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ORGINAL RESEARCH

Water quality dynamics in earthen ponds with and without fish

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Abstract Tilapia is one of the most cultured fish species globally and over the last two decades, its culture has been intensified. However, water quality management in tilapia pond culture is a major barrier for higher productivity. This study assessed the water quality dynamics in 150 m^3 earthen ponds with or without fish over a period of 12 weeks. The two treatments were ponds stocked with fish (fed ponds) and ponds with water but no fish (control pond). The fed ponds comprised two ponds stocked with all-male Nile tilapia (*Oreochromis niloticus*) sub-adults (Mean mass ~40g) fed twice daily with a commercial feed (30% crude protein) while two other ponds were assigned as control. Physicochemical, biological water quality variables as well as nutrients were monitored in all ponds every four days over the 12 weeks. Dissolved oxygen (DO), pH, temperature and conductivity levels were measured *in-situ* between 7.00 and 8.00 a.m., while water samples were analysed in the laboratory for turbidity, total suspended solids (TSS), total dissolved solids (TDS), alkalinity, ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), ortho-phosphate, biological and chemical oxygen demand (BOD & COD), organic matter (OM) and organic carbon (OC). Additionally, a 24h DO monitoring as well as sludge accumulation and sludge characteristics were determined every three weeks in the experimental ponds. Mean DO levels over the trial duration was 42% lower in the fed ponds. The increased nutrient loadings from the fish and the supplementary feed presumably increased all biological WQ parameters measured which resulted in a higher sludge accumulated in the fed ponds. The fed ponds consistently recorded pre-sunrise DO levels of <1 mgL^{-1} while the control ponds recorded DO levels >2 mgL^{-1} during the same period. Generally, the results of the study showed deterioration of water quality was more evident in the fed ponds.

Keywords Water quality dynamics . Sludge accumulation . Earthen pond . Dissolved oxygen variation

Introduction

Aquaculture production is dominated by carps and tilapias which constitute about 64% of freshwater aquaculture globally (FAO 2022). In 2020, Nile tilapia (*Oreochromis niloticus*) production reached more than 4.4 million metric tons (FAO 2022). Tilapia are mostly cultured in shallow earthen ponds (<2 m), thus, the interactions between the soil and water greatly influence pond water quality dynamics. Water quality (WQ) directly influences fish growth at all life stages as well as fish production and constitutes one of the critical considerations in aquaculture (Bryan et al. 2011). Even when stocked at optimum density with high quality seed and fed with nutritionally balanced diets, poor water quality can directly or indirectly limit growth.

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While some parameters have been found to be of higher importance than others, the interactive nature of WQ parameters generally makes WQ management challenging, although it is well recognised as a key factor in successful aquaculture (Edziyie and Perschbacher 2017). For any given species, it is imperative to understand the critical WQ variables and their interrelation, in particular how they affect fish growth and health.

The functionality of earthen ponds as an aquaculture system is ensured by aquatic food web where the primary production is driven by solar radiation. WQ variables change over time due to biological activities that greatly influence the diel and seasonal pond WQ. Diel changes of WQ in ponds are mostly evident in variables affected by photosynthesis and respiration. Even in the absence of fishes in ponds, there can be wide variations in WQ over time and understanding this underlying dynamic is important and provides the basis for adequate control and management of the culture environment. In order to avoid wide variations in WQ, pond culture should adopt efficient management practices (Boyd and Tucker 1998).

Several studies have shown that, fish growth depends mainly on the quality of feed consumed (Slawski et al. 2012), the stocking density (Ma et al. 2006); biotic factors such as the age and sex of the fish (Imsland and Jonassen 2003) and genetic quality fish as well as plankton and bacteria biomass and types. Similarly, abiotic factors such as temperature, DO, pH, nutrients and organic fraction of water (Boyd and Tucker 1998; Sikoki and Veen 2004; Bhatnagar and Devi 2013; Imsland et al. 2017) influence growth performance. An understanding of both the abiotic and biotic fraction of the water in both space and time (day, different life stages and season) is critical to its management. A good WQ management cannot be practised without proper monitoring (Bhatnagar and Devi 2013; Makori et al. 2017).

