International Journal of Fisheries and Aquatic Research
ISSN: 2456-7248; Impact Factor: RJIF 5.44
Received: 08-07-2020; Accepted: 25-07-2020; Published: 03-08-2020
www.fishjournals.com
Volume 5; Issue 3; 2020; Page No. 29-37

Effects of inorganic fertilizer application and supplementary feeding on water physico-chemical parameters, growth performance and yield of Nile Tilapia (*Oreochromis niloticus*) cultured in earthen ponds

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Abstract
This study was carried out for 180 days to assess the growth performance, water physico-chemical parameters, yield and profitability of Nile tilapia (*Oreochromis niloticus*) culture in earthen ponds. The fish were reared in nine earthen ponds with average size of 177 m^2 and subjected to three treatments i.e. pond fertilization alone (T_1), concentrate feeding alone (T_2) and a combination of pond fertilization plus concentrate feeding (T_3). Sex- reversed Nile tilapia fingerlings were stocked at a density of 3 fish/m^2. For T_1 and T_3, urea and Diammonium phosphate (DAP) fertilizers were applied in pond water weekly at a rate of 3 g/m^2 and 2 g/m^2, respectively. For T_2 and T_3 the fish were fed a diet containing 25.1% crude protein (CP) at a rate of 5% and 2.5% of body weight, respectively. Pond water physico-chemical parameters were measured weekly. A total of 30 fish from each pond were harvested biweekly and individually measured for body weight and length. Dissolved oxygen (DO), pH, Secchi disk reading, conductivity, salinity, phosphorous, nitrate and alkalinity differed ($p \leq 0.05$) but temperature did not differ ($p > 0.05$) among treatments. In all treatments the water quality parameters were within the acceptable range for tilapia culture. Within a 24 hours period, DO, pH and temperature were highest at 1500 hours and lowest at 0600 hours. The fish reared under T_3 showed higher ($p < 0.05$) body weight gain (194.1 ± 4.5 g), growth rate (GR) (1.5 ± 0.1 g/day), estimated yield (13 065 ± 458 kg/ha/year) and gross margin (12 364.41 ± 1 376.75 USD/ha) than those under the other treatments. The FCR was higher (4.1 ± 0.3) for the fish subjected to T_2 and lower (2.0 ± 0.1) for the fish reared under T_3. The highest condition factor (K) (2.54 ± 0.0) was observed for the fish reared in ponds under T_1 whereas fish under T_2 had the lowest value (2.05 ± 0.0). It is concluded that, the combination of pond fertilization plus concentrate feeding (T_3) is the best strategy for rearing *Oreochromis niloticus*, since it reduces feed utilization and results into higher growth performance and profit.

Keywords: condition factor, fish growth rate, gross margin, water physico-chemical parameters

1. Introduction

Growth performance of fish depends on availability of essential nutrients from either natural food (plankton) and/or supplemented feed. Fertilizers applied in pond water releases nutrients which promote the growth of phytoplankton as primary producers. The growth of phytoplankton in ponds water increases the level of dissolved oxygen, pH and total phosphorus [1, 2]. In addition, phytoplankton traps ammonia excreted by the fish, hence, improves water quality parameters [2]. Moreover, phytoplankton is food for zooplankton and other herbivore animals which are, in turn, eaten by fish. The overall result of pond fertilization is increased fish growth and yields at harvest. The presence of natural food in the pond can support fish growth without the need for supplementary feeds. However, as the fish grows and weight increases, the amount of natural food becomes inadequate to sustain the increasing fish weight. This leads to slow growth rate which, in turn, prolongs the production cycle and causes low yield. To promote fast growth of the fish and, hence, obtain higher yield at harvest, supplementation of cultured fish with an artificial feed is necessary. But artificial feed is the most expensive input in intensive or semi-intensive aquaculture systems due to the high competition of the same resources among human, livestock and fish production [3]. The best way to reduce feed costs is to combine fertilization plus supplementary feeding. This strategy uses minimal feed, thereby reduces production costs [4].

Studies done in Nepal, Cambodia, Kenya and Thailand to assess the effects of pond fertilization plus supplementary feeding on growth performance of Nile tilapia revealed that fish cultured under the combination of fertilization plus supplementary feeding performs better in terms of growth performance and yield compared to those grown under fertilization alone [5, 6]. In Tanzania the combined effects of pond fertilization plus supplementary feeding on water physico-chemical parameters, growth performance, yield and economic return of fish are unknown. Therefore, this study was conducted to compare the effects of inorganic fertilizer application alone, concentrate diet feeding alone and the combination of fertilizer application plus concentrate diet feeding on pond water physico-chemical parameters, fish growth performance, yield and profitability of Nile Tilapia cultured in earthen ponds.

