RESEARCH ARTICLE

Shading Influenced Water Quality and Seed Production of Nile Tilapia (*Oreochromis niloticus* L.) in the Hapa-within-Pond System During Warm Months

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ABSTRACT

This study evaluated the influence of shading designs on water quality and Nile tilapia seed production in hapa-within-pond system. Metal frames were installed in three 200 m^2 ponds and covered with greenhouse nets. Treatments were: no shading (NoS); top portion of frame covered (TopS); half of top and side portions of frame covered (HalfS); and top and sides of frame covered (TotalS). Twenty-four conditioned breeders (6♂:18♀) were bred on each hapa (1 m x 2 m x 1 m) installed in the ponds. Seeds were collected after 14 days. In both trials, significant differences in water temperature at 1500 h were observed among all treatments, with the lowest recorded in the TopS. The spawning rates of NoS (18.1±10.5%; 2.8±5.6%) were significantly lower than those of TopS (72.2±12.0%; 65.3±10.5%), HalfS (56.9±22.4%; 58.3±13.2%) and TotalS (66.7±23.6%; 65.3±10.5%). TotalS (8,563±3769 fry) and TopS (7,305±2491 fry) had significantly higher total seed production (TSP) than that of NoS (1,219±1150 fry) during the first trial, while TSP of HalfS (5,200±3051 fry) was comparable to those of the other treatments. During the second trial, shaded treatments had comparable TSPs but were significantly higher than NoS. For economic reasons, maximum reduction of water temperature, and optimum seed production during summer, the TopS design is recommended.

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1. INTRODUCTION

An increase in worldwide production of the aquaculture industry is needed to cope with the problem of shortage in protein food supplies, particularly in developing countries. However, with the growing human population comes more provision for global warming through the increasing carbon dioxide emission. Climate change, i.e., variations that occur in the statistical distribution of weather over extended periods (decades to millions of years), is now considered a risk to global food production and a significant threat to the quality and quantity of production (Beach and Viator 2008; Yazdi and Shakouri 2010; Hamdan et al., 2015; Myers et al. 2017). Climate change is projected to affect food security in Asia by the middle of the twenty-first century, with South Asia being the most severely affected (FAO 2016). The Philippines, along with Bangladesh, Cambodia, China, India, and Vietnam, were identified as the most vulnerable countries to global warming worldwide (Handisyde et al. 2006). This increasing air and water temperature due to climate change will risk global fish production, with freshwater fishes more likely affected than marine fishes.

Environmental changes brought about by climate change and economic limitations can hamper the growth of the tilapia aquaculture industry. Another restriction in increasing tilapia production is the limited supply of seeds. Most fishes spawn during warm seasons because warmer temperatures and more extended photoperiods are essential factors that trigger the precise timing of gamete maturation and spawning (Van Der Kraak and Pankhurst 1997; Biswas et al. 2005). However, in tropical countries, the tilapia seed production industry is affected by the increasing average water temperature, especially during the summer months leading to low seed production. The reproductive processes from gamete development and maturation to larval and juvenile development of tilapia depend on water temperature; thus, maintaining optimal rearing temperature is essential in hatchery management (Fath El-Bab et al. 2011).

Reproduction of tilapia is best at 28-30ºC (Likongwe et al. 1996; Fath El-Bab et al. 2011). Below 20°C, tilapia reproduction is inhibited and slows in 21-24°C waters, most frequently in waters above 25°C (Popma and Lovshin 1996). Above 35°C, which can occur in the afternoon during summer, tilapia reproductive performance is inferior (Bevis 1994). Moreover, water temperatures above 33°C will lead to high egg mortalities, and many hatchlings may also be very weak and eventually die (Faruk et al. 2012). Tilapia eggs and fry should therefore be reared between 25°C and 30°C, but optimal growth occurs between 28°C and 30°C (FAO 1990; Likongwe et al. 1996; Fath El-Bab et al. 2011). In the tropics, there are specific periods of the year when inland water temperatures are high beyond favorable levels for the growth and reproduction of tilapia. This problem needs to be addressed at the soonest time possible. Spawning units should therefore be designed and constructed in such a way as to meet severe climatic conditions. The use of shading structures during these periods of the year may be an option to reduce the increase in water temperature in the pond. Thus, this study assessed the effect of three shading designs on water temperature, dissolved oxygen, and seed production of Nile tilapia. Developing seed production technologies addressed to climate change will significantly help the tilapia seed production industry.