The WQ requirement for different fish species vary and knowing the requirement for a culture species enhances optimum growth (Kausar and Salim 2006). For example, according to Popma and Lovshin (1995) and DeWalle et al. (2011), the preferred temperature range for optimal Nile tilapia growth is 25 to 31 °C. Changes in water temperature affect the physiology and productivity of the fish and their response to diseases. Photosynthesis during the day and respiration of the fish are known to affect pond pH (Boyd 1976; DeWalle et al. 2011). In ponds, plankton and bacteria are significant drivers of oxygen (O_2) production and consumption and requires regular monitoring to prevent severe problems in production since DO levels less than 3 mgL^{-1} is considered critical for tilapia production (Nduka et al. 2008). Additionally, fluctuations in WQ parameters such as turbidity, total suspended solids (TSS), total dissolved solids (TDS), alkalinity, ammonia (NH_3-N), nitrite (NO_2), nitrate (NO_3), ortho-phosphate (ortho-P), biological and chemical oxygen demand (BOD and COD), organic matter (OM) and organic carbon (OC) are known to affect the survival, growth and the physiology of tilapia. This study assessed the effect of fish on the WQ dynamics in earthen ponds over a period of 12 weeks.

Materials and methods

Study area and experimental design

This study was conducted in four ponds (15 ×10 ×1 m each) over 12 weeks on an experimental fish farm at the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. The study was designed with duplicated pond systems either stocked with Nile tilapia sub adults at a density of 2 fish m^{-2}, or ponds filled with water but without fish. All experimental ponds were filled with water from ground water. Physicochemical and biological WQ parameters were measured every four days over the experimental period. Diel fluctuations in DO levels and sludge accumulation were profiled every three weeks.

Pond preparation and stocking of Nile tilapia (*Oreochromis niloticus)*

The experimental ponds prior to stocking were drained and allowed to dry for three weeks before agricultural lime ($CaCO_3$) was applied at a rate 1 kg m^{-2} to the pond bottom. All experimental ponds were filled with water to a 1 m depth. Each pond was then fertilized at a rate of 100 g of nitrogen and 25 g of phosphorus daily for the first three weeks of the study with urea and mono-ammonium phosphate, respectively. After the first week of fertilization, all male Nile tilapia sub-adults with mean mass of 40 g were stocked in two of the experimental ponds. Fish were then fed twice daily with a commercial Nile tilapia feed (30%

protein) at a level corresponding to 3% of the biomass.

Growth performance and feed utilization

In order not to disturb the pond bottom because of the sludge monitoring, fish sampling was done at the end of the study. Fifty fish were randomly sampled from each pond and bulk-weighed using a portable field digital scale (Ohaus Navigator, NVL20000). Feed utilization and growth performance of the fish were calculated as:

$$\text{Weight gain}(g) = \text{Final body weight (g) - Initial body weight (g)}$$

$$\text{Weight gain}(\%) = 100 * \frac{\text{Final body weight (g) - Initial body weight (g)}}{\text{Initial body weight}(g)}$$

$$\text{Feed Intake}(g) = \frac{\text{Feed offered}(g)}{\text{Average total weight of the fish (g)}}$$

$$\text{Specific growth rate}(\%) = 100 * \frac{\text{In}(\text{final body weight}) - \text{In}(\text{initial body weight})}{\text{Experimental days}}$$

$$\text{Feed conversion ratio} = \frac{\text{Dry feed consumed}(g)}{\text{Wet weight gain by the fish (g)}}$$

$$\text{Feed efficiency ratio} = \frac{\text{Weight gain by the fish (g)}}{\text{Amount of feed fed}(g)}$$

Water quality measurements in the experimental ponds

All WQ variables measured *in-situ* were performed at a depth of 20 cm below the water surface between 7.00 and 8.00 a.m. All water samples for laboratory analysis were collected into 500mL sterilized bottles wrapped with aluminium foil to prevent light penetration and stored on ice to the laboratory for analysis. Physicochemical parameters such as DO, temperature, pH and conductivity were measured *in-situ* with a multi-parameter (Hach, Hd40Q) probe. TSS, TDS and alkalinity of the experimental water were analysed at the laboratory by methods described by APHA (1999). Turbidity was analysed with turbidimeter (Hach, 2100Q).

Diel DO profiles in the experimental ponds were monitored (at 15 minutes interval) a week before stocking and every three weeks after stocking until the end of the experiment.

Biological WQ parameters like chlorophyll-a (chl-*a*) and BOD were determined by HMSO (1983) APHA (1999) respectively. The closed reflux method was used for COD analysis. By using the volumetric method, total organic carbon as described by Schumacher (2002) was used to estimate OC and OM of the experimental water. NH_3-N, NO_2, NO_3 and ortho-P were determined spectrophotometrically (DS, 1975, 1991). WQ measurements were divided into 2 weeks periods and defined as P1-P6.

