OPTIMIZING THE USE OF COMMERCIAL FEEDS IN SEMI-INTENSIVE POND PRODUCTION OF TILAPIA IN GHANA; FROM NURSERY TO GROW-OUT

Production System Design and Best Management Alternatives/Experiment/16BMA02PU

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ABSTRACT

Pond-based tilapia production in Ghana still suffers from the absence of a viable nursery sector and high cost of production due to high feed cost and suboptimal use of fertilization and feeding strategies. This investigation used a series of experiments and economic analyses to determine areas where both nursery and grow-out feeds and feeding can be optimized as well as make the feed ingredients local, sustainable, and low-cost. Experiments were carried out at the Kwame Nkrumah University of Science and Technology fish farm, the Pilot Aquaculture Center of the Fisheries Commission, and a private fish farm, all in Kumasi, Ghana. In the first experiment we showed that a grow-out feed with 25% crude protein (CP) results in the same growth in fertilized ponds as the standard 23% CP feed on the market while costing approximately 15% less. Therefore, reduced protein feed would result in substantial profitability of tilapia grow-out operations. In the second experiment, we showed that feeding tilapia on alternate days or daily at half ration both result in substantial reduced cost of production not offset by slightly reduced growth, compared with feeding daily at full ration. The two treatments resulted in approximately triple and double, respectively, of the return on investment when compared with the standard practice. The remaining studies considered nursery production systems and comprised three successive experiments to determine the optimum stocking density and growth performance of Nile tilapia fingerlings using both commercial and experimental feeds. Additionally, zooplankton consumption was studied and represented an important part of the fish's diet. In the first of the nursery experiments commercial feed (48% CP) was used to raise 2-g tilapia in $1m^3$ hapas in ponds to >20g. Four stocking densities were used; $28/m^3$, $55/m^3$, $83/m^3$ and $110/m^3$ and growth observations were made10, 20, 30 and 40 days after the experiment. In the second nursery experiment, experimental feeds (48% CP) in three iso-nitrogenous and iso-caloric diets were formulated and compared with the commercial diet used in earlier. A digestibility experiment was carried out in 120L indoor tanks and ammonia excretion rates were determined. For the third experiment, the best two diets from the second experiment were field tested along with the commercial diet. Stocking density was $100/1m^3$ in $1m^3$ hapas in a pond and the experiment lasted for 40 days with sampling done every 10 days. In all cases, survival rates, feed conversion ratio (FCR), growth performance and water quality variables were monitored. For the last experiment, gut content analysis was also conducted. For the first nursery experiment, survival rates ranged from 77-85% and decreased slightly but significantly with stocking density. FCR was below 1 for all treatments and averaged 0.67 ± 0.02 standard error. Mean final weight did not differ among the treatment at the end of the 40 days. For the digestibility experiment, fecal matter output was highest for diets 2 and 3 (relatively higher fiber content) and differed from the control (commercial feed). Protein and dry matter digestibility were similar for all diets. Diet 3 however, had a lower lipid digestibility compared with the others. The FCR was similar among the diets with a low of 1.61 ± 0.17 (sd) in the Diet 2 and a high of 1.79 ± 0.12 (sd) in diet 3 with a survival rate ranging between 83-97%. For the last nursery

experiment (field testing), survival rates were 75-92%. There were no significant differences between the mean weights of the fingerlings harvested among the different diets. FCR ranged from 0.55 in the Control to 0.65 in Diet 3. Fish fed Diet 2 consumed more zooplankton than the control, and diet 3. The most common zooplankton in the diets for all treatments were the rotifers, especially *Brachionus spp*. This investigation shows that numerous opportunities exist from nursery through grow-out in the practice of tilapia farming in Ghana, to reduce feed and feeding cost, increase profitability, and sustainably increase tilapia production in the country.

INTRODUCTION

The small-scale pond sector of the aquaculture industry in Ghana is still struggling to effectively integrate routine and profitable use of commercial floating feeds into farming operations, despite a growing availability of high-quality commercial feeds in the country. Recent AquaFish Innovation Lab studies of growth performance of Nile tilapia (*Oreochromis niloticus*) during the grow-out phase in Ghana showed the superiority of commercial floating feeds compared to farm-made sinking feeds (Ansah and Frimpong 2015). Most farmers already acknowledge that commercial feeds would increase profitability during grow-out, hence a growing number of small-scale tilapia farms have tried commercial floating feeds or use them routinely in their production. For pond-based semi-intensive tilapia farms in Ghana using commercial feeds, feed constitute approximately 60% of the cost of production (Frimpong and Anane-Taabeah 2017). Due to importation of feeds or feed ingredients, this component of cost increases as the value of the local currency depreciates continually against major world currencies.