2. Materials and Methods

2.1 Description of the study location

The study was conducted for 180 days at Tindiga village, Kilosa district, Tanzania. Kilosa district lies between latitude 5º 55′S and 8º 53′S and longitude 36 º30′E and 37º30′E. Tindiga village is located 13 km from Kilosa town. The area receives rainfall for an average of eight months. The rainfall falls from October to May, with the highest amount received between March and April. Mean annual rainfall ranges between 800 and 1400 mm and the average temperature is 25 ºC per year [7].

2.2 Pond and fish management

Nine earthen ponds, each with an average size of 177 m^2 were used. The ponds were randomly allocated to three treatments, with three replicates per treatment. The treatments were pond fertilization alone (T_1), concentrate feeding alone at 5% of fish body weight (FBW) (T_2) and pond fertilization plus concentrate feeding at 2.5% of FBW (T_3). Urea and Diammonium phosphate (DAP) inorganic fertilizers were applied in pond water weekly at the rates of 3 and 2 g per m^2, respectively for both T_1 and T_3. Prior to stocking all ponds were drained, dried, refilled with water, fertilized and left for seven days. The surface water that drains through a canal adjacent to the ponds was used to fill the experimental ponds. Sex-reversed Nile tilapia fingerlings with an average weight of 0.9 g were collected from Ruvu fish farm and stocked at a stocking density of 3 fish /m^2. Concentrate diet was compounded as shown in Table 1. The feed ingredients were ground in a hammer mill machine with an average of 2 mm sieve size. Fish were fed twice per day at 1000 and 1600 hours at the levels of 10% and 5% of FBW for the first two months, then the amount of feed was reduced to 5% and 2.5% for the last four months for T_2 and T_3, respectively. During fish feeding, the mash feed was broadcasted in the pond water surface at specific area for the fish to adapt.

Table 1: Percentage of ingredients in the formulated diet

Feed Ingredient	Composition (%)
Wheat bran	50
Fish meal	25
Sunflower seed cake	10
Cotton seed cake	10
Maize meal	4
Mineral premix	1

2.3 Chemical composition analysis of feeds

Three random samples approximately 250 g each of compounded feed were taken. Each feed sample was weighed, dried at 60 ºC for 48 hours and then stored in the air tight bottle for analysis. Dry matter and ash contents were determined using standard procedure. Crude protein was determined by Kjeldahl method [8]. Crude fat was determined by Soxhlet extraction method [8]. The proximate analysis of the compounded feed showed that the crude protein content (CP) was 25.1% as shown in Table 2.

Table 2: Proximate composition (%) of compounded diet

Proximate component	Composition (%)
Dry matter	91.94
Moisture content	8.06
Organic matter	84.65
Ash	15.35
Crude protein	25.09
Crude fat	9.6

2.4 Determination of water physico-chemical parameters

Pond water physico-chemical parameters i.e. temperature (ºC), conductivity (µS/cm), salinity (mg/L), total dissolved solids (TDS), pH and dissolved oxygen (mg/L) were measured by using multiparameter DO meter (HI 98198 PH/EC/DO Multiparameter HANNA instruments made in Romania). The water physico-chemical parameters were measured at the top, middle and bottom of the pond water column weekly at 0600 hours. In order to determine 24 hours fluctuations, the same parameters were measured at three hours intervals for 24 hours at the beginning of the experiment, and then after three months and at the end of the experimental period. In addition, 500 ml of water samples were collected weekly from each pond at a depth of 15 cm between 0900 and 1100 hours for alkalinity, total phosphorous and nitrogen determination. Alikalinity, phosphoous and nitrogen were determined by using Titrametric, spectrophotometric and Kjeldahl methods, respectively, as described by Asuero [9].

2.5 Fish sampling and growth performance determination

To determine growth performance, the fish cultured in the ponds subjected to the three treatments were measured for body weight and length at the beginning of the experiment and then every two weeks throughout the experimental period. A random sample of 30 fish was taken from each pond using a net (1 mm mesh size) and each fish was individually measured. Fish body weight (g) was measured using a portable digital weighing balance while body length (cm) was measured using a ruler fixed on a measuring board. After measuring body weight and length, the fish were returned back into their respective ponds. Death of fish was observed and recorded daily. At the end of the experiment, all fish were harvested by using a seine net with a size of 1.5 m x 15 m and mesh size of 15 mm. The fish harvested were counted to determine the survival rate and yield. Fish growth rate (GR), specific growth rate (SGR), feed conversion ratio (FCR), survival rate (SR) and condition factor (K) were calculated by using the following formulae:

$$GR = \frac{\text{Final weight (g)} - \text{initial weight (g)}}{\text{Experimental period (days)}}$$

Where: GR is growth rate ………………………………………… (1)

$$SGR = \frac{[\text{In (Final weight (g)} - \text{In (initial weight (g)]}}{\text{Experimental period (days)}} \times 100$$