Sludge accumulation

Sludge accumulation was determined by collecting sludge samples from the bottom of the experimental ponds with a 3 cm diameter PVC pipe using a modification of the methods described by Ayres et al. (1993) and Birchall et al. (2008). Prior to sampling, seven sampling points in the experimental ponds (two sampling points each from the outlets and inlets and three sampling points in the middle of the ponds) were pre-determined with ropes (3 m interval on the dykes). This was used as a reference point for sampling. At each sampling point, the PVC pipe was vertically pushed through the pond sediment until it could be

Table 1 Mean ± SD physicochemical water quality parameters among the treatments over study period sampled every 4 days in the morning between 07.00 and 08.00h. Different superscripts indicate significant differences, n = 24

Parameters	Control pond	Fed pond	P-value
DO (mgL^{-1})	3.76±0.28[a]	1.57±0.18[b]	< 0.0001
pH	7.33±0.07[a]	7.31±0.05[a]	0.783
Temp (°C)	28.17± 0.18[a]	28.61±0.18[a]	0.125
Conductivity (μScm^{-1})	125.8± 3.92[a]	141.6± 3.163[b]	0.003
TDS (mgL^{-1})	62.88±1.96[a]	70.82± 1.58[b]	0.003
TSS (mgL^{-1})	0.048± 0.01[a]	0.096±0.01[b]	<0.0001
Alkalinity ($mgL^{-1}CaCO_3$)	32.92 ±1.82[a]	38.75± 1.71[b]	0.024
Turbidity (NTU)	61.47 ± 4.47[a]	155.3 ± 15.45[b]	<0.0001

pushed no further. The open end of the pipe was sealed and the pipe slowly withdrawn from the ponds while maintaining the pressure at the sealed end. The lower end of the tube was held over a bucket and the seal released to discharge the sludge. After taking sludge samples from the pre-determined sampling points in each pond, the samples were mixed to obtain a composite sample on which sludge characteristics were determined with a multi-parameter (Hach, Hd40Q) probe. The mixture was then poured into a 2 L cylinder of diameter 4 cm and left to settle for 30 minutes. The layer between the settled sediment and the surface water was then measured and estimated as sludge accumulation.

Data analysis

All data were checked for normality and the appropriate statistical test chosen in each case. Nutrient levels were analysed with the Mann-Whitney test as they failed the normality test. All physicochemical and biological parameters were subjected to the student's t-test. Sigma Plot 12.0 was used for data analysis and graphical representation, while the tables were generated with Microsoft Excel. All data were expressed as mean ± standard deviation. Data was considered significant at $P < 0.05$.

Results

Physicochemical parameters

Throughout the 12 weeks, several of the measured WQ parameters were better in the control ponds than in fed ponds (Table 1). In the mornings, the DO levels in the fed ponds were 42% lower than the control ponds ($P < 0.0001$). The water pH had a broader range for control ponds from 6.66 to 7.86, while for fed ponds pH was 6.90 to 8.05. However, no significant variation was observed among the treatments (Table 1). Mean temperature was higher in the fed ponds though variations between the treatments was not significant (Table 1). Alkalinity measured in the control ponds were about 17% less of the fed ponds however, the variation in treatments was significant ($P= 0.024$) (Table 1). Conductivity and TDS were about 12% each higher in the fed ponds than the control ponds. In the fed ponds, turbidity and TSS were more than two-folds recorded in the control ponds (Table 1).

Biological parameters

All biological parameters recorded in the fed ponds were higher than in the control ponds. Feed loading resulted in an increase in mean BOD and COD of 76% and 50% respectively. The mean chl-*a* level of the fed ponds was more than two-fold higher, and OM was increased by 30%. Except for OC, the levels of all the other biological parameters were significantly higher in the fed pond than in the control ponds (Table 2).

Nutrients

The measured nutrients in the experimental ponds are shown in Table 3. No significant differences in ortho-P concentrations were observed between the two treatments. A significant difference was also observed

Table 2 Mean ± SD biological water quality parameters among the treatments over the 12 weeks study period. Different superscripts indicates significant differences between treatment, n= 24

Parameters	Control pond	Fed pond	p-value
BOD (mgL^{-1})	19.06 ± 1.29^{a}	30.60 ± 1.83^{b}	<0.0001
COD (mgL^{-1})	112.0 ± 8.64^{a}	168.40 ± 12.40^{b}	0.0005
Chl-*a* (μgL^{-1})	176.34 ± 134.04^{a}	366.93 ± 277.55^{b}	<0.0001
OM (%)	1.50 ± 0.23^{a}	1.99 ± 0.22^{b}	0.005
OC (%)	0.32 ± 0.13^{a}	1.05 ± 0.13^{a}	0.14