A combination of high feed cost and lack of technical know-how in the efficient use of feeds and optimal fertilization has been identified as an obstacle to increased yield and profitability of small-scale fish farming in Ghana. Secondly, in spite of modest progress made in the development of an improved strain of Nile tilapia in Ghana, pond farmers scattered through the regions still face a lack of access to all-male fingerlings of the appropriate size for expanded production. Since demand for fingerlings exceeds its supply and the fingerling size and sex reversal needs for cage and pond farms differ, most pond farms can only access fingerlings from the wild or are forced to purchase fingerlings that are too small (fry) and not properly sex-reversed, leading to high mortality, high in-pond breeding, and ultimately, low productivity. Overall throughout the country, not only are hatchery capacities limited but also no true nurseries exist. Therefore, high demand for fingerlings have driven down the size of fingerlings that hatcheries are able to produce and buyers are willing to take, leading to the sale of increasingly smaller sizes of fingerlings that are more susceptible to mortality when handled.

A practical solution for pond farmers is to buy fry at 1.5 - 2g and transport long distances. Others acquire broodstock and produce their fry on-farm. Techniques are needed for farmers to raise fry on quality feed to rapidly reach the sizes at which the tilapia sexes can be identified visually (15-30g) and separated before sexual maturity. For small-scale, pond-based farming, manual separation of the tilapia sexes for stocking continue to be the most viable approach for monosex grow-out since hormonal sex-reversal continue to deliver unacceptably low success rates (70% - 90% male) in numerous trials. Profitable on-farm nursery of tilapia will require optimization of growth rate, survival rate, and feed conversion, whether undertaken with commercial or farm-made feeds.

Due to high protein content, nursery feeds available in Ghana (~48% CP) cost twice as much as grow-out feeds (~30% CP). For both nursery and grow-out feeds, there is a need for sustainable and cost-saving technologies; including reductions in protein content and replacement of fishmeal with alternate, locally available protein sources (Hasan 2017; El-Sayed 2018). Feed development therefore remains critical in the successful establishment of commercial nurseries and pond-based grow-out. Agbo et al. (2011) and Obirikorang et al. (2015) have shown that various agro-by products in Ghana can be a good supplementary protein source in formulating tilapia diets. In this proposed study, a series of experiments and economic analyses were performed to develop a locally verified base of knowledge on cost-saving feeds and feeding strategies for pond-based tilapia producers in Ghana.

OBJECTIVES

1. To evaluate the survival, feed conversion, and growth of Nile tilapia raised in ponds on high-protein (48%) commercial feeds from fry to fingerling sizes.
2. To compare the growth and yield of Nile tilapia in grow-out ponds fed full ration on 30%, 28%, and 25% protein on commercial feeds in combination with fertilization.
3. To compare growth and yield of Nile tilapia in grow-out ponds with 30% protein commercial feeds at full ration, half ration, and alternate-day full ration, in combination with fertilization.
4. To evaluate the palatability/acceptability, digestibility of experimental diets made from locally available ingredients fed to Nile tilapia from fry to fingerling sizes.
5. To evaluate the survival, feed conversion, and growth performance of Nile tilapia raised in ponds on experimental diets from fry to fingerling sizes.
6. To determine the zooplankton composition and importance in fingerling diet.
7. To assess the profitability of the different feeds and feeding strategies for the nursery and grow-out scenarios.

MATERIALS AND METHODS

Study Area

Nursery experiments were carried out in aquarium tanks and hapas mounted in ponds at the Fish Farm at Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. Grow-out experiments were conducted in ponds at KNUST farm, Pilot Aquaculture Center of the Fisheries Commission (PAC), and a private farm in Kumasi.

Source of Fish and Water

Well water was used for all studies. Fish for the study was sourced from PAC and a private hatchery in Akosombo, Eastern Region of Ghana. Fish estimated for stocking hapas or ponds were packaged separately in well well-oxygenated plastic bags to prevent over-handling. The fish were acclimatized to the study conditions before each experiment was conducted. For grow-out experiments, fry (about 2g) were first raised in fertilized ponds in hapas on high protein commercial feeds to a target size of 30-40g. Females were then visually identified and removed before stocking males in open ponds at desired densities of approximately $2/m^2$.