2. MATERIALS AND METHODS

The breeders used in this study were obtained and maintained at the pond facilities of the Freshwater Aquaculture Center, Central Luzon State University, Philippines. Breeders were of similar age (10 months) and weight. The male and female breeders were conditioned separately for 10 days in 2 m x 3 m x 1 m V-net enclosures and fed with commercial feeds three times a day at 2% of their body weight. Before the conditioning period, the weight of each breeder was taken, and male and female mean body weights were 338.8±2.0 g (n = 24), and 302.1±0.9 g (n = 72), respectively. The study was conducted under the authority of the university's Animal Care and Use Committee.

Four ponds (200 m^2 each) were used in the study. A metal frame (GI pipe, 2 in. diameter) with a height of 2 m was installed in each of the three 200 m^2 ponds with a water depth of one meter. A greenhouse net (CCM208-2/W-W-SLV) with 40% shading capacity was installed on top of the ponds supported by the metal frames. Four treatments were employed, namely: 1) no shading/control treatment (NoS); 2) top portion of the frame covered/shaded (TopS); 3) half of the top and side portions of the frame were covered (HalfS); and 4) top and sides of the frame were covered (TotalS). Four net enclosures (2 m x 3 m x 1 m) were installed in each pond, serving as replications. Twenty-four Nile tilapia breeders with a sex ratio of 1 male: 3 females were stocked in each breeding unit. They were fed with commercial feeds for one week, three times a day at 2% of their body weight.

Egg and fry collection was done 14 days post-stocking of breeders. The spawning rate was computed by dividing the total number of female breeders that spawned by the total number of female breeders in the net enclosure, multiplied by 100. One hundred (100) fry or egg samples were obtained from the total population and weighed to get the mean weight per fry or egg and served as the basis for the computation of the total number of fry or egg produced. The total number of fry produced per breeder or hapa was estimated by getting the total bulk weight of the population to reduce stress. The same procedure was done for the collected eggs to estimate the absolute fecundity. Collected eggs were artificially incubated until they were hatched. Then, hatched eggs or yolk-sac fry were counted and added to the total number of previously recorded fry to come up with the total seed production. The hatching rate was computed by dividing the total number of hatched eggs or yolk-sac fry by the total number of eggs incubated, multiplied by 100. Top and bottom dissolved oxygen (DO) levels and water temperature were monitored four times daily at 900, 1100, 1300, and 1400 h using the YSI DO meter, Model EcoSense® DO200A. Top readings were taken 5 cm from the water surface, while bottom readings were taken 75 cm from the water surface. Two breeding trials were done, each for 14 days, and both trials were done during the warm or dry season (April and May). The two trials were two weeks apart (for conditioning of breeders), and the same set of breeders used in the first trial was used but distributed randomly in the second trial.

Percentage data were arcsine transformed before statistical analysis. All data were analyzed using Analysis of Variance (ANOVA), and significant mean differences were determined using Least Significant Difference.

3. RESULTS

On water quality, generally, at 900 and 1100 h periods, there were several days that the DO concentrations were below the ideal concentration of >5 mg/l (Table 1). However, at 1300 and 1500 h, the DO concentrations were within the ideal concentration. The temperature readings for the pond water's top and bottom layers in trials 1 and 2 showed the same pattern. The mean DO concentrations were significantly highest in NoS at 0900, 1100, 1300, and 1500 h, followed by HalfS, TopS, and the lowest was recorded in TotalS. During the first trial, there were treatments with insignificant differences during the 1100 (i.e., Nos and TopS) and 1300 h (i.e., Nos and TopS; NoS and HalfS).

The temperature peak in both the top and bottom layers was recorded at 1500 h and the lowest at 900 h. For the top layer, in both trials, NoS showed significantly highest mean temperature among all treatments, followed by HalfS, TotalS, and TopS, except in trial 2 at 900 and 1100 h, where mean temperature readings in NoS were comparable to those of HalfS (see Table 2). At 1500 h, a significant difference in the mean temperature readings was observed among all treatments in both the first and second trials. The lowest temperature was recorded in the TopS treatment.