Where: In is the natural logarithm and SGR is specific growth rate ………………… (2)

$$FCR = \frac{\text{Total weight of food consumed (g)}}{\text{Total weight gained by fish (g)}}$$

Where: FCR is feed conversion ratio ………………………………………… (3)

$$SR = \frac{\text{Total number of fish stocked} - \text{total number of died}}{\text{Total number of fish stocked}} \times 100$$

Where: SR is survival rate ………………………………………… (4)

Condition factor (K)

Condition factor as an indicator of the wellbeing of the fish was calculated using the formula below:

Condition factor as an indicator of the wellbeing of the fish was calculated using the formula below:

$$K = \frac{100 \times W}{L^b}$$

Where: K= condition factor; W = weight of the fish at harvest (g); L = length of the fish at harvest (cm); b = The slope of the regression line (also referred to as Allometric coefficient) … (5)

Note: the slope of the regression line (b) was obtained by using the formula below:

$$W = a L^b$$

Where: W = weight of the fish (g); a = The intercept of the regression line on the Y axis; L= Length of the fish (cm); b = The slope of the regression line (also referred as Allometric coefficient) ………………………………………… (6)

The log-transformened data gave the regression equation indicated below:

$$\text{Log } W = \text{log}a + b\text{log}L$$

a = Constant; b =The regression coefficient ………………………………………… (7)

2.6 Economic analysis

Gross margin analysis was used to determine the profitability of the fish cultured under the three treatments. The variable costs recorded per treatment were costs of feed, fertilizer, fingerling and labour. The value of the harvested fish was determined by using the market price of fish/kg. Total harvest, revenue and gross margin were determined as follows:

2.7 Statistical analysis

Data were analysed using R Studio software version 3.5.0 (2018) [11, 12]. Before the analysis, the data were checked for normality and transformed whenever necessary to reduce skewedness and increasing error homoscedasticity. One-way ANOVA was used to assess the effects of treatments on growth performance variables, water physico-chemical parameters, production costs, yields and revenue. Initial weight and length were used as a covariate in the analysis for growth performance data. A Tukey's test ($p = 0.05$) was used for Post Hoc analysis to determine the significance difference between pairs of treatment means when the treatment had significant effect. The relationships between fish growth and water physico-chemical parameters were determined by using Pearson correlation and multiple regression analyses.

3. Results

3.1 Water physico-chemical parameters

Results for pond water physico-chemical parameters are summarised in Table 3. Dissolved oxygen (DO) and pH values at dawn differed significantly ($p < 0.05$) among the treatments. The highest mean DO value (4.35 ± 0.04 mg/L) was observed in ponds subjected to fertilization alone while the lowest value (3.79 ± 0.03 mg/L) was observed in ponds under concentrate feeding alone. The highest pH value was observed in ponds under fertilization alone (8.24 ± 0.01) while the lowest value was found in the ponds under the combination of fertilization plus concentrate feeding (8.07 ± 0.01). Temperature did not differ among the treatments ($p > 0.05$) and the mean temperature ranged from 25.17 ± 0.04 to 25.24 ± 0.04 ºC.

Diurnal variations of DO, pH and temperature are shown in Figure 1 (a), 1 (b) and 1 (c), respectively. The results show that, within 24 hours period dissolved oxygen (DO), pH and temperature had the lowest values at 0600 hours and highest at 1500 hours. The highest values were observed in ponds under fertilization alone and the lowest values in ponds under concentrate feeding alone. However, temperature values showed a narrow variation among the treatments within 24 hours period (Fig. 1 (c).

The results also show that, the mean conductivity, total dissolved solids (TDS) and salinity were significantly lower in ponds under fertilization alone (T_1) than those under concentrate feeding alone (T_2) and the combination of fertilization plus concentrate feeding (T_3). However, the differences between the ponds subjected to feeding alone and the combination of fertilization plus concentrate feeding were not significant ($p > 0.05$) (Table 3). Furthermore, the ponds under fertilization alone had significantly ($p < 0.05$) higher Secchi disk reading (25.3 ± 0.1 cm) than those on feeding alone (24.4 ± 0.1 cm) and the combination of fertilization plus concentrate feeding which had the lowest value (23.1 ± 0.2 cm).

Water alkalinity was significantly ($p < 0.05$) lower in ponds under the combination of fertilization plus concentrate feeding than in those subjected to either fertilization alone or concentrate feeding alone. Total nitrogen, nitrate and phosphorous were significantly ($p < 0.05$) higher in ponds under fertilization alone than in those under feeding alone and the combination of fertilization plus concentrate feeding.