Pond Preparation

Experimental ponds ranged in size from $150m^2$ to $630m^2$. Ponds were drained, dried and limed at a rate of 1kg agriculture lime per $10m^2$ to improve alkalinity and ensure that fish eggs from nearby rivers were eliminated. Ponds were then filled and fertilized. Fertilization was achieved with mono ammonium phosphate (MAP) at 2g per m^2 and urea at 3g per m^2; strictly according to the phytoplankton abundance, using Secchi-disk depth as a proxy for abundance. The right proportions of MAP and urea for all the ponds were measured into a container, dissolved with approximately 15 liters of pond water and fertilizer solutions broadcast over the surface of pond.

Experimental Design

Objectives 1-6 are respectively matched with experiments E1, E2, E3, E4, E5, and E6.

Experiment E1 & E5

Experiment E1 & E5 followed a completely randomized design with two factors: 1) Density at 28, 55, 83, and $110/m^3$, and 2) Time (i.e. number of days till fish are observed) at 10, 20, 30, and 40 d (Figure 1). Each treatment was replicated 3 X for a total of 48 experimental units. Each experimental unit is a hapa of size 1m^3 in a pond of >1 m water depth. All fish were stocked at the same size of approximately 2g and fed twice daily, targeting a feeding rate of 10% average body weight (ABW) through 30d and switching to 8% ABW through 40d. Experiment E1 fish were fed on a 48% CP commercial feed, whereas E5 was repeated for each of the best two performing 48% CP experimental feeds (described later) with the commercial feed as a control. For E5, fish were conditioned for one week and the initial weight of the fish used became 3.4g. Only the stocking density of 100/m^3 was used for E5 and the feeding rate was maintained at 8% throughout the experiment. Fish sampling was done every ten days till the end of the experiment after which the quantities of feed fed were adjusted. Physicochemical water quality variables; temperature, DO, pH, and Secchi depth were monitored throughout the experiment.

Density	**28 fry/m^3**				**55 fry/m^3**				**83 fry/m^3**				**110 fry/m^3**			
Days till Observed	10d	20d	30d	40d	10d	20d	30d	40d	10d	20d	30d	40d	10d	20d	30d	40d
	10d	20d	30d	40d	10d	20d	30d	40d	10d	20d	30d	40d	10d	20d	30d	40d
	10d	20d	30d	40d	10d	20d	30d	40d	10d	20d	30d	40d	10d	20d	30d	40d

Figure 1.- Experimental design for experiment E1.

Experiment E2

The first round of Experiment E2 was carried out in six 150-200m^2 experimental ponds at KNUST farm and nine 450-630m^2 at a private farm in Kumasi. One of the larger ponds was lost as an experimental unit due to a flood that allowed an unknown number of adult female tilapia to enter the pond after stocking. The second round was run in nine 250-450m^2 ponds at PAC and six 450-600m^2 ponds at a private farm in Kumasi. This was a one-factor experiment at 3 levels of crude protein (30%, 28%, and 25% protein) following a completely randomized design. The 30% and 28% protein feeds were available on the market in Ghana from a locally-based feed producer. The 25% feed was produced under a special arrangement with the producer and primarily involved replacement of protein with starch. Fish for this experiment was first be stocked as 2g fry in a hapa within each pond and fed on high-protein feeds until they attained approximately 30-40g before being sorted by size and sex for stocking all males at approximately 2/m^2 in experimental ponds. Thereafter, feeding was done two times a day (approximately 10:00am and 4:00pm) starting at 3% ABW/day and reducing through the growth period to 2% ABW/day at experiment termination. For each trial fish growth was monitored for at least 12 weeks to allow growth differences to be clear among treatments.

Experiment E3

Experiment E3 was carried out in nine 350m^2 ponds at PAC. This was a one-factor experiment at 3 levels of feeding (full ration & 30% protein (control); half ration & 30%; alternate day & 30%) following a completely randomized design with 3 replicates per treatment. Stocking, feeding and monitoring followed protocols described for experiment E2.

Experiment E4

This experiment was carried out in a modified Guelph system, with 12 cylindro-conical tanks of volume 150L each and a reservoir tank. Water temperature was maintained at ~25ºC at a water exchange rate of 100Lh^{-1} and tanks were well aerated (≥70% dissolved oxygen saturation) and a light regime of 12 hour light: 12 hour dark throughout the experiment. Each tank was fitted with a sedimentation column at the bottom which allowed for ease of feces collection. Four treatments; one a commercial diet (same as in experiment 1) and three experimental diets were tested. All diets were iso-nitrogenous (crude protein – 48%) and iso-caloric diets (gross energy – 17kJg^{-1}). The treatments were randomly assigned to the experimental units in triplicates and the variables monitored were feed acceptability (using feed intake as a proxy), fecal output, and nutrient digestibility.