Table 3 Mean ± SD of nutrients measured for the control and fed ponds over the 12 weeks study period. Different superscripts indicate significant differences among the treatments, n= 24

Parameters	Control pond	Fed pond
Ortho-P (mgL^{-1})	10.430 ± 2.03^{a}	9.349 ± 2.37^{a}
NO_2 (mgL^{-1})	0.005 ± 0.00^{a}	0.008 ± 0.00^{b}
NO_3 (mgL^{-1})	0.715 ± 0.16^{a}	2.105 ± 0.01^{a}
NH_3-N (mgL^{-1})	0.005 ± 0.01^{a}	0.009 ± 0.01^{b}

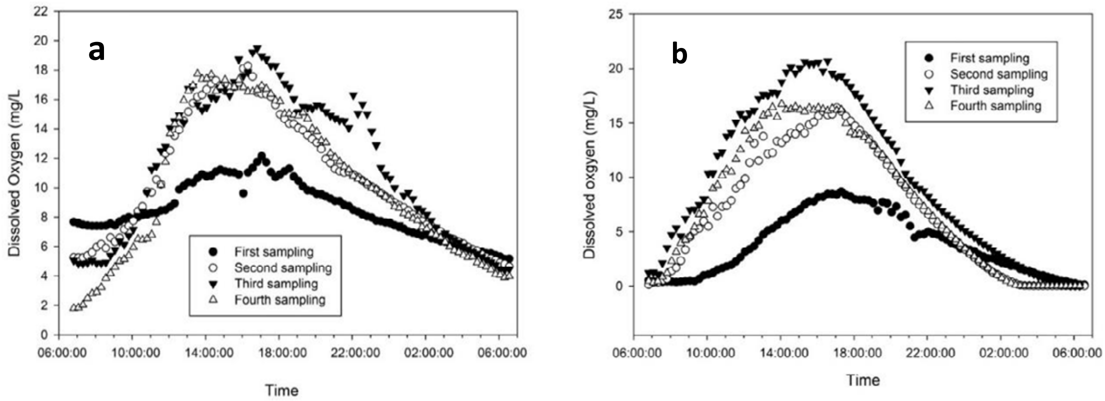

Fig 1. Diel oxygen cycles in the (a) control and (b) fed pond at 20 cm beneath the pond surface

between NO_2 (P=0.015) and NH_3-N (P=0.038) among the treatments. Even though the NO_3 levels were higher in the fed ponds, at the end of the study, no significant variation was noticed between the treatments (P=0.151).

Diel dissolved oxygen levels

Data on 24-hour DO level monitoring in the experimental ponds followed a similar pattern, where peak and lowest DO levels were recorded in the afternoon and early morning respectively (Fig. 1). The variations in DO levels among the sampling times were most prominent during the low and high O_2 periods. DO levels in the control ponds did not go below 1.8 mgL^{-1} (Fig. 1a). The DO fluctuations in both ponds appeared to be driven by phytoplankton with peaks between 12 and 22 mgL^{-1} occurring between 3 and 5 p.m. during the different sampling periods. The O_2 peaks for the fed pond were marginally higher than the peaks for the control pond (Fig. 1b). For both treatments, the peak O_2 levels were recorded during the third sampling period. The pre-sunrise DO levels of fed ponds were consistently <1 mgL^{-1} for all the sampling periods while the control ponds recorded DO levels >2 mgL^{-1}. The rates of O_2 declines following the peak values were steeper in the fed ponds. The O_2 declines for the fed ponds ranged from 0.8 to 1.9 $mgL^{-1}h^{-1}$ compared to between 0.5 to 1.2 $mgL^{-1}h^{-1}$ for the control pond.

Temporal trends in the water quality parameters

Daily average DO levels decreased with time in both treatments (Fig. 2a). The fed ponds consistently

