kaewnern, M., Yoonpundh, R., Taparhudee, W. 2019. Oxygen consumption rates of hybrid red tilapia at different sizes during challenge to water velocity. J. Fish. Env. 43: 57–65.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall, Inc. Englewood Cliffs, NJ., USA.

Koranantakun, K., Sinchaiphanich, C. 2006. Tilapia Cage Culture. Department of Fisheries, Ministry of Agriculture and Cooperatives. Bangkok, Thailand. [in Thai].

Kumara, A., Moulick, S., Mal, B.C. 2013. Selection of aerators for intensive aquacultural pond. Aquacult. Eng. 56: 71–78.

Pauly, D. 1981. The relationships between gill surface area and growth performance in fish: A generalization of von Bertalanffy's theory of growth. Berichte der Deutschen Wissenchaftlichen Kommission fur Meeresforschung. 28: 251–282.

Pongthana, N., Nguyen, N.H., Ponzoni R.W. 2010. Comparative performance of four red tilapia strains and their crosses in fresh and saline water environments. Aquaculture 308: S109–S114.

Post, J.R., Lee, J.A. 1996. Metabolic ontogeny of teleost fish. Can. J. Fish Aquat. Sci. 53: 910–923. doi.org/10.1139/f95–278.

Raveh, A., Avnimelech, Y. 1979. Total nitrogen analysis in water, soil and plant material with persulphate oxidation. Water Res. 13: 911–912.

Ritvo, G., Dixon, J.B., Lawrence, A.L., Neill, W.H., Speed, M.F. 1998. Accumulation of chemical elements in Texas shrimp pond soils. J. World Aquac. Soc. 29: 422–431.

Romana-Eguia, M.R.R., Eguia, R.V. 1999. Growth of five Asian red tilapia strains in saline environments. Aquaculture. 173: 161–170.

Santa, K.D., Vinatea, L. 2007. Evaluation of respiration rates mechanical aeration requirements in semi-intensive shrimp (*Litopenaeus vannami*) culture ponds. Aquacult Eng. 36: 73–80.

Shapiro, J., Zur, O. 1981. A simple in situ method for measuring benthic respiration. Water Res. 15: 283–285.

Soderberg, R.W. 1995. Flowing water fish culture. Lewis Publishers. Boca Raton, FL, USA.

Steeby, J., Hargreaves, J., Tucker, C. 2004. Factors affecting sediment oxygen demand in commercial channel catfish ponds. J. World Aquac. Soc. 35: 322–334.

Tanthulwet, M., Pornprapha, P. 2001. Water Quality Management and Waste Water Treatment in Fish Ponds and Other Aquatic Animals. Volume 1 Water Quality Management. Chulalongkorn University Printing. Bangkok, Thailand. [in Thai]

Tanveer, M., Roy, S.M., Vikneswaran, M., Renganathan, P., Balasubramanian, S. 2018. Surface aeration systems for application in aquaculture: A review. Int. J. Fish. Aquat. Stud. 6: 342–347.

Tunsutaphanich, S., Mungkung, R., Gheewala, S.H. 2006. Energy performance evaluation of aerators for shrimp farming. The 2nd Joint International Conference on "Sustainable Energy and Environment (SEE 2006)". 21–23 November 2006. Bangkok, Thailand.

Tveteras, R. 2016. Global fish production data & analysis. https://www.aquaculturealliance.org/wp-content/uploads/2017/06/Day1_RagnarTveteras.pdf, 24 April 2018.

Vinatea, L., Muedes, W., Arates, R. 2011. The impact of oxygen consumption by the shrimp *Litopenaeus vannamei* according to body weight, temperature, salinity and stocking density on pond aeration: A simulation. Acta Scientarum, Biological Science. Mariga´. 3: 125–132.

Yuvanatemiya, V., Boyd, C.E. 2006. Physical and chemical changes in aquaculture pond bottom solid resulting from sediment removal. Aquacult. Eng. 33: 199–205.