Experimental Feeds

The three feeds were formulated using Winfeed Ver 2.8 (Table A1[1]). The protein sources used were agro by-products (soybean meal, and fermented copra meal) and fishmeal. The copra meal was fermented with oyster mushroom *(Pleurotus ostreatus*) following methods described by Agbo and Prah (2014) to help reduce the fiber and lipid contents while improving the overall protein content. The carbohydrate and lipid sources in the diet were wheat bran and palm oil respectively. A vitamin/mineral premix was also added to each diet with tapioca added on as a binder. All ingredients used in diet preparation were finely ground, sieved, weighed at pre-determined quantities and thoroughly mixed with hot water and other ingredients and pelletized using a Bosch meat grinder model MFW67440 with 2mm die plate. The diets were then oven dried for 48 hours at a temperature of 40ºC, cooled and pellets separated by hand.

Fish Stocking and Feeding

Each 150L experimental tank was stocked with 225 all male tilapia fingerlings of 2g average weight. The fish were acclimated for two weeks. Fish were hand fed twice a day at 8% of their body weight.

Feed Intake, Fecal Matter, Nutrient Digestibility and Growth Performance

Feed intake for the experimental period was calculated as average weight of feed taken per fish. All uneaten feed was accounted for throughout the experiment. Fecal matter was collected in sedimentation tanks covered with an ice jacket for nine days. Feces were collected daily before feeding from each tank using the sedimentation column which was housed in a Styrofoam jacked that contained ice to prevent the breakdown of nutrient in the feces during collection. The samples were transported on ice to the laboratory stored at -20^{0}C to slow down bacterial decomposition until analyzed. Fecal matter for the estimation of fecal output were oven dried (105ºC) and expressed as gDMkg-1 of ingested feed.

The dry matter, lipid, and protein digestibility of each diet was determined by comparing the quantity of nutrients consumed with what remained in the feces at the end of the digestive process. For each treatment, the proximate composition of the diet and the feces were determined at the Faculty of Renewable natural Resources at KNUST following methods described in AOAC (2005). Digestibility was expressed as percentage (%) of the absorbed nutrients divided by the nutrients in the feed according to Jobling (1994).

$$Digestibility\ (\%) = \frac{(Nutrient\ in\ feed - Nutrient\ in\ faeces)}{Nutrient\ in\ feed} * 100$$

Growth performance was estimated based weight gain at the end of a three week growth trial and specific growth rate calculated as:

$SGR\ (\%/day) = \frac{(LnFW - LnIW)}{D}$,

Where:

IW is the initial weight and FW is the final weight and D is the number of days between weighing.

[1] Tables A1-9 are listed in the "Additional Tables and Figures" section at the end of this report.

Ammonia Excretion Rates
Ammonia excretion rates were determined for each diet. Fish were starved 24 hours to ensure that previously eaten food was removed from their system. Fish in each tank were then fed a single diet of 2% of total biomass. After feeding, the recirculation system was shut down and 15ml water samples were taken from each tank every 3 hours over a 24-hour period for TAN measurements. The total ammonia-nitrogen (TAN) concentrations in water were determined by the use of a YSI 9300 photometer.

Experiment E6
At each fish sampling event during E5, four hapas were randomly selected and five fish from these hapas were harvested for gut content analyses. Zooplankton species and numbers in the gut of fish sampled from the various treatments (n=20) were determined for days 10, 20, and 40. The harvested fish were preserved on ice and transported to the FRNR laboratory where the gut for each fish was removed and preserved in 4% formalin. For identification, the content of the preserved stomach was emptied into a petri dish and 2ml sub samples were taken and observed under a Celestron Digital LCD microscope (X40). Zooplankton species were identified to the genus level using an identification guide (Shiel, 1995).

Statistical and Economic Analyses- *Data Analysis*
Experimental data on growth, survival, FCR and other tested variables were analyzed using general linear models; including linear regressions and Analysis of Variance (ANOVA), and response surface methods implemented in R. Proportional response such as survival was analyzed in some cases with logistic regression. Other one-way ANOVA were conducted using the Graphpad Prism 5 software and Tukey multiple comparison tests at an alpha of 0.05 was used in post hoc analyses.

