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Effects of seasonal and environmental changes on aquaculture production in tropical Lake Volta, Ghana

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Abstract

Globally, aquaculture production is faced with numerous challenges, notable among which is water quality. The study determined seasonal environmental changes in Lake Volta and its implications on cage production of Nile tilapia, *Oreochromis niloticus* in experimental and commercial farm (Sun Woo Farm) set-ups. For each set-up, three cages were used, each measuring 81 and 162.5 m^3 for experimental and commercial, respectively. The cages were stocked with 22.5 g fingerlings at a rate of 40 and 80 m^{-3} in experimental and commercial cages, respectively, and fed commercial diet. The growth performance, yield, economics, and selected water quality parameters were monitored during the dry and wet seasons between November 2014 and July 2015. There were no differences in water quality parameters between dry and wet seasons ($p > 0.05$). Water quality for both seasons remained within limits required for good Tilapia growth in both set-ups. There were minimal variations in growth characteristics between seasons which were not significant; however, final mean weight and yields were high in the dry seasons in both set-ups. The cost of feed and fingerling accounting for about 80% of total costs were the major components identified to affect cost of production. A higher profit index and returns on investment were observed in the dry season in both set-ups and was linked to higher survival rates in the season. Production of Nile tilapia in cages can be cultured throughout the year without any adverse effects as exhibited in similar production patterns in both experimental and commercial set-ups.

Keywords Lake Volta · Nile tilapia · Production · Profit index · Water quality · Wet and dry seasons

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Abbreviations

APHA	American Public Health Association
BW	Body weight
CSIR-WRI	Council for Scientific and Industrial Research - Water Research Institute
CP	Crude protein
DO	Dissolved oxygen
FR	Feeding rate
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
MOFAD	Ministry of Fisheries and Aquaculture Development

Introduction

The global trend of aquaculture is gaining importance in the contribution to total fish supply due to decline in capture fisheries and also the need to utilize existing inland waters for food production (De Silva and Phillips 2007). World aquaculture production of fish accounted for 44.1% of total production from capture fisheries and aquaculture in 2014, increasing from 42.1% in 2012 and 31.1% in 2004 (Food and Agriculture Organization (FAO) 2014, 2016a). This development has contributed significantly to the economies of many nations globally.

In Ghana, fisheries constitute an important sub-sector in the national economy contributing 4.5% of national gross domestic product (GDP), in 2013 (Ghana Statistical Service 2014) and is the most important source of animal protein as compared to livestock production. It provides more than 60% of protein requirement of the population (Aggrey-Fynn 2001; FAO 2006), one of the highest in sub-Saharan Africa (FAO 2004, 2016b). Despite its contribution to the national GDP, fish deficit is estimated at 600,000 tons worth over US$200 million of imports per annum (FAO 2016b). Capture fisheries has shown a decline since 1999, from almost 420,000 to 202,000 tons in 2014 mainly as a result of increase in effort (number of fishermen and canoes) and the use of highly efficient gears which catches all sizes of fish resulting in overfishing (FAO 2016b). However, aquaculture production increased from 1200 tons in 2005 to 38,500 tons in 2014 (FAO 2016b) due to the government's effort in supporting farmers with technical support services such as training of hatchery operators and improvement of selective breeding programs to boost production (FAO 2016b). Aquaculture therefore has a great potential to bridge the huge gap existing between fish demand and supply and also ensure food security in the country.

Lake Volta is Ghana's most important source of inland fishery and for the mainstay of cage aquaculture in the country. Currently, freshwater fish production from cages accounts for more than 80% of aquaculture production in the country, supporting the livelihood of over 2.2 million people (Seini et al. 2004; Ministry of Fisheries and Aquaculture Development (MOFAD) 2012; Kassam 2014). The Nile tilapia, *Oreochromis niloticus*, is the major species farmed and constitutes about 80% of aquaculture production with the catfishes (*Clarias* sp., *Heterobranchus* sp.) and *Heterotis niloticus* accounting for the remaining 20% (Kassam 2014; FAO 2016b).

Despite the enormous benefits derived from aquaculture such as the provision of food fish for the population and the generation of employment, the industry is faced with numerous challenges, notable among them are inadequate supply of quality fingerlings and feed, survival, and changes in environmental conditions and its effects on production and profitability.