Table 3: Dawn water physico-chemical parameters (Mean ± se) for ponds under fertilization alone, feeding alone and the combination of fertilization plus concentrate feeding

Water physico-chemical parameter	Treatments		
	Fertilization alone (T_1)	Feeding alone (T_2)	Combination (T_3)
DO (mg/L)	4.35 ± 0.04^{a}	3.79 ± 0.03^{c}	4.21 ± 0.05d^{b}
pH	8.24 ± 0.01^{a}	8.10 ± 0.01^{b}	8.07 ± 0.01^{c}
Temperature (^{O}C)	25.17 ± 0.04^{a}	25.24 ± 0.04^{a}	25.22 ± 0.04^{a}
Conductivity (µS/cm)	1322 ± 3.28^{b}	1360 ± 3.06^{a}	1358 ± 4.16^{a}
TDS	670 ± 1.70^{b}	688 ±1.56^{a}	688 ± 2.04^{a}
Salinity (mg/L)	0.660 ± 0.0^{b}	0.679 ± 0.0^{a}	0.679 ± 0.0^{a}
Secchi disk depth (cm)	25.3 ± 0.1^{a}	24.4 ± 0.1^{b}	23.1 ± 0.2^{c}
Alkalinity (mg/L)	191.82 ± 2.45^{a}	194.39 ± 2.43^{a}	181.97 ± 3.25^{b}
TN (mg/L)	20.82 ± 0.24^{a}	20.28 ± 0.43^{b}	16.69 ± 0.33^{c}
Nitrate (mg/L)	11.85 ± 0.12^{a}	11.19 ± 0.10^{b}	10.86 ± 0.10^{b}
Phosphorous (mg/L)	0.33 ± 0.01^{a}	0.15 ± 0.01^{b}	0.18 ± 0.01^{b}

^{abc}= Means with the same superscript letter in the same row are not significantly different ($p > 0.05$).
Note: se = standard error, DO = Dissolved oxygen, TN = Total nitrogen, TDS = Total dissolved solids.

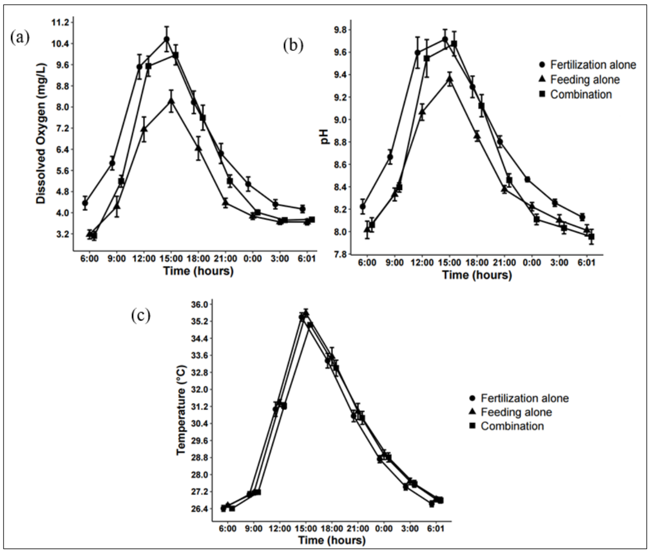

Fig 1: Diurnal variations (Mean ± se) of (a) DO, (b) pH and (c) temperature in earthen ponds under fertilization alone, feeding alone and combination of fertilization plus concentrate feeding

3.2 Growth performance and survival rate of Nile tilapia

Results for growth performance, survival rate and FCR of sex reversed *O. niloticus* cultured in ponds under the treatments of fertilization alone, concentrate feeding alone and combination of fertilization plus concentrate feeding are presented in Table 4 and Figure 2. Generally, fish cultured in ponds subjected to the combination of fertilization plus concentrate feeding (T_3) showed significantly ($p < 0.05$) higher mean growth performances (weight gain = 194.1 ± 4.5 g, length gain =18.6 ± 0.2 cm and growth rate =1.5 ± 0.1 g/day) than those reared in ponds under concentrate feeding alone and fertilization alone (Table 4). However, the difference in specific growth rate between the fish grown under feeding alone (T_1) and those under the combination of fertilization plus concentrate feeding (T_3) was not significant ($p > 0.05$). The condition factor (K) varied significantly among the treatments, with the highest value (2.54 ± 0.0) being observed in fish under fertilization alone and the lowest value (2.05 ± 0.0) in fish under concentrate feeding alone. Feed conversion ratio (FCR) was assessed only for treatments which involved feeding (T_2 and T_3). The results show that, fish reared in ponds under the combination of fertilization plus concentrate feeding had significantly ($p < 0.05$) lower FCR than those cultured in ponds under concentrate feeding alone.