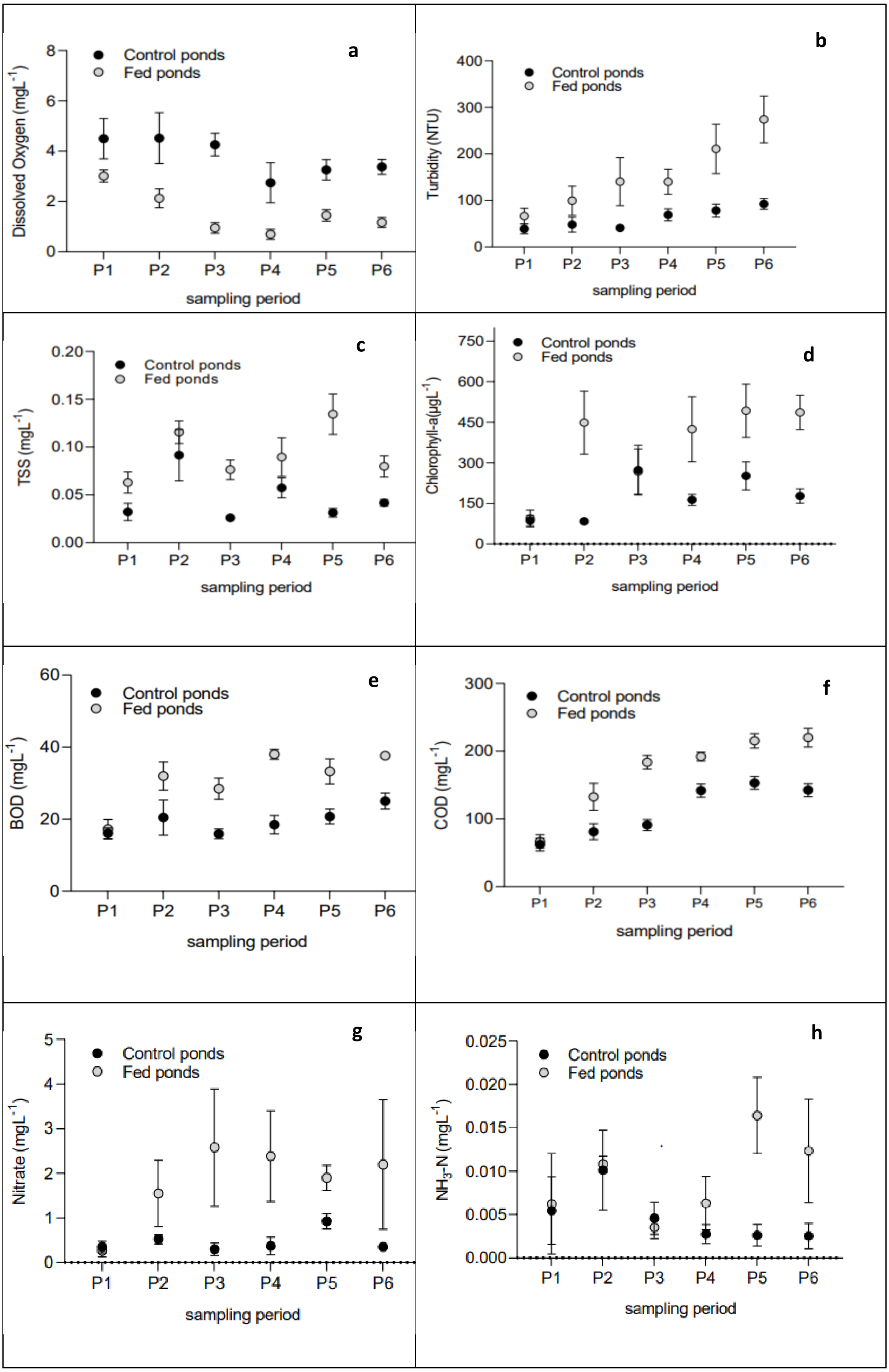

Fig 2. Temporal trends (mean ± SD) of some water quality parameters in the control and fed ponds over the study period

recorded lower DO levels during each measurement period. Conversely, turbidity progressively increased over the trial period although the control pond recorded turbidity increments over a narrower scale (35.01 to 92.65 NTU) compared to the treatment pond (66.60 to 274.04 NTU) (Fig. 2b). TSS also showed an increasing trend in both the control and fed ponds. The TSS levels were higher in the fed ponds (Fig. 2c). Generally, chl- *a* levels increased from P1 to P6 over the study period. The chl-*a* levels recorded were higher in the fed ponds than the control ponds. The highest chl-*a* level in the fed ponds was recorded at P6 (Fig. 2d). At P3 and P2 the highest and lowest chl-*a* levels respectively, were recorded in the control ponds. The BOD levels measured throughout the study were higher in the fed ponds. There was a slight decline in BOD levels in both treatments at P3, 15.94 ± 3.63 and 28.49 ± 8.36 mgL^{-1} for the control and fed ponds respectively (Fig. 2e). COD levels followed a similar trend as the BOD. Generally, the COD levels in the ponds were 3 times higher than the BOD levels in the same ponds (Fig. 2f). NH_3-N in the fed ponds were higher than in the control ponds. However, the levels were very similar during P1 and P3 in all experimental ponds. NH_3-N concentrations in the experimental ponds were not above 0.02 mgL^{-1} (Fig. 2h). Nitrate levels were higher in the fed ponds than in the control ponds from P2-P6 (Fig. 2g). With the exception of period 5, the nitrate levels in the control ponds were below 1 mgL^{-1} on the other hand, the levels in the fed ponds were >2 mgL^{-1} for P3-P6. The period with marked difference in nitrate levels between the two ponds was observed at P6. For each treatment, there was a trend of increasing nitrate levels over the study period (Fig. 2g).