It is evident that seasonal variation and the culturing activity in the aquatic environment has an impact on growth performance, survival and yields on aquaculture production (Casselman et al. 1999; King et al. 1999; Brander 2010). These changes in the biophysical and chemical characteristics of the aquatic environment have significant effects on the ecosystem that support fish and can alter growth and feeding behavior of cultured fish. The potential impacts on fish farming activities cannot be attributed to one single factor of environmental change; often, it is a combination of confounded effects that become causative and not a single recognizable factor (De Silva and Soto 2009). Some of the critical parameters affecting the aquatic environment include water temperature, dissolved oxygen, suspended solids, pH, and ammonia (Timmons et al. 2001).

Water temperature is one of the most important physical variables affecting fish growth and production (Viadero 2005). Fish are cold-blooded animals which assume approximately the same temperature as their environment (FAO 2008), hence changes in temperature above or below tolerance ranges of the habitats is expected to have a significant influence on general metabolism and hence implications for growth and therefore total production (Otterlei et al. 1999; Peck et al. 2006).

Feed which accounts for about 70% of operation cost is another important factor influencing performance of cultured fish and is affected by factors such as quality (nutritional and physical characteristics of the feed), feeding frequency, and environmental factors (Alemayehu and Getahun 2017). Environmental factors also affect pellet stability and leaching rates which in turn affect the quality of the environment (Riche et al. 2004). In ensuring best feeding practices, good water quality management of cultured fish is a critical husbandry practice that can boost the production capacity and efficiency of a culture system in addition to determining the economic viability of production system in intensive aquaculture (Ronald et al. 2014).

The climate of Ghana is characterized by two main seasons: the wet and the dry seasons. The wet season, characterized by rainfall, occurs between March to July and September to October with the heaviest rainfall occurring in June. This causes lower water temperatures and mixing of the waters (van Zwieten et al. 2011). The dry season, typically occurring from November to February, brings dry and warm temperatures, rainless conditions, and haze originating in the Sahara (van Zwieten et al. 2011). These seasonal variations are expected to influence the quality of the aquatic environment with changes in biophysical and chemical parameters resulting in changes in feeding behavior, survival, and growth of cultured fish.

Several studies on the lake with respect to cage farming has focused on the sustainable development of the aquaculture practice, the potential impacts of water quality on cage fish farming, and production economics of tilapia in cages (Ofori et al. 2010; Asmah et al. 2014; Odei 2015; Osei-Konadu 2015; Karikari 2016). However, seasonal environmental changes and its implications on cage culture production in the lake is still unknown and of great interest to fish farmers and lake managers. This work therefore aimed at determining seasonal effects on fish production and seasonal environmental changes in the lake and its implications to cage fish production. To secure standardized and fully controlled feeding and growth measurements, results from an experimental cage aquaculture was compared with similar results from a commercial cage aquaculture.

Materials and methods

The study was carried out in Stratum II of Lake Volta which lies within longitudes 0° 20′ E and 0° 08′ W and latitudes 6° 17′ N and 6° 45′ N (Fig. 1) at Ajena in the Akosombo gorge area in the Asuogyaman District of the Eastern Region of Ghana. This area is most suitable because of its lacustrine nature, which makes it suitable for cage production. It currently houses about 80% of aquaculture production in the country and also with the ease accessibility to inputs such as feed and fingerlings (MOFAD 2012; FAO 2016b). Two production cycles were used in each set-up (experimental and commercial), one in the dry (from November 2014 to March 2015) and one in the wet (March 2015 to July 2015) seasons each with three replicates.