Table 4: Growth performance (Mean ± se) of *O. niloticus* cultured in earthen ponds under fertilization alone, concentrate feeding alone and the combination of fertilization plus concentrate feeding

Growth variable	Treatments		
	Fertilization alone (T_1)	Feeding alone (T_2)	Combination (T_3)
Initial body weight (g)	1.1 ± 0.1^a	0.9 ± 0.1^b	0.7 ± 0.0^b
Initial body length (cm)	3.7 ± 0.1^a	3.5 ± 0.1^b	3.3 ± 0.1^b
Final body weight (g)	66.7 ± 1.1^c	161.8 ± 3.6^b	194.8 ± 4.5^a
Final body length (cm)	15.5 ± 0.1^c	20.1 ± 0.2^b	21.9 ± 0.2^a
Weight gain (g)	65.6 ± 1.1^c	160.9 ± 3.6^b	194.1 ± 4.5^a
Length gain (cm)	11.8 ± 0.1^c	16.6 ± 0.2^b	18.6 ± 0.2^a
Growth rate (g/day)	0.6 ± 0.0^c	1.3 ± 0.0^b	1.5 ± 0.1^a
Condition factor (K)	2.54 ± 0.0^a	2.05 ± 0.0^c	2.14 ± 0.0^b
Specific growth rate (%)	2.4 ± 0.1^b	3.1 ± 0.1^a	3.2 ± 0.1^a
Survival (%)	90.0 ± 0.0^a	89.6 ± 0.02^a	89.7 ± 0.04^a
FCR	-	4.1 ± 0.3^a	2.0 ± 0.1^b

^{abc}= Means with the same superscript letter in the same row are not significantly different (p > 0.05).
Note: se=standard error, FCR= Feed conversion ratio.

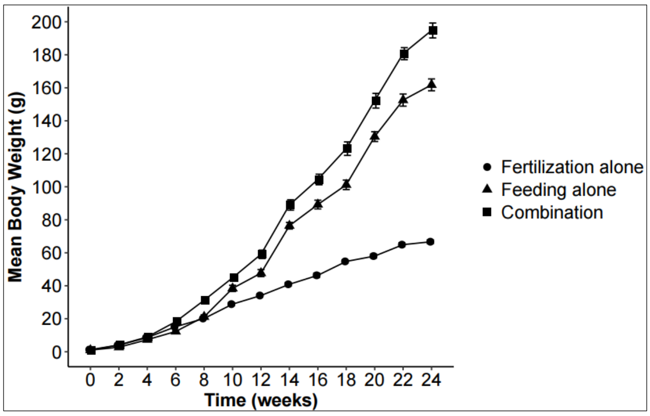

Fig 2: Growth performance of *O. niloticus* cultured in earthen ponds for six months under fertilization alone, concentrate feeding alone and the combination of fertilization plus concentrate feeding

3.3 Influence of water physico-chemical parameters on growth rate of Nile tilapia

The results for regression analyses of growth rate and water physico-chemical parameters of fish reared in the ponds under fertilization alone, concentrate feeding alone and the combination of fertilization plus concentrate feeding treatments are shown in Table 5. Dissolved oxygen (DO), pH, temperature and Secchi disk reading significantly ($p < 0.05$) influenced the growth rate of *O. niloticus* (Table 5). Nitrate (NO_3), phosphorous, conductivity, TDS and salinity did not significantly ($p > 0.05$) influence the growth rate of *O. niloticus*. Fish growth rate increased significantly ($p < 0.05$) as pH, DO and Secchi disk reading in pond water decreased. Also, water temperature positively ($p < 0.05$) influenced fish growth rate.

Table 5: Regression of fish growth rate on pond water physico-chemical parameters for fish cultured in ponds

Water parameter	Partial regression coefficient estimates (b)	se	*p*-value
pH	-1.32	0.09	0.001

DO (mg/L)	-0.09	0.02	0.001
Conductivity (µS/cm)	0.00	0.00	0.417
TDS	0.01	0.01	0.305
Salinity (mg/L)	0.02	0.00	0.104
Temperature (^{O}C)	0.23	0.02	0.001
Secchi disk (cm)	-0.01	0.00	0.002
Nitrate (NO_3) (mg/L)	-0.02	0.01	0.162
Phosphorous (mg/L)	0.20	0.06	0.934

Note: DO =Dissolved oxygen, TDS = Total dissolved solids, se = standard error, b=regression coefficient

3.4 Fish yield and economic return

Results for variable costs, yield and gross margin for the fish reared in ponds under fertilization alone, concentrate feeding alone and the combination of fertilization plus concentrate feeding are shown in Table 6. Total variable costs did not differ between ponds under concentrate feeding alone and the combination of fertilization plus concentrate feeding but were significantly higher than that for ponds under fertilization alone. Moreover, the cost of producing one kg of fish differed significantly ($p < 0.05$) among the treatments. The highest cost (USD 3.66 ± 1.51) per kg of fish was observed in ponds under feeding alone and the lowest cost was found in the other two treatments. The average cost per kg of fish did not differ significantly between the fish reared under the treatment of combination and those under fertilization alone. Fish reared in ponds under the combination of fertilization plus concentrate feeding and concentrate feeding alone had the higher yield and revenue compared to those reared under fertilization alone. But the differences in fish yield and revenue between feeding alone and the combination treatments were insignificant. Gross margin differed significantly ($p < 0.05$) among the treatments. The highest gross margin value was obtained from the fish reared under the combination of fertilization plus concentrate feeding treatment (USD 12364.41 ± 1376.75) and the lowest value was observed from the fish reared under the feeding alone treatment (USD -2005.69 ± 1601.48).