Sludge accumulation and characteristics

After 12 weeks of measuring sludge in the experimental ponds, the fed ponds had a relatively higher sludge accumulation about 70% more than that in the control ponds. However, there were no significant variation (P=0.11) between the treatments. Data on sludge characteristics are shown in Table 4.

Growth and feed utilization of *O. niloticus*

Fish sampling was done at the end of the study. There was three-fold increase in the weight of the fish. Data on growth performance and feed utilization are presented in the Table 5 below.

Discussion

Water quality parameters

Dissolved oxygen is the first most critical water quality parameter in fish culture owing to its impact on the physical and biological processes of aquatic life. In this study, the control ponds had higher DO levels at all sampling times compared to the fed ponds. Average DO levels ranged between 2.0-6.07 mgL^{-1} and 0.06-3.3 mgL^{-1} for the control and fed ponds respectively. DO concentration of 3 mgL^{-1} has been recommended as the minimum for tilapia growth in ponds (Makori et al. 2017). However, for optimum growth DO concentration should be above 5 mgL^{-1} (Riche and Garling 2003). In the ponds, O_2 is produced through photosynthesis by phytoplankton during the day (Datta 2012). The fed-ponds had lower DO levels than the minimum required for tilapia culture. Aside bacterial respiration in the water column, sediment oxygen uptake and respiration by the cultured organisms contributes significantly to decline of O_2 levels in ponds (Teichert-Coddington and Green 1993; Datta 2012). Steeby et al. (2004) stated that, the cultured organism consumes about 15% of the total O_2 produced in the pond. In this study, the low DO in the fed-ponds could be due to respiration by fish and high rate of biological activity measured in the fed ponds as indicated by the BOD and COD, which consumed more O_2 through bacteria degradation of organic matter. Data on chl-*a* was significantly higher in the fed ponds, which could have resulted from the relatively higher nutrients from the supplemental feed and waste from the fish as observed in this study (Table 3). Additionally, the DO levels in ponds correlates with the level of chl-*a* resulting from phytoplankton biomass (Kunlasak et al. 2013). Increase in phytoplankton biomass increases amount of chl-*a* (Hardy 1973) so does DO due to photosynthesis at daytime and during the night DO can drop to very low concentrations, which is consistent with the findings of this study. In addition, low DO in the fed ponds could result from O_2 sinks because of relatively higher sludge levels accumulated at the bottoms of the fed ponds.

Table 4 Sludge accumulation and sludge characteristics of the experimental ponds measured at three-week intervals. No significant variations were observed among the treatments (P >0.05), n=4

Parameter	Control pond	Fed pond
Sludge accumulation thickness (cm)	1.20	2.04
DO (mgL^{-1})	0.18	0.15
pH	6.88	6.70
Temperature (°C)	28.38	28.11
Conductivity (µS/cm)	122.73	153.20
Water content (%)	79.6	71.6

Table 5 Mean ± SD of growth and feed utilization of *O. niloticus* for the fed ponds at the end of the 12 weeks study period

Parameter	Mean ± SD
Initial body weight (g)	38.00 ±2.16
Final body weight (g)	125.75 ± 39.95
Weight gain (g)	87.76 ± 37.79
Feed intake (g/fish/day)	2.73 ± 0.00
Feed conversion ratio	2. 36 ± 0.75
Feed efficiency ratio	0.31 ± 0.13
Specific growth rate (%/day)	1.14 ± 0.26

Although the alkalinity levels were quite low <50 mgL^{-1} $CaCO_3$; this did not influence the pH particularly in the fed ponds. For optimum tilapia growth, temperature in the pond should range between 25 and 31 °C (DeWalle et al. 2011). The temperature recorded over the study ranged between 26-30 °C for the control and fed ponds, respectively. Stocking of fish and application of supplementary feed in the experimental ponds during this study had no influence on temperature.