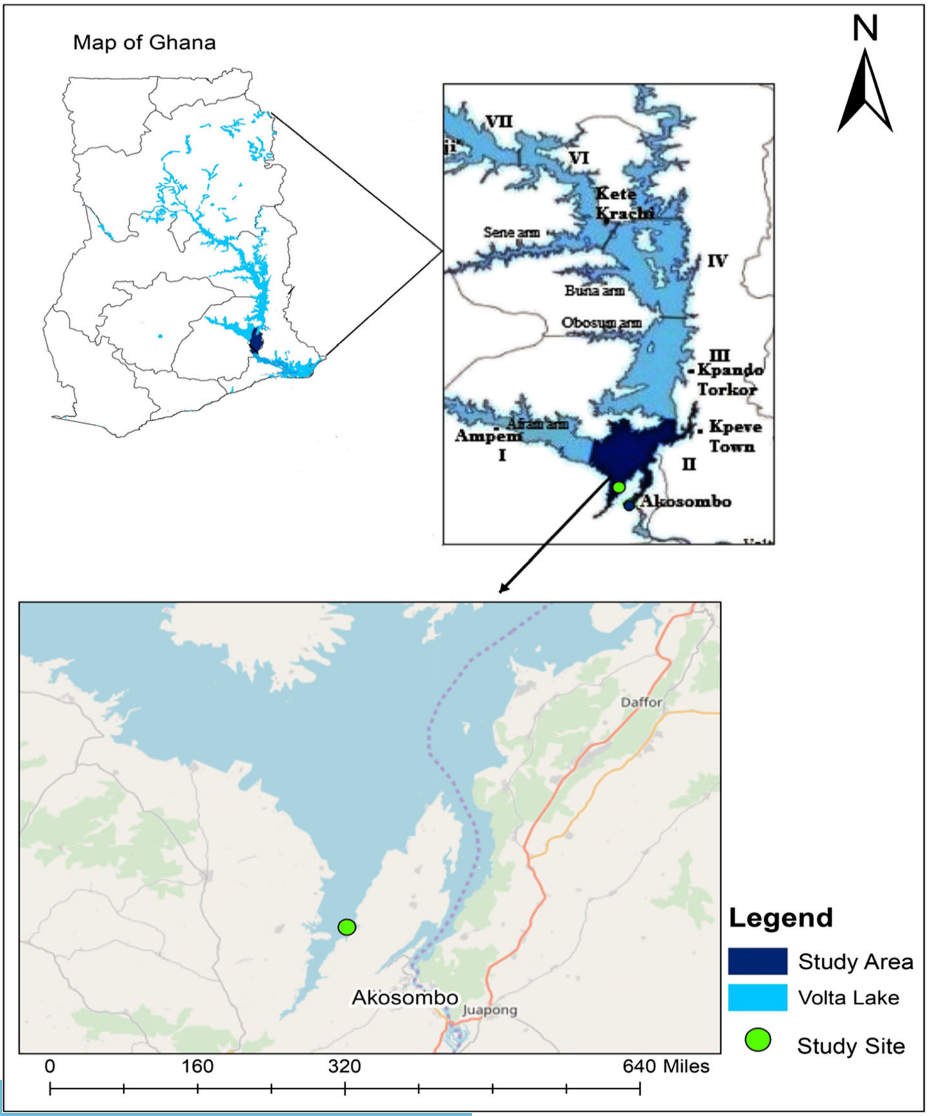

Fig. 1 Map of Lake Volta showing the study area

Experimental set-up

Experimental cages

Three experimental cages of size 81 m^3 (6 m × 3 m × 4.5 m) were constructed with galvanized pipes, welded into a rectangular frame. The inner (fingerling) and outer (production) nettings, all made of nylon material, of mesh sizes 25.4 and 50.8 mm, respectively, were securely fixed onto the rectangular frame. The cages were mounted on the lake using rubber 250-L rubber drums as floats and anchored using a concrete structure to prevent it from being drifted by the water currents (Fig. 2a) in an area with an average water depth of 20 m.

Stocking of fingerlings

Fingerlings of all male Nile tilapia were obtained from the Water Research Institute's Aquaculture Research and Development Centre at Akosombo, Ghana. They were transported in oxygenated containers and stocked in experimental cages at a rate of 40 m^{-3} (3200 fingerlings per cage). The fish were allowed to acclimatize in the cages for 7 days before the study began. During this period, mortalities encountered were replaced. Fifty individuals were obtained randomly from each cage by scooping with a dip net, weighed individually using a digital scale (KERN EMB 500-1 model) to the nearest ± 0.1 g to obtain the initial average weight of 22.5 g.