Table 6: Mean variable costs, yield, revenue and gross margin of the *O. niloticus* cultured for six months in earthen ponds under fertilization alone, concentrate feeding alone and combination of fertilization plus concentrate feeding

Variable costs (USD /ha/yr)	Treatment		
	Fertilization alone (T1)	**Feeding alone (T2)**	**Combination (T3)**
Fingerling Cost	8300.12 ± 217.37^{a}	8025.67 ± 364.84^{a}	8128.85±493.43^{a}
Labour cost	648.10 ± 18.99^{b}	7414.78 ± 812.79^{a}	9397.09 ± 56.29^{a}
Fertilizer cost	1498.41 ± 29.48^{a}	-	1467.85 ± 22.41^{a}
Feed cost	-	23772.92 ± 2465.81^{a}	13984.33 ± 248.54^{a}
Total variable cost	10446.43 ± 265.84^{b}	39213.37 ± 3643.44^{a}	32978.11 ± 820.66^{a}
Production cost/kg of fish (USD)	2.29 ± 0.14^{b}	3.66 ± 1.51^{a}	2.53 ± 0.07^{b}
Output			
Yield (kg/ha/yr)	4 602 ± 376^{b}	10 720 ± 962^{a}	13 065 ± 458^{a}
Total revenue (USD/ha/yr)	15974.14 ± 1305.23^{b}	37207.67 ± 3338.94^{a}	45342.52 ±1587.76^{a}
Gross margin (USD/ha/yr)	5527.51 ± 1127.15^{b}	-2005.69 ± 1601.48^{c}	12364.41 ± 1376.75^{a}

**Values are expressed as means ± se; ^{abc}= Means with the same superscript letter in the same row are not significantly different (p > 0.05), Note: yr = year, USD =United State Dollar*

4. Discussion

4.1 Water physico-chemical parameters

The growth of tilapia in ponds is usually limited by DO as one of the most important water quality parameters for fish survival and growth. The lowest DO value observed in ponds under the concentrate feeding alone treatment may be due to the existence of a lot of microbial activities involved in decomposition of leftover feeds [13, 2]. Studies have shown that the differences in amount of organic matter in pond water leads to variation in DO levels among ponds, especially at night when fish, algae and microbes consumes DO and releases CO_2 [13, 2]. Since the ponds under the combination treatment received only 50% of the feeds used for the feeding alone treatment, the amount of uneaten feeds in those ponds was low and consequently the rate of decomposition was lower than in the ponds under the treatment for feeding alone. This resulted into less microbial activities and relatively higher levels of DO in pond water subjected to the combination treatment compared to those under feeding alone treatment [2, 14]. For the ponds subjected to fertilization alone, there were less microbial activities due to minimum decomposition process. This is because there were no feed remains, hence, low organic matter decomposition and less use of DO in the decomposition of organic matter [13].

The dawn DO values reported in the present study are lower compared to the values reported by Shoko *et al.* [15] and Abdel-Warith [16] which ranged from 6.2 to 13.7 mg/L for the experiment done between 0900 and 1700 hours. It is well established that DO levels fluctuate within 24 hours period and are lowest at dawn and highest at dusks [17, 6, 18]. These findings support the results of the present study.

The mean value for dawn pH followed the same trend as DO values. Low pH in the ponds under the treatments of combination and feeding alone could be caused by the accumulation of CO_2. The presence of uneaten feeds may result into an increase in microbial decomposition activities, hence, high respiration rates [13], especially during night times where both fish, plankton and microbes use oxygen and respire CO_2. Bhatnagar and Devi [19] and Makori *et al.* [18] noted that pH in the water is determined by the concentration of CO_2 which exists in the form of carbonic acid. In addition, the daily pH fluctuation may be caused by the change in the rate of photosynthesis in response to daily photoperiod [20, 18].

Temperature did not differ significantly among the treatments and was within the range acceptable for tilapia growth. The preferred water temperature for tilapia growth is approximately between 20.27 to 30 ºC [19, 6, 15]. Such range agrees with the findings of the present study. In the present study assessment of diurnal temperature fluctuations, revealed that temperature was higher than the optimal range, especially at dusk. This condition might have lowered feed intake and consequently low fish growth rate. It is well documented that as the temperature increases beyond the acceptable range the solubility of DO decreases [19].