Turbidity in the fed-ponds was higher than the control ponds. This could result from the activity of the stocked fish as well as the supplemental feeds fed, which could contribute to the high-suspended particles hence the higher turbidity levels recorded in the fed ponds. Frimpong et al. (2014) observed that feeding fish contributed to turbidity in the receiving ponds. Furthermore, the increase in turbidity was due to the high OM measured in the fed ponds. The fed ponds had a higher TSS and lower than the threshold levels of 10 mgL^{-1} (Ntengwe 2006) for tilapia culture. Boyd and Tucker (1998) stated that the permissible range of BOD level for pond aquaculture should be 30 mgL^{-1} or less. For this study, BOD levels ranged from 4 to 31 mgL^{-1} and 13 to 40 mgL^{-1} for the control and fed-ponds respectively. High BOD in the fed ponds could be attributed to external factors such as feed application and internal factors through waste from the fish hence increasing the organic load in the ponds and promoting bacteria growth. Mean COD levels at the end of the study was 168.4 and 112.0 mgL^{-1} for both the fed and control treatments, respectively. According to Sharma and Olah (1986), ponds with higher COD concentrations resulted in low DO levels due to decomposition of organic compounds. Furthermore, in the ponds higher COD levels could result from anaerobic decomposition occurring in sludge layer in the solubility of some organic compounds to the pond water (Polprasert et al. 1983). In the present study, the fed ponds had a higher OM and lower DO levels throughout the study confirming the observation of Polprasert et al. (1983).

OC in ponds reflects dead plankton and other OM present. Low OM and OC recorded in the control ponds confirms the findings of Havens (1991) who stated that, if no feed is applied to a pond, there is always a low turbulence or disturbance and less re-suspension in the water column hence the low levels of these parameters measured in the control ponds. Excessive organic load in ponds can lower DO levels and increase OM in the overlying water and sediment interface (Paerl 2006). In this study, the fed ponds had a relatively higher sludge accumulation and higher OM, which could have contributed to lower DO levels observed as results of decomposition. According to Paerl (2006), nutrients that are not assimilated contribute to OM production in ponds hence the high OM in the fed ponds.

Nutrients

Ammonia, the by- product from metabolism of proteins excreted by the cultured organisms and bacterial

decomposition of organic matter such as uneaten feeds, waste from the cultured organism, plankton die offs among others (Bhatnagar and Devi 2013). During production, high levels of ammonia (> 0.1 mgL^{-1}) can cause gill damage in fish, destroy mucous producing membranes and cause sub-lethal effects like reduced growth and poor feed conversion (Santhosh and Singh 2007; Bhatnagar and Singh 2010; Floyd and Watson 2012; Bhatnagar and Devi 2013). Though the findings of this study showed that the fed ponds had relatively higher NH_3-N levels, its concentration was low to cause toxicity to the fish during the study.

High nitrogen loading in aquaculture ponds can result in accumulation of NO_2 through nitrification or denitrification (Boyd and Tucker 1998). NO_2 concentrations (<0.1 mgL^{-1}) is ideal for pond tilapia culture since even at low concentrations, can be toxic to the cultured fish (Boyd and Tucker 1998). Consistent with this study, the mean NO_2 concentrations in both treatments were within the acceptable limits (<0.1 mgL^{-1}) for tilapia culture. NO_3 concentrations in aquaculture ponds are usually low and the least toxic of the nitrogen compounds to aquatic animals (Boyd and Tucker, 1998). To avoid eutrophication, NO_3 should be monitored in the ponds (Sajitha and Smitha 2016). NO_3 concentrations in this study were 2.11 mgL^{-1} and 0.71 mgL^{-1} for the fed and control ponds, respectively. Several studies; Acu (2000), Ramadevi et al. (2009) and Ancy and Shaji (2016) have stated that the 0.1 to 4.0 mgL^{-1} is the favourable range for NO_3 concentration in tiapia farming. The NO_3 levels in this study were within the stated range, which makes the experimental ponds suitable for tilapia culture. Though the fed ponds recorded relatively higher NO_3 levels, yet it was within the acceptable ranges for tilapia growth.

Phosphorus is one of the limiting nutrients in aquatic systems; its addition often promotes primary productivity in production systems (Boyd 1990; Diana et al. 1991). Ortho-p levels in the present study showed no statistical variation in the experimental ponds. The ponds that received supplementary feed measured low ortho-p levels. Algal activities in ponds consume most ortho-p in water (Elnady et al. 2017). The decrease in ortho-p level could be due to high phytoplankton levels in the fed ponds, which consumed the phosphorous content. Ortho-p is formed when phosphorus fertilizers dissolve in pond water in addition to organic compounds such as faecal matter and decomposition of dead phytoplankton cells. Grazing of fish on phytoplankton in the pond can reduce primary production. In this study, since the control ponds were not stocked hence no feed was applied and there was a natural die offs of phytoplankton; the higher ortho-p levels recorded in the control ponds could be linked to decomposition of dead phytoplankton cells.