Feeding and growth monitoring

A 40% crude protein (CP) diet at an initial rate of 4% of fish body weight (BW) was administered to fingerlings by hand broadcast three times daily (8:30 a.m., 12:00 p.m., and 4:00 p.m.) for the first 2 months of culture. This was followed by a 33% CP diet at 3% BW during the third month of culture and 30% CP diet at 2% BW for the last month of culture. Daily feed fed to fish and mortalities were recorded.

Fish were sampled biweekly by partially lifting the cage netting and randomly scooping fish with a dip net. At least 50 individuals were measured for their standard length to the nearest ± 1.0 mm using a measuring board and weighed using a digital scale (KERN EMB 500-1 model) to the nearest ± 0.1 g. The amount of feed fed to fish per cage was adjusted based on the average weight obtained following each sampling.

Fig. 2 Experimental (**a**) and commercial (**b**) cage set-ups on the lake for the culture study

The feeding rate (FR) was determined using the formula:

$$FR = \%\text{body weight} \times (\text{Biomass},)$$

where biomass = average weight × total number of fish.

Water quality monitoring

Water samples for determination of the environmental variables were collected biweekly at the experimental site at 8:00 a.m. at a depth of 1 m into pre-cleaned 1-L Nalgene sample bottles using a Van-dorn water sampler. Samples for dissolved oxygen were carefully collected in 250-mL pre-cleaned dark glass bottles. Two-milliliter magnesium sulfate and 2-ml alkali-iodide-azide were added immediately to fix the oxygen.

Water temperature, pH, and turbidity were measured in the field using a TESTO 110 temperature probe, a HACH EC 20 portable pH meter and a HACH 2100 P turbidimeter, respectively. At the Water Research Institute's laboratory, dissolved oxygen was measured with the azide modification of the Winkler method and nutrients were determined using the following methods: diazotization for nitrite-nitrogen (NO_2–N), hydrazine reduction for nitrate-nitrogen (NO_3–N), direct nesslerization for ammonia-nitrogen (NH_4–N) and stannous chloride for orthophosphate (PO_4–P) following standard methods described by the American Public Health Association (APHA) (2012).

Commercial farm set-up, Sun Woo

A similar seasonal production cycle was also monitored on a fish commercial farm (Sun Woo Farms) in the same stratum. The farm has been operating since 2005 with an annual production of Nile tilapia estimated at about 75 metric tons. This farm was chosen because of its regular record keeping. Data on fish production and water quality measures from the farm were collected from three cages of sizes 162.5 m^3 (~6 m × 6 m × 4.52 m) stocked at a rate of 80 fingerlings m^{-3} (Fig. 2b) within the same period of the experimental culture. Similar feeding (based on stocking rate) and sampling regime was adopted as in the experimental set-up.

Determination of growth characteristics and data analysis

The following growth characteristics were monitored at the end of each production cycle:

- Specific growth rate (SGR) = ($\text{In}W_f - \text{In}W_i \times 100)/t$ (Ricker 1975)

where $\text{In}W_f$ = natural logarithm of the mean final weight (g); $\text{In}W_i$ = natural logarithm of the mean initial weight (g), t = time (days) between $\text{In}W_f$ and $\text{In}W_i$

- Condition factor (K) = BW/SL^3 (Tesch 1971)

where BW = average body weight of fish (g), SL = standard length of fish (cm)

- Feed conversion ratio (FCR) = feed given to cage (g)/wet weight gain (g), (Castell and Tiews 1980) • Mean daily weight gain (MDWG) = $W_f - W_i/t$, where W_f = final weight at harvest, W_i = initial weight at stocking, and t = duration of culture

- Gross yield (GY) = average final weight × total number of survivors (Mohammed et al. 2006)
- Net yield (NY) = biomass harvested − biomass stocked (Mohammed et al. 2006)

At the end of the trial, all fish were sold at the prevailing market price. The cost of feed, fingerlings, and total revenue generated from harvest in both seasons were estimated. A simple economic analysis, profit index, and the return on investment (ROI), was used to estimate the profitability and its implication on production for the seasons.

- Profit index = value of fish crop/total cost of feed (Mensah et al. 2013)
- ROI = (gain from investment − cost of investment)/cost of investment

The growth pattern of fish for both seasons in each set-up is presented in a line graph using Microsoft Excel. To determine whether there were differences in growth characteristics and environmental parameters between the seasons, data were analyzed using *t* test with the PAST v-3 software package (Hammer et al. 2001). If dataset had less than 30 observations, the non-parametric test using Mann-Whitney test was used. A comparison of economic analysis were also made for both seasons in the two set-ups.

Results

Water quality

Environmental parameters monitored throughout the production cycle for both seasons for the two set-ups are shown in Table 1. In the experimental set-up, the average water temperature measured for the dry season was 29.9 °C, which was about 0.84 °C higher than what was recorded in the wet season and dissolved oxygen recorded was on the average above 5 mg L^{-1} for both seasons. Throughout the production cycles, pH levels remained fairly stable in the range between 6.7 and 7.5 pH units with turbidity values higher in the wet season (4.4 nephelometric turbidity unit (NTU)) than in the dry season (2.8 NTU). In the wet season, the nitrate-nitrogen and nitrite-nitrogen levels were slightly higher than in the dry season; however, the orthophosphate and ammonia-nitrogen levels remained low in the wet season as compared to the dry season.

In the commercial set-up, average temperatures of 28.4 and 28.0 °C were recorded for dry and wet seasons, respectively, while mean dissolved oxygen levels measured were 3.77 mg L^{-1} for the dry and 3.40 mg L^{-1} for the wet seasons. Turbidity levels was higher in the wet season with an average of 6.0 nephelometric turbidity unit (NTU) as compared to 4.6 NTU recorded in the dry season. The nutrients: nitrate-nitrogen, nitrite-nitrogen, and orthophosphate levels were slightly higher in the wet season; however, low ammonia-nitrogen levels were recorded in the wet season.

All environmental parameters determined for both seasons for the two set-ups showed no significant difference ($p > 0.05$) when subjected to a Mann-Whitney *t* test.

Table 1 Environmental variables monitored during the dry and wet seasons of culture at the experimental and commercial site on Lake Volta, Akosombo

Variable	Experimental set-up		Commercial farm	
	Dry season	Wet season	Dry season	Wet season
Temperature (°C)	29.9 ± 0.33	29.0 ± 0.84	28.5 ± 0.33	28.0 ± 0.73
DO (mg L^{-1})	5.29 ± 0.32	6.10 ± 0.80	3.77 ± 0.68	3.40 ± 0.79
pH (pH units)	6.94 ± 0.14	6.98 ± 0.33	7.04 ± 0.38	6.77 ± 0.16
Turbidity (NTU)	2.80 ± 1.48	4.4 ± 2.07	4.6 ± 1.14	6.0 ± 2.74
NO_2–N (mg L^{-1})	0.008 ± 0.008	0.029 ± 0.018	0.002 ± 0.002	0.010 ± 0.014
NO_3–N (mg L^{-1})	0.042 ± 0.049	0.051 ± 0.018	0.067 ± 0.017	0.122 ± 0.250
PO_4–P (mg L^{-1})	0.139 ± 0.056	0.062 ± 0.047	0.197 ± 0.128	0.245 ± 0.154
NH_3–N (mg L^{-1})	0.227 ± 0.227	0.094 ± 0.085	0.185 ± 0.249	0.054 ± 0.041

Mean ± standard deviation

Fish production characteristics

The growth trend of fish in both seasons cultured in experimental and commercial set-ups is shown in Fig. 3a, b, respectively. The growth of fish in experimental set-up progressed steadily from an initial average weight of 22.59 ± 0.15 g to the final average weights of 311.96 ± 24.84 g and 283.77 ± 4.79 g during the dry and wet seasons, respectively. In the commercial set-up, growth of fish reached an average weight of 326.85 ± 3.61 g and 297.00 ± 3.39 g in the dry and wet seasons, respectively, from an initial average weight of 22.45 ± 0.57 g. For up to the 10th week of the culture period, fish cultured in the wet season performed better than those cultured in the dry season in both set-ups, however at the end of the 20th week, fish cultured in the dry seasons had attained the highest growth weight.

The growth characteristics determined for both seasons and for the set-ups is shown in Table 2. The instantaneous rate of growth measured as the specific growth rate, the physiological well-being of the fish determined as condition factor, and the daily growth rates were slightly higher in the dry season for both set-ups. Fish survival in general was greater than 70% but high during the dry seasons probably resulting in the higher gross and net yields as compared to the wet seasons. Feed utilization determined as the feed conversion ratio ranged from 1.34 to 1.75 and was more efficient during the dry seasons compared to the wet seasons, which was reflected in the growth rates. The growth characteristics showed no significant differences ($p > 0.05$, t test) in seasons for both set-ups.

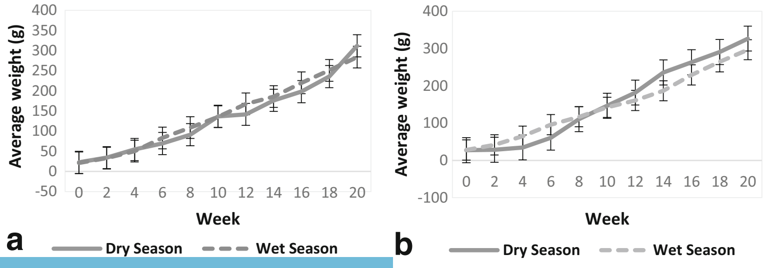

Fig. 3 Trend in growth performance of *Oreochromis niloticus* cultured in the dry and wet seasons at both experimental (**a**) and Sun Woo Farms (**b**) on Lake Volta, Akosombo

Table 2 Growth characteristics of *Oreochromis niloticus* cultured in the dry and wet seasons at both experimental and Sun Woo Farms on Lake Volta, Akosombo

Growth parameter	Experimental set-up		Commercial farm	
	Dry season	Wet season	Dry season	Wet season
Initial mean wt. (g)	22.40 ± 0.04	22.70 ± 0.05	22.10 ± 0.71	22.80 ± 0.14
Final mean wt. (g)	311.96 ± 6.72	283.77 ± 6.80	326.85 ± 3.61	297.00 ± 3.39
Specific growth rate (g day^{-1})	1.88 ± 0.06	1.80 ± 0.02	1.92 ± 0.01	1.83 ± 0.01
Mean daily wt. gain (g day^{-1})	2.06 ± 0.18	1.86 ± 0.05	2.18 ± 0.03	1.96 ± 0.02
Condition factor (g cm^{-3})	3.99 ± 0.17	3.95 ± 0.04	–	–
Gross yield (kg)	856.39 ± 91.45	762.29 ± 67.98	3472.00 ± 366.28	2829.90 ± 5.88
Net yield (kg)	715.10 ± 99.35	707.93 ± 90.85	3127.50 ± 366.28	2468.50 ± 4.04
Food conversion rate	1.34 ± 0.16	1.57 ± 0.10	1.70 ± 0.14	1.75 ± 0.21
Survival (%)	86.48 ± 12.90	76.73 ± 6.35	80.0 ± 8.49	73.3 ± 0.99

Mean ± standard deviation

Economic analysis

The economic implications of fish cultured in the both seasons for the two systems are presented in Table 3. The cost of fingerlings for the two set-ups varied as a result of differences in stocking densities. The cost per kilogram of feed (GH¢3.67) was same for both set-ups; however, feed applied, total feed cost, and value of fish crop differed because of varying stocking rates, growth rates, and survival. Feed was the major component of cost averaging over 50% of the total cost of operation while fingerling purchase accounted for an average of about 40% of total cost. The average selling price at harvest was GH¢11.75 per kilogram live weight. For both set-ups, the revenue generated from the sale of fish, profit index, and the return on investment estimated was high in the dry seasons.

Discussion

Environmental variables measured throughout the seasons in both set-ups were within optimal ranges and this has been observed in previous studies on the Lake (Karikari et al. 2013; Asmah et al. 2014; Osei-Konadu 2015). The fish environment is an important limiting factor that can

Table 3 Economics of *Oreochromis niloticus* cultured in the dry and wet seasons at both experimental and Sun Woo Farm sites on Lake Volta, Akosombo

Economic parameters	Experimental set-up		Commercial farm	
	Dry season	Wet season	Dry season	Wet season
Prize of fingerling (GH¢)	1.0	1.0	1.0	1.0
Cost of fingerlings (GH¢)	3200	3200	13,000	13,000
Prize of feed/kg (GH¢)	3.67	3.67	3.67	3.67
Total feed fed (kg)	944.4	950.7	5300	5070
Total cost of feed (GH¢)	3465.95	3489.07	19,451.00	18,606.90
Value of fish crop (GH¢)	7564.56	6896.45	38,461.20	35,521.10
Profit (GH¢)	898.61	207.38	6010.20	3914.20
Profit Index	8.01	7.25	7.26	7.01
Return on investment (%)	13.48	3.10	18.52	12.38

significantly affect fish health, growth, and ultimately, production (Timmons et al. 2001). The average seasonal temperature, dissolved oxygen, pH, turbidity, and nutrients during the study remained within the limits suitable for tilapia culture in the tropics (Boyd 2010).

Temperature, which is an important parameter, influences several other parameters and can alter the physical and chemical properties of water hence its influence on fish growth (Wetzel 2001). Although temperatures recorded between seasons were not significantly different, the slightly higher temperatures observed in the dry season may have accounted for better feed conversion rates resulting in higher yields. The feed conversion rates obtained in the study was within a range of typical *O. niloticus* cage aquaculture systems in Africa which, according to Ofori et al. (2010), is between 1.4 and 2.5. The overall specific growth rates of between 1.80 and 1.92 compares favorably with 1.8 g per day calculated in an intensive tilapia cage culture from the lake reported by Ofori et al. (2010).

Some studies such as Svobodová et al. (1993) have demonstrated that relatively high temperatures increase fish metabolic rate of activity resulting in higher feed intake and faster growth for warm water species. Azaza et al. (2008) and Santos et al. (2013) reported that the growth performance of *O. niloticus* was temperature-dependent with growth rate increasing with an increase in water temperature and reaching its optimal at 30 °C, then declined significantly at 34 °C. They suggested that digestion becomes more rapid and efficient at higher temperature (26–30 °C) compared to lower temperatures (21–24 °C), resulting in best growth performance. In this study, high growth rates were achieved in the dry seasons, which could be because of the high temperature that accompanies the season.

The metabolic rate of fish is highly affected by the concentration of oxygen in the rearing environment and its requirement increases with increasing temperature. However, an inverse relationship exists between temperature and dissolved oxygen (DO) with higher temperatures resulting in lower DO levels. As DO levels decrease, respiration and feeding activities also decrease resulting in reduced growth rate (Boyd 2010). Although there were slight DO fluctuations in both seasons at both experimental (5.2–6.1 mg L^{-1}) and commercial (3.4–3.8 mg L^{-1}) sites, these were within the optimum requirements (above 3 mg L^{-1}) for tilapia (Popma and Masser 2017) and did not differ significantly between the seasons. The lower levels of DO at the commercial site can be linked to the relatively higher stocking densities and cluster of cages (Fig. 2b) in that area as well as obstruction of water current flows by the cage structures which were likely to reduce the DO levels available to fish for respiration. Abdel-Tawwab et al. (2015) indicated that tilapia growth and feed utilization were adversely affected by low DO levels (1.0–1.5 mg L^{-1}), and could be enhanced when the DO levels are improved hence for best feeding practices, more feed could be applied when levels of DO are high. However, the present study does not indicate an oxygen induced reduction in fish growth in the commercial cages compared to the experimental cages. Lake Volta, in general, as suggested by Karikari et al. (2013), is fairly mixed throughout the year with marginal differences between seasons although relatively high concentrations are expected in the wet season as a result of turbulence due to rainfall and the associated windy weather during that period.

The pH values obtained for both seasons for the sites were similar and fell within the range (6.0–9.0) considered suitable for fish growth and natural productivity (Jobling 1995; Chapman 1996; Popma and Masser 2017) and similar to findings of Asase (2013) and Asmah et al. (2014) who recorded values of 7.1 and 6.8, respectively, on the lake. Some authors including El-Shafai et al. (2004) and El-Sherif and El-Feky (2009) have demonstrated that waters with pH level between 7 and 8 are more suitable and optimum for the growth performance and survival rate of Nile tilapia indicating no seasonal impact on fish in this study.

Turbidity was quite low for both seasons and results comparable to earlier studies by the Council for Scientific and Industrial Research-Water Research Institute (CSIR-WRI) (2003) and Karikari et al. (2013) where turbidity values of between 1.70 and 6.50 NTU were obtained. Turbid conditions result from dissolved and suspended solids such as clay and humic compounds or microorganisms such as phytoplankton as a result of erosion during runoffs. Turbidity level in the wet season characterized by rainfall was, as expected, higher but not significant from that in the dry season. The slightly high turbidity values recorded at the commercial site in the wet season can be associated with excess feed and fish feces resulting from the higher stocking density.

Nutrient concentrations in freshwater ecosystems are influenced by human activity, or pollution by animal or human waste or fertilizer runoff (Chapman 1996), and levels may increase during the wet seasons. Despite the proliferation of aquaculture activities in the lake, and a total of about 12,295 kg of feed added during the study period, nutrient levels (nitrates-nitrogen, nitrite-nitrogen, ammonia-nitrogen, and orthophosphates) are low (Karikari et al. 2013; Asmah et al. 2014; Karikari 2016) with no detectable effects of cage aquaculture on water quality in the vicinity of the production site. The nutrient levels from the commercial site was expected to be higher because of the concentration of cages and the discharges of effluents and feeds from cages; however, levels from both set-ups and for the two seasons (Table 1) were within optimal ranges for tilapia growth. Thus, nutrients considered could hardly affect the seasonal growth performance and therefore, production of fish in cages probably because of the way they are dispersed in the water by currents away from the cages. Other studies conducted on the lake on cage farms such as Asase (2013), Ameworwor (2014), and Osei-Konadu (2015) all have observed low concentrations of nutrients in connection to cage farms that may not have a significant impact on production.

El-Shafai et al. (2004) and El-Sherif and El-Feky (2008) demonstrated that growth performance significantly decreased with increasing concentration of nutrients such as ammonia. Zweig et al. (1999) also reported that ammonia becomes toxic to fish at concentrations between 0.6 and 2.0 mg L^{-1}, which is far higher than recorded in this study for both seasons. Besides, tilapia can tolerate higher ammonia and nitrate levels than many other cultured freshwater fish.

In the present study, production economics was mainly affected by cost of feeds and fingerlings irrespective of the season. The cost of feed and fingerlings together accounted for about 80% of the operational cost and these factors has also been identified by Ofori et al. (2010) and Moniruzzaman et al. (2015) as factors limiting profitability. In a country where most aquaculture feeds are imported, this has a ripple effect on profit margins. For an aquaculture venture to be sustainable, farms should be able to produce quality fingerlings in order to meet their demand and reduce their operational cost. The revenue generated in both set-ups was high in the dry season probably as a result of high survival and good growth rates hence a high profit index and the return on investment was obtained. The low economic return found in the wet seasons was also possibly due to low-selling price of small-sized fish thus low total production at harvest. This observation is in agreement with Ofori et al. (2010) who recorded low profit margins in small-sized fish cages in the Volta. Survival rate according to Mikolasek et al. (1997) and De La Cruz-Del Mundo et al. (1997) is a major cause of low yields and profits. They suggested that typical survival rate in tilapia cage culture should be in the range of 70–80% and this was within the rates achieved in the study.

In conclusion, the water quality in Lake Volta did not vary much between the two seasons; this makes the lake well suited for year-round culture of tilapia without any adverse effect on production. The survival of fish in cages was identified a major determinant of yield and profitability in both experimental and commercial set-ups. Turbidity levels seem to be inversely associated with the profit index and this needs to be further investigated.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no relation with data or software enterprises which might lead to conflict of interests with the companies. In addition, all authors are trained researchers with the information herein meant merely for scientific rationale and therefore they account their output based on research and information dissemination. All information obtained from different sources have been duly referenced and acknowledged.

Ethical statement The authors warrant that the manuscript submitted is their own original work and that all authors participated in the work in a substantive way and are prepared to take public responsibility for the work. All authors have also seen and approved the manuscript as submitted. The manuscript has not been published elsewhere and that the text, illustrations, and any other materials included in the manuscript do not infringe upon any existing copyright or other rights of anyone.

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