The lowest mean Secchi disk reading observed in ponds under the combination of fertilization plus concentrate feeding might be due to high water turbidity and total dissolved solids (TDS). Total dissolved solids (TDS) and plankton are among the factors that increase water turbidity [19]. Significantly higher TDS values in ponds under feeding treatments, suggest that some of the feeds sank into the water. This is because some particles of the mash feed do not float, therefore sink to the bottom and decompose and hence, increased TDS of pond water. It has been reported that, high water turbidity, TDS, conductivity, salinity and low Secchi disk reading reflects the amount of suspended clay particles, feed leftover, abundance of plankton and pigments from decomposition of organic matters in the water column [19, 21]. Research findings shows that Secchi disk reading decreases as the plankton and TDS increases in the water column [22, 23]. Nevertheless, the Secchi disk values observed in this study were in the acceptable range of between 15 and 40 cm for fish growth [19, 24].

Likewise, conductivity and salinity values observed in this study were within the acceptable ranges for fish growth and survival, which is between 30 and 5000 µS/cm for conductivity and 0 and 7000 mg/L for salinity [19, 26, 25]. The lowest alkalinity value observed in ponds under the combination of fertilization plus concentrate feeding might be contributed by the low concentration of CO_2 after dawn hours. Water samples were taken after dawn hours when photosynthesis was taking place. Ponds under combination treatment showed low Secchi disk reading which may imply high amount of plankton, thus high photosynthesis which lowers CO_2 levels [14]. Interestingly, the alkalinity values obtained in the current experiment for all treatments were in the acceptable range of between 115 and 329 mg/L for fish culture [6]. The higher alkalinity mean values in the ponds under fertilization alone and feeding alone treatments indicates the higher capacity of pond water to resist pH fluctuation compared to the ponds under the combination of fertilization plus feeding [26].

The highest concentrations of nitrate and total nitrogen in the ponds under fertilization alone probably were caused by application of inorganic fertilizer (urea). The same amount of inorganic fertilizers was applied in ponds under fertilization alone and the combination of fertilization plus feeding treatments. But the ponds subjected to the combination treatment had relatively lower nitrate and total nitrogen concentration perhaps because of higher biomass of phytoplankton and, hence, high consumption of nitrate by phytoplankton. Values of nitrate concentration (NO_3) in pond water observed in this study were within the acceptable range for fish growth of between 0 and 90 mg/L [23, 19].

Phosphorous is the major element and performs vital functions including transfers of energy and genetic information in the cells for sustenance, growth and development of algae [27]. The higher phosphorous content in ponds under fertilization alone could be caused by input of phosphorous from inorganic fertilizer (DAP) and the presence of less phytoplankton to consume the phosphorous, thus most of it was left in pond water [19]. Phosphorous content in pond water observed in the present study was within the standard range of between 0.05 and 1.0 mg/L [28, 29].

4.2 Growth performance and survival rate of Nile tilapia

Higher fish growth rate observed under the combination of pond fertilization plus concentrate feeding than in other treatments is due to the fact that the fish reared in ponds under the combination treatment consumed nutrients from both supplementary feed and natural food stimulated by essential nutrients from fertilizers and leftover feeds. This is in agreement with the findings of other researchers [30, 31, 4, 16, 6]. Also, it has been shown that, in a semi-intensive system, fish can depend on natural food to a limited size, beyond that it requires supplementary diet to attain optimum growth [23].

The highest condition factor (K) observed on the fish under fertilization alone suggests that, fish grew slower in length relative to weight. A study done by Abdel-Warith [16] on the effects of fertilization plus feeding, manure plus feeding and feeding alone on tilapia growth also reported higher condition factor for the treatments with low growth rate as in the present study. The differences in condition factor among the treatments may be the result of the differences in feeding strategy that possibly altered the environmental conditions of the pond. However, since the condition factor was greater than one in all treatments, the fish in ponds under all treatments were in good health conditions [32].

Survival rate of the fish was not affected by feeding strategies. Fish survival can be reduced by presence of diseases and/or poor water quality beyond the acceptable range [33, 19]. Water physico-chemical parameters in all ponds in the present study were within the acceptable ranges for fish growth. The lower feed conversion ratio (FCR) in fish reared under the combination of fertilization plus concentrate feeding is because, the amount of feed used to feed fish was 50% of that used under feeding alone treatment. Also, the weight gained by fish under the combination treatment was higher than that in feeding alone treatment. The same results have been reported by Abdel-Warith [16], Zahid *et al.* [10] and Opiyo *et al.* [3] who observed that FCR of the fish decreased when both fertilizer and supplementary feed are used. This suggests that by feeding the fish the combination of natural food and concentrate feed, the efficiency of fish to convert feed into tissue biomass becomes high [2, 6]. The results in the present study revealed that the feed conversion efficiency (FCE) was almost doubled in the fish under the combination treatment compared to those under feeding alone as it has been reported by Manyala *et al*. [6].