The experimental results provided input to economic analysis of relative profitability of the feeding strategies. Standard methods for profitability analysis, including enterprise budgets followed Engle and Neira (2005). Feed prices for estimating the cost of production were obtained both from the market and from the feed producer's pricing schedule. Current farm-gate prices of tilapia in Ghana at the time of analysis were obtained from the market. Based on extrapolation of the producer's price schedule, the 25% protein feed, for example, would be priced about 15% less per kg compared to the 30% protein feed. It is possible then to determine the cost savings if pond farmers of tilapia can use the 25% feed for grow-out and achieve an insignificant difference in growth performance compared to the 30% feed.

RESULTS

Experiment E1
The overall survival rate had a negative relationship with stocking densities and varied from 77-85%. The logistic regression showed a significant effect of stocking density on survival ($p < 0.001$), although survival was very variable (Figure A1[2]). Growth as a function of Time showed interaction with Feeding Rate, which made a simple linear or non-linear regression not very useful since feeding rate varied by period and effective feeding rate varied by experimental unit as inferred with the survival data. A smoothed (loess) interpolation of growth showed growth stanzas corresponding to the periods and indicating that the feeding rate adjusted by the time period or interval affected growth (Figure A2). A regression capturing the effect of feeding rate and the number of days of growth was used to generate a two-dimensional contour plot which would serve as a look-up table for hatchery operators using the commercial feed for nursery (Figure 2).

[2] Figures A1-4 are listed in the "Additional Tables and Figures" section at the end of this report.

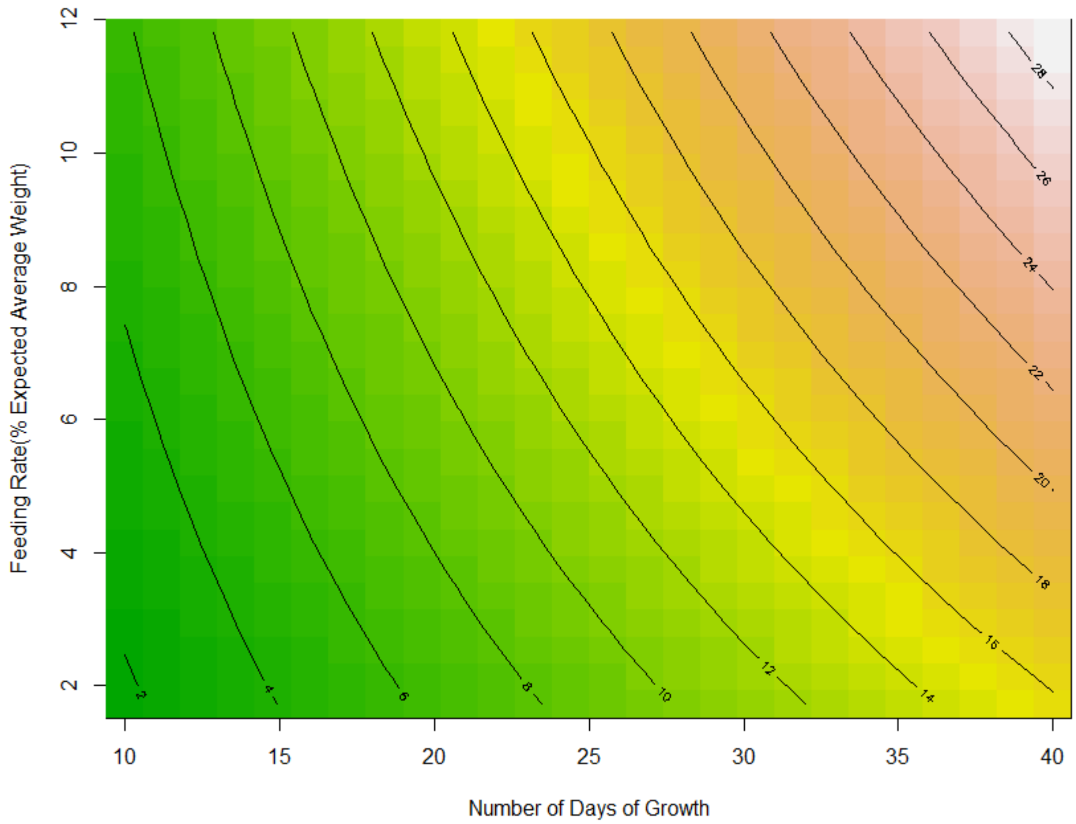

Figure 2.- Predicted weight gain based on the number of days of growth and feeding rate for fry raised in fertilized ponds and fed 48% CP commercial nursery feed at 33.5ºC.