Table 3 shows the mean±S.E. of the breeders' absolute fecundity (AF) during the first and second trials. No significant differences were observed among the three shaded treatments on the first [TopS (549.0±69.1 eggs/breeder); TotalS (533.5±24.3 eggs/breeder); HalfS (508.3±6.7 eggs/breeder)] and second trials [TopS (554.0±71.0 eggs/breeder); TotalS (541.5±41.5 eggs/breeder); HalfS (542.3±34.7 eggs/breeder)]. However, during the first trial, NoS (402.0±24.1 eggs/breeder) had significantly lower mean AF than those in the three shaded treatments. On hatching rate (HR), the mean ranged from 59.4±7.1% (TotalS) to 66.5±4.2% (TopS) during the first trial and 59.5±3.8% (HalfS) to 64.6±5.6% (TotalS) during the second trial. No HR was recorded in NoS since there was no egg collected. Statistical analysis showed no significant differences in mean HR among the different treatments in both trials.

Table 4 shows the fish's spawning rate (SR) during the first trial. No significant difference was observed among the three shaded treatments [TopS (72.2±12.0%); TotalS (66.7±23.6%); HalfS (56.9±22.4%)]. However, during the second trial, TopS (77.8±16.4%) and TotS (65.3±10.5%) had significantly

Table 1. Summary of average readings for dissolved oxygen concentrations on the top layer of the ponds during the breeding period for warm season trials.

Treatment	Mean (±S.E) Dissolved Oxygen Concentration (mg/l)							
	900 h		1100 h		1300 h		1500 h	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
NoS	3.97±0.07[a]	4.13±0.09[a]	4.64±0.08[a]	4.83±0.13[a]	5.98±0.19[ab]	6.29±0.21[a]	6.73±0.18[a]	7.07±0.24[a]
TopS	3.84±0.02[c]	3.96±0.01[c]	4.43±0.01[b]	4.50±0.01[c]	5.47±0.01[a]	5.70±0.01[c]	6.34±0.02[c]	6.54±0.01[c]
HalfS	3.92±0.02[b]	4.05±0.02[b]	4.60±0.05[a]	4.72±0.05[b]	5.82±0.09[bc]	6.10±0.10[b]	6.48±0.03[b]	6.81±0.07[b]
TotalS	3.67±0.06[d]	3.76±0.07[d]	4.32±0.07[c]	4.31±0.10[d]	5.24±0.14[d]	5.44±0.16[d]	5.97±0.12[d]	6.08±0.18[d]

Means (n=4) in a column superscripted with different letters are significantly different at 5% level (P <0.05)

Table 2. Summary of average readings for water temperature on the top layer of the ponds during the breeding period for warm season trials.

Treatment	Mean (±S.E) Water Temperature (°C)							
	900 h		1100 h		1300 h		1500 h	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
NoS	30.8±0.8[c]	30.7±0.8[c]	32.4±0.8[d]	33.0±0.8[c]	34.4±1.0[c]	35.1±1.3[d]	35.0±1.4[d]	35.7±1.4[d]
TopS	28.9±0.5[a]	28.9±0.6[a]	29.8±0.3[a]	30.0±0.6[a]	31.0±0.6[a]	31.5±0.9[a]	31.5±0.6[a]	31.9±0.9[a]
HalfS	30.1±0.4[b]	30.2±0.8[bc]	31.5±0.4[c]	32.3±0.8[c]	32.8±1.0[b]	34.0±1.3[c]	33.5±0.8[c]	34.4±1.2[c]
TotalS	29.7±0.4[b]	29.7±0.7[b]	30.9±0.5[b]	31.1±0.6[b]	32.2±0.7[b]	32.7±0.8[b]	32.5±1.0[b]	33.0±1.0[b]

Means (n=4) in a column superscripted with different letters are significantly different at 5% level (P <0.05)

Table 3. Summary of average absolute fecundity and egg hatching rate for the two trials conducted during warm season.