4.3 Influence of water physico-chemical parameters on growth rate of Nile tilapia

The negative correlation between fish growth rate and dissolved oxygen in the present study probably might be the result of the effect of experimental time. Previous studies have shown that organic matter in the ponds increase with experimental time [6]. The increase of organic matter in the pond is the results of decay of high algae biomass and accumulation of uneaten feeds. The organic matter accumulation in the pond water increases microbial decomposition activities and this demands more dissolved oxygen, thus lower DO levels [34]. Low DO levels below 3 mg/L in the water may affect fish growth [35]. In the present study, DO levels supported fish growth as experimental time increases since the DO did not fall below the recommended level.

The highest fish growth rate was observed in ponds under the combination of fertilization plus feeding, which had relatively lower pH compared to the ponds under the other treatments. Previous studies have shown that high fish growth is achieved at the pH of between 6.5 and 8.5 which is close to the average fish blood pH (7.4) [19, 18]. Among the three treatments, the ponds under the combination of fertilization plus feeding had pH level close to the fish blood pH. Pond water temperature values in this study were within the acceptable range for fish growth [19]. The increase in temperature in the present study resulted into an increase in fish growth. Studies have shown that high temperature favours the metabolic and physiological activities of the fish [19, 18]. The negative relationship between Secchi disk reading and fish growth rates suggest that, Secchi disk reading decreased as availability of feed in ponds increases. This limits light penetration in ponds water and reduces Secchi disk reading but more feeds become available for fish as reported by Abdel-Tawwab *et al*. [23].

4.4 Fish yield and economic return

The high unit cost of producing one kg of fish under feeding alone treatment was probably caused by the large quantity of feeds used to feed the fish and this resulted into high feed cost. The feed cost under the feeding alone treatment exceeded that of the combination of fertilization plus feeding by 70%. Feed cost accounted for 61 and 42% of the total variable costs under feeding alone and the combination of fertilization plus supplementary feeding treatments, respectively. This is in agreement with the findings documented by Jabir *et al*. [36] and Abdel-Warith [16] that, feed costs comprise 40-70% of total operational costs. Although the unit cost for one kg of fish under fertilization alone was the same as that observed under the combination of fertilization plus concentrate feeding treatment, fish cultured in ponds under fertilization alone had lower yield and thus, low gross margin. The fish reared in ponds under feeding alone resulted into a loss due to high feed cost compared with the fish cultured in ponds under the combination of fertilization plus feeding treatment. This is because fish reared in ponds under feeding alone treatment were fed 50% more feed than those under the combination of fertilization plus supplementary feeding.

The gross margin for the fish reared in ponds under the combination of fertilization plus feeding was higher compared to those under feeding alone, suggesting that the combination of pond fertilization plus supplementary diet feeding is the cost-effective strategy for growing tilapia under semi-intensive production system. Similar results have been reported by Thakur *et al.* [13] and Manyala *et al.* [6] that the culture of fish in fertilized ponds accompanied with supplementary feeding results in better performance in terms of yield and gross margin. This is mainly the result of reduction of feed costs and efficient utilization of feeds under the combination treatment, hence, high fish growth and yield [6].

5. Conclusions and recommendations

This study has shown that, the culture of *Oreochromis niloticus* in earthen ponds subjected to the combination of weekly inorganic fertilizer application plus concentrate feeding at 2.5% of the fish body weight result into faster fish growth and higher food conversion efficient (FCE), than the culture of fish in ponds under fertilization alone or feeding alone at 5% of the fish body weight. Moreover, the combination of weekly fertilization and concentrate feeding at 2.5% of fish body weight reduces feed cost significantly and hence, increases the gross margin compared to feeding alone at 5% of fish body weight. Weekly fertilizer application either under fertilization alone or the combination of fertilization plus concentrate feeding does not affect the water quality parameters beyond the acceptable range for optimum fish growth. However, application of fertilizer plus concentrate feeding decreases water Secchi disk reading which is negatively correlated with fish growth performance. It is recommended that further study be done on the effect of fertilization and feeding floating pelleted feeds. The use of floating pelleted feeds will reduce feed leftovers. Moreover, alternative day feeding should be done as this may reduce feed cost and increase profit.

6. Acknowledgment

Funding for this research was provided by the Aquaculture and Fisheries Innovation Laboratory (AquaFish Innovation Lab). The AquaFish Innovation Lab is supported in part by United States Agency for International Development (USAID), Cooperative Agreement No. EPP-A-00-06-00012-00 and by contributions from participating institutions. The authors also acknowledge the assistance of laboratory technicians from the Department of Animal, Aquaculture and Range Sciences (DAARS) and Department of Soil and Geological Sciences at Sokoine University of Agriculture for their supports during sample analyses.

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