The SGR and feeding rate had a very tight, near-linear, approximately 1:1 relationship, reflecting a consistent low (FCR < 1) across treatments averaging 0.67(±0.02, std. error). This implies that most of the feed fed was utilized for growth, with little or no overfeeding or waste (Figure 3). Overall and approximate Interval FCRs were not predicted by any variables that were measured. Start Density had the highest (but still very low) correlation with FCR, and a linear regression was not significant ($p > 0.05$). A t-test combining the low density treatments against the high density treatment was also not significant (Figure 4). Therefore, while FCR showed a slight trend of potentially deteriorating at high stocking density, the stocking densities in this study may not have been high enough to be of concern. This relationship is worth further investigation with a larger dataset and in follow-up studies using the design of this experiment. It will require additional treatments at higher stocking densities.

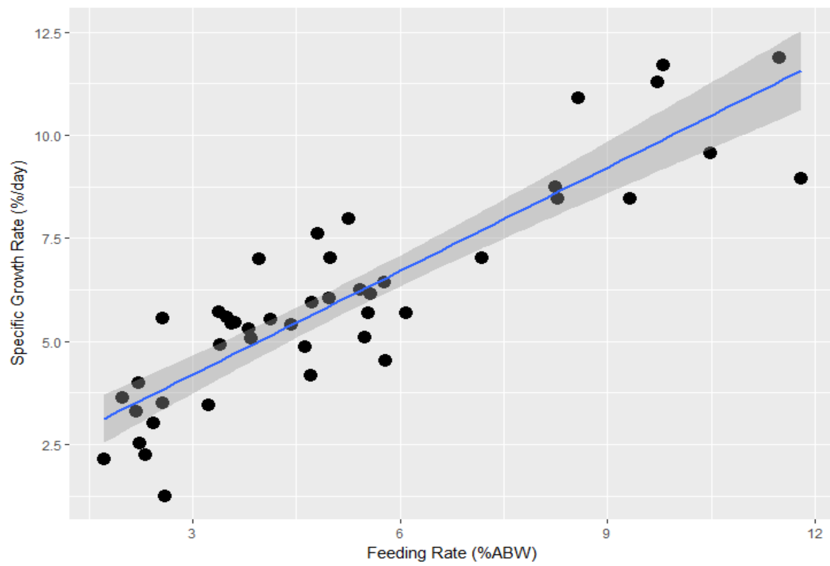

Figure 3.- Relationship between feeding rate and SGR in nursery hapas mounted in fertilized ponds

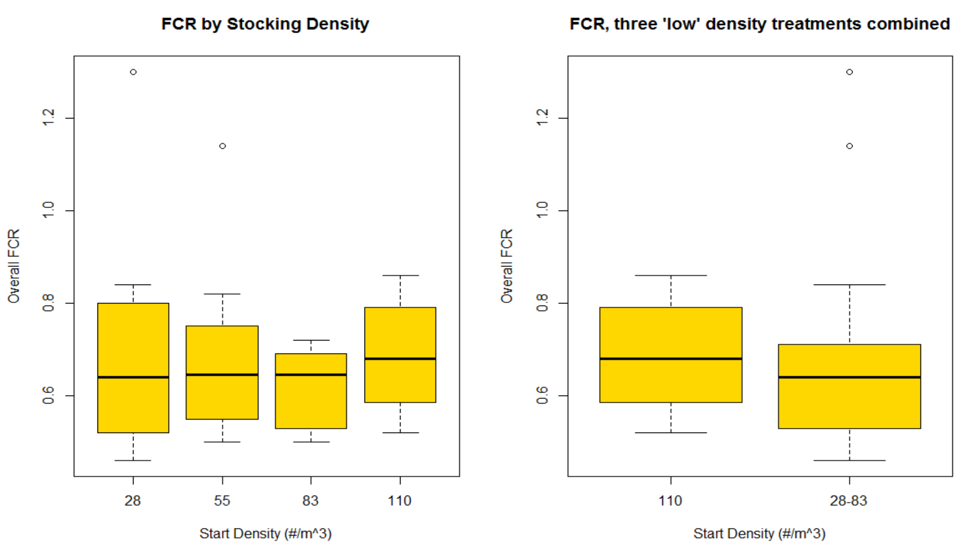

Figure 4. The relationship between FCR and stocking density

Since mortality was not strongly affected by stocking density, the highest treatment was associated with the best profit. An enterprise budget based on a 40-d production cycle to raise fry from 2g to 20g (Table A2) showed a profit margin of > 100% (B/C = 2.08) per fingerling sold. This represented a highly profitable business.

Experiment E4, E5 & E6

Acceptability and Digestibility of Experimental Diets

By the end of the acclimation period, the fish in all treatments readily accepted all the diets used in the experiment and were consuming all the feed fed. Overall feed intake was not significantly different among the different treatments; were 6.63±0.17 (control), 5.76±0.23 (Diet 1), 6.26±0.48 (Diet 2) and 6.67±1.08 (Diet 3). FCR did not differ among the treatments (p>0.05). The control Diet had a slightly higher SGR and weight gain than the experiment diets but not statistically different from the other diets (Table 1).

Table 1.- Growth performance, feed intake and utilisation of juvenile Oreochromis niloticus fed experimental diets for three weeks

Parameter	Control	Diet 1	Diet 2	Diet 3
Initial Weight (g)	1.98±0.39	2.21±0.10	2.23±0.36	1.97±0.29
Final Weight (g)	6.10±0.63	5.74±0.19	6.15±0.70	5.70±0.75
Weight Gain (g)	4.12±0.69	3.52±0.18	3.93±0.67	3.73±0.60
SGR (%day^{-1})	2.84±0.39	2.26±0.13	2.37±0.30	2.38±0.30
Feed Intake (g/fish)	6.63±0.17	5.76±0.23	6.26±0.48	6.67±1.08
Feed Conversion Ratio	1.65±0.32	1.64±0.04	1.61±0.17	1.79±0.12

Each value is the mean ± SD

Fecal matter output ranged from 192.22 1.39 to 231.77 24.15 gDMKg-1 (Figure 5). Fish in the tanks fed the Control and Diet 1 had a lower fecal output; the control diet had a significantly lower ($p< 0.001$) fecal output compared to Diets 2 and 3. There were no significant differences in the dry matter and protein digestibility of fish fed the different diets, however, the lipid digestibility for Diet 3, was significantly lower than that of the other three diets (Figure 6). Mean temperatures and dissolved oxygen levels remained above 27ºC and 6mg/L respectively throughout the study with pH ranging between 5.75 and 7.83 (Table A3). The TAN excretion rates for all diets followed the same trend with the peak rate occurring 6 hours after feeding for all diets and were as follows: 5.48±0.61 mg kg^{-1} hr^{-1} for the Control Diet, 7.39±1.37 mg kg^{-1} hr^{-1} for Diet 1, 6.94±3.42 mg kg^{-1} hr^{-1} for Diet 2 and 5.69±2.26 mg kg^{-1} hr^{-1}.

Growth Trial with Experimental Nursery Feeds

The survival rates for this experiment ranged from 75-92%; there were no significant differences among the treatments (Table 2). There were no significant differences between the mean weights of the fingerling fed the different diets. FCR was 0.55 in the control, 0.59 for Diet 2 and 0.65 in Diet 3. Feed intake was lowest for Diet 3 compared with the other treatments (Table 2). Mean temperatures were above 28ºC and lowest pH recorded was 6.7. Dissolved oxygen levels were higher in the control pond than in the experimental ponds and Secchi depth was highest for the Diet 2 (Table A4).

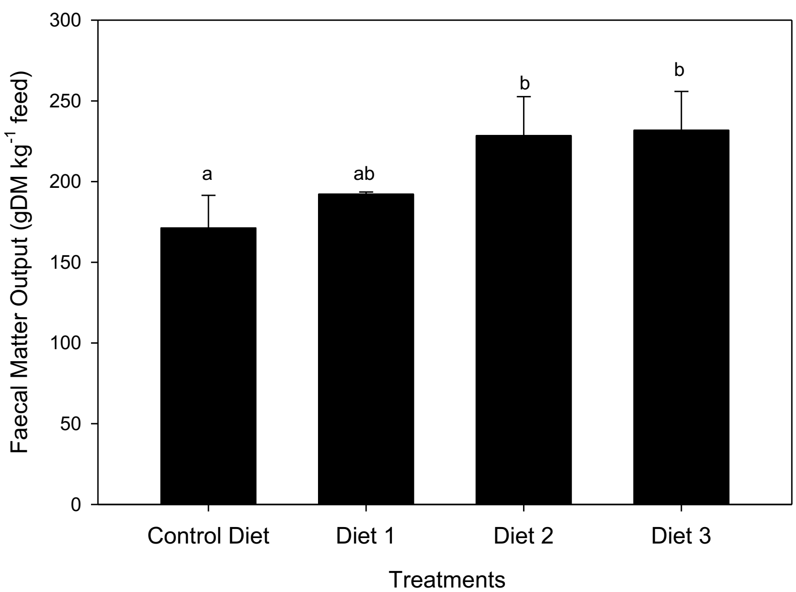

Figure 5.- Faecal matter production (mean ± SD) of Nile tilapia fry fed the different experimental diets.

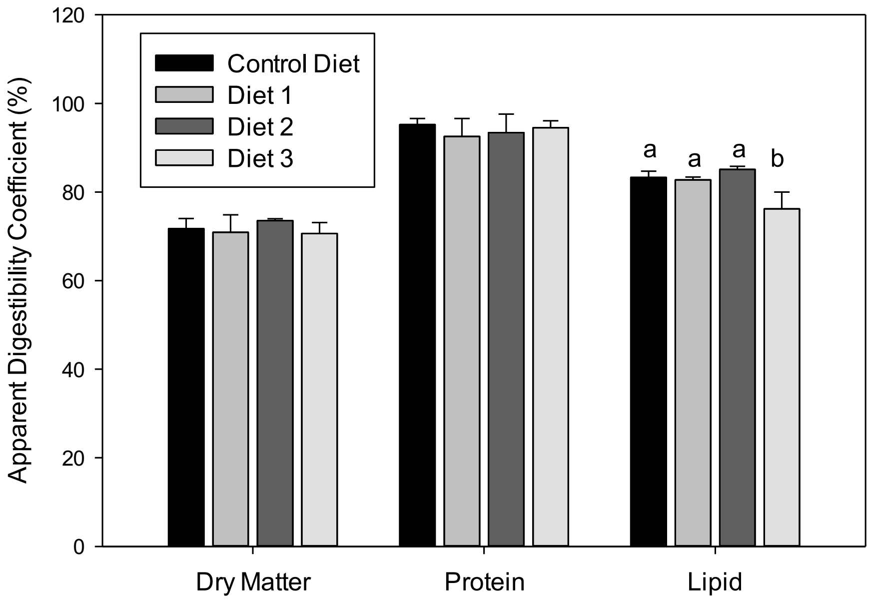

Figure 7. Apparent nutrient digestibility coefficients of the experimental diets and control diets used in this study (treatment means with different letter are significantly different, ANOVA, $p<0.05$).

Table 2. Survival, growth performance, feed intake and utilization of juvenile Oreochromis niloticus fed experimental diets in hapas in ponds for 40days.

Parameters	Control	Diet 2	Diet 3
Survival (%)	91.75	74.50	87.25
Initial weight (g)	3.95	3.93	3.93
Final weight (g)	20.88	12.91	12.41
Weight gain (g)	16.90	12.84	8.48
Weight gain (%)	427.89	326.34	218.58
FCR	0.55	0.59	0.65
SGR (%/day)	7.06	6.37	5.34
FER	2.85	2.78	1.92
Feed intake (g/fish/day)	0.15	0.12	0.11
Protein efficiency ratio	5.94	5.79	2.39

By day 10, the fingerlings in all treatments were consuming more zooplankton than at the end of the experiment; fish fed the D2 diet generally consumed more zooplankton than the control, and diet 3 (Table A5). The most common zooplankton in the diets for all treatments were the rotifers especially *Brachionus spp* in the first 20 days, the rotifers were still the most encountered species at Day 40 but for diet 3 the ostracods were the most abundant. Frequency of occurrence was highest in Diet 2, followed by the control, with the lowest being Diet 3. Zooplankton numbers were highest at day 20 and lowest at day 40. The most abundant species were the *Trichocerca spp* (Table A5). The phytoplankton encountered was partially digested making it impossible to identify them.

Experiment E2
The detailed statistical and economic analyses presented in this report are based on a concurrent trial at KNUST and a private (ENIN) farm. The trial at KNUST was terminated early due to significant pond volume lost during the dry season overlapping with the experiment. In addition, a high female proportion among the batch of fry led to reproduction occurring in some hapas much earlier than would be anticipated, and before sorting and separating fingerlings. On comparable grow-out periods, both growth (Figure A3) and FCR (Figure A4) were better at the private farm regardless of treatment, pointing to a strong site (ponds) effect. We report a more detailed analysis of data from ENIN farm for a 15-week grow-out period. Overall, the results from the private farm are closer to practical results expected when better management practices are observed. Proximate analysis results closely tracked the manufacturer's label for protein content (Table A5).

Fish weight increased from an initial mean of 59.8 ± 9.5g at the start of the trial to 299.6 ± 10.8g, 277.1 ± 2.0 and 305.4 ± 3.0g for the 25%, 28% 30% protein