Treatment	Mean (±S.E) Absolute Fecundity (eggs/ breeder)		Mean (±S.E) Hatching Rate (%)	
	Trial 1	Trial 2	Trial 1	Trial 2
NoS	402.0 ± 24.1[b]	-	61.3 ± 4.4[a]	-
TopS	549.0 ± 69.1[a]	554.0 ± 71.0[a]	66.5 ± 4.2[a]	63.9 ±3.9[a]
HalfS	508.3 ± 6.7[a]	542.3 ± 34.7[a]	61.0 ± 5.7[a]	59.5 ± 3.8[a]
TotalS	533.5 ± 24.3[a]	541.5 ± 41.5[a]	59.4 ± 7.1[a]	64.6 ± 5.6[a]

Means (n=4) in a column superscripted with different letters are significantly different at 5% level (P <0.05)

Table 4. Summary of average spawning rate and total seed production for the two trials conducted during the warm season.

Treatment	Mean (±S.E) Spawning Rate (%)		Mean (±S.E) Total Seed Production (number of fry)	
	Trial 1	Trial 2	Trial 1	Trial 2
NoS	18.1 ± 10.5[b]	2.8 ± 5.6[c]	1219 ± 1150[b]	143 ± 286[b]
TopS	72.2 ± 12.0[a]	77.8 ± 16.4[a]	7305 ± 2491[a]	10803 ± 3892[a]
HalfS	56.9 ± 22.4[a]	58.3 ± 13.2[b]	5200 ± 3051[ab]	8262 ± 3288[a]
TotalS	66.7 ± 23.6[a]	65.3 ± 10.5[ab]	8563 ± 3769[a]	10302 ± 2263[a]

Means (n=4) in a column superscripted with different letters are significantly different at 5% level (P <0.05)

higher mean SR than that of HalfS (58.3±13.2%). The mean SRs of NoS were very low for both trials (18.1±10.5%; 2.8±5.6%) and were significantly lower than those of TopS, HalfS, and TotalS.

On total seed production (TSP), TotalS (8,563±3769 fry) and TopS (7,305±2491 fry) had significantly higher mean TSP than that of NoS (1,219±1150 fry) during the first trial, while the mean TSP of HalfS (5,200±3051 fry) was comparable to those of the other three treatments. During the second trial, shaded treatments had comparable mean TSPs [TopS (10,803±3892 fry); TotalS (10,302±2263 fry); HalfS (8262±3288 fry)] but were significantly higher compared to that of NoS (143±286 fry).

4. DISCUSSION

Shading the breeding pond can reduce the pond water's mean dissolved oxygen concentrations. As expected, the greater the area of the pond shaded, the lower the dissolved oxygen concentrations in the water. This may be attributed to the lower dissolved oxygen production due to photosynthesis. As the light intensity decreases (i.e., due to shading), the rate of photosynthesis also decreases, as there is less light available to drive the reactions of photosynthesis (Wimalasekera 2019).

Shading the breeding area can also reduce mean water temperature during dry summer months by as much as 3.8 °C during the hottest period of the day. However, evaluating the three different shading designs indicated that top shading was the most efficient in reducing water temperature during the hottest period of the day compared to half and total shading designs. In the case of the half-shading design, only half of the water's surface area was covered. However, although the whole steel frame was covered with netting materials, the total shading design trapped heat inside the shading structure, causing a mean water temperature at 900 h higher in total shading than in top shading treatment.

Tilapia's reproductive performance is greatly affected by their environments, such as the soil and water's physical, chemical, and biological characteristics, which may impose stress on them (Vera Cruz et al. 2020). Tilapia, like all other coldblooded animals, are affected by the temperature of the surrounding water, which in turn influences the body temperature, food consumption, feed conversion efficiency, growth rate, egg production, and other body functions (Britz et al. 1997; Azevedo et al. 1998; El-Sayed and Kawanna 2008; Nivelle et al. 2019). The influences of temperature on tilapia growth and reproduction depend on the strain/species and age. This is also affected by the duration of exposure of the fish, geographical location, culture and breeding system, and other environmental factors (El-Sayed 2006). Temperature is a fundamental physical regulatory factor in the lives of fish. It controls all reproductive processes from gamete development and maturation, ovulation and spermiation, spawning, embryogenesis, and hatching to larval and juvenile development, growth, and survival (Pankhurst and Munday 2011).