Diel dissolved oxygen monitoring

Phytoplankton populations generally influence O_2 dynamics in semi-intensive aquaculture ponds. These populations photosynthesize during daylight, increasing oxygen concentrations, however, respiration at night, drops the DO levels (Boyd 1990). The diel oxygen flux were similar among the treatments where the first O_2 monitoring recorded relatively lower DO levels during the day and highest at early morning compared to the other sampling times. This was due to low nutrient and organic inputs at the start of the experiment hence low phytoplankton biomass to produce and consume oxygen.

DO levels decreased over the experimental period in both treatments owing to increasing nutrient loads and phytoplankton abundance in the ponds. DO concentrations dropped sharply after sunset in both treatments. The decline in oxygen concentration could be due to bacterial respiration, plankton respiration and fish respiration at night (Boyd 1990; Diana et al. 1991; Teichert-Coddington and Green 1993).

The magnitude of fluctuations in DO concentration increases as phytoplankton density increases in response to nutrient loading. If the biomass of phytoplankton and other organisms are too high, DO concentration often drops to critically low levels at night (Diana et al. 1991). The low DO in the fed ponds could result from nutrient loading, fish excreta and relatively higher chl-*a* level in the pond. Moreover, at the fourth sampling, DO concentration was near zero at dawn in the fed ponds. This is in agreement with Steeby et al. (2004) who started that as phytoplankton biomass increases in response to greater feed inputs, gross oxygen production during photosynthesis increases. However, oxygen uptake by the biotic community through respiration increases leading to critically low oxygen levels at dawn.

Temporal trends of water quality parameters

Dissolved oxygen concentrations were highest during the first sampling period in both treatments and

declined steadily over the study period. The decrease in DO concentrations in both treatments could be attributed to increased accumulation of organic matter in the experimental ponds. Apart from fish and other organisms, in semi-intensive aquaculture systems, total oxygen demand in ponds can be tied to feeding rate and biological oxygen demand of the supplementary feed given as well as pond oxygen demand due to uneaten feed and excreted organic waste (David 1997). The growth of fish sizes over the study period corresponded with an increase in feed. Increase in fish biomass in the pond increased ammonia excretion in ponds over time thus, an increase in algal detritus production and oxygen cycling (Elnady et al. 2017). The low oxygen trends in the fed-ponds could be attributed to the higher OM from uneaten feed and excreta from the fish. The fed ponds had a relatively higher OM and NH_3-N levels. According to Elnady et al. (2017), bacterial degradation of organic matter utilizes more oxygen. DO concentrations decreased with increasing turbidity and TSS levels in the experimental ponds that is similar to the findings of David (1997) and Elnady et al. (2017) that turbidity and TSS increased over time through the accumulation of organic matter in ponds with supplementary feeding. The fluctuations at P3 and P4, in DO concentration, turbidity and TSS levels were due to heavy rains a day to sampling.

Sludge accumulation and sludge characteristics

Results of this study showed no significant variation in the sludge accumulation and sludge characteristics measured. Notwithstanding, high sludge accumulation in the fed ponds was presumably the result of high waste loads from the feeding and waste of the fish. Previous studies by Burford and Longmore (2001) showed that uneaten feed, faeces and other detritus from the water column inevitably settles on the sediment floor, which undergoes remineralisation processes. This may also explain the low DO levels in the sludge of the fed ponds through decomposition of the settled organic matter in the pond bottoms. According to Boyd et al. (2018), considerable levels of O_2 are consumed during microbial decomposition of uneaten feed and faeces. In addition, Edberg and Hofsten (1973) and Walker and Snodgrass (1986) have also stated that, low DO in the overlying water decreases the O_2 supply to the sediments. In agreement with these authors, throughout this study, the fed ponds had low DO in the overlying water that could limit O_2 available in the sediments for sediment respiration hence low DO recorded in the sludge for the fed ponds.

Conclusions

This study assessed the water quality dynamics in ponds with and without fish. The findings of the present study showed that WQ dynamics in earthen ponds were greatly influenced by the cultured fish and the application of supplementary feed. Deterioration of WQ was more evident in the fed ponds. DO being the first limiting factor in aquaculture production was highly impaired in the fed ponds which in effect could limit the growth of the cultured organism.

Competing interests The authors declare no competing interests.

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