Although tilapia are thermophilic fish that can tolerate a wide range of water temperatures, the exceptionally high temperature of water (>36° in the afternoon) during summer in tropical countries brought about by climate change inhibits the fish from reproducing. The growth of *O. niloticus* is optimum at 28-30˚C (Likongwe et al. 1996; El-Sayed and Kawanna 2008; Fath El-Bab et al. 2011), and it is also at this temperature range that favors reproduction. The temperature significantly affects egg production and spawning of *O. niloticus*, so it should be carefully maintained for better tilapia seed production (Faruk et al. 2012). The rate of the development of eggs and fry of tilapia is temperature-dependent; thus, maintaining optimal breeding temperature is essential (Fath El-Bab et al. 2011; Faruk et al. 2012). El Sayed (2006) found that the effect of nychthemeral rhythm in tilapia is very evident. They spawn at a specific time of day at a favorable temperature (28–32°C) and photoperiod, and rest at night. Since spawning occurs during the daytime, the temperature during the day must be within the level favorable for reproduction. According to Popma and Lovsin (1996), tilapia reproduction is most frequent in waters above 25°C, less frequent in 21 to 24°C waters, and inhibited at water temperatures below 20°C. However, water temperatures above 33°C decreased seed production. The significantly lower fecundity at higher temperatures in this study is supported by the study of Faruk et al. (2012) that egg production decreased with increased water temperature. A maximum number of eggs was produced at 25°C and a minimum at 33°C. This is also supported by Bevis (1994), who found that tilapia reproductive performance had been very poor at temperatures higher than 35°C, which can occur between 1300 to 1500 h in the afternoon during the dry season in the tropics. This poor reproductive performance results from poor egg development and low egg production at high temperatures.

This study showed that when the water temperature reached 36°C, it affected reproduction, as shown in the control treatment (NoS). Water temperature in ponds is affected by water depth, light penetration, season, and pond morphology. Shallow ponds usually have a higher temperature, especially during the summer, affecting all other water parameters and biochemical processes essential to fish production and reproduction. Due to climate change, a rise in temperature in ponds is observed. An increase of a few degrees in water temperature can set off ecological changes that will affect most aquatic life forms (Pandit and Nakamura 2010). Due to this climate change, several approaches should be undertaken and practiced to address the different problems. In tilapia seed production, one solution is installing a shading structure to regulate the extreme rise of water temperature during summer, thus making it favorable for reproduction.

Shading can increase the absolute fecundity of the breeders, the spawning rate by 28 times (mean of 2.8% in NoS compared to 77.8% in TopS), and can increase seed production by as much as 75.5 times (mean of 143 fry in NoS compared to 10,803 fry in TopS). Furthermore, TopS design will require lesser materials, especially regarding the net and frame, and lesser labor cost during installation than TotalS design. Finally, in using a shading structure, it is recommended to cover the top of the frame with netting material for economic reasons, maximum reduction of water temperature, and optimum seed production during summer.

5. CONCLUSION

Shading the breeding unit using a greenhouse net with 40% shading capacity can significantly reduce the water temperature. At the hottest period of the day (1500 h), the lowest temperature can be obtained using the top-portion-of-frame-covered-design (TopS). The absolute fecundity, spawning rates, and total seed production of the breeders can be significantly increased using all shading designs. However, for economic reasons, maximum reduction of water temperature, and optimum seed production during summer, the TopS design is recommended.

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AUTHOR CONTRIBUTIONS

Vera Cruz EM: Conceptualization, Visualization, Methodology, Supervision, Writing - Review and Editing. **Jimenez EBT**: Data curation, Investigation, Software, Writing - Original draft preparation, Validation. **Bartolome ZP**: Conceptualization, Visualization, Investigation.

CONFLICT OF INTEREST

To the best of our knowledge, no conflict of interest exists.

ETHICS STATEMENT

The study was conducted following the protocol suggested by the Animal Care and Use Committee of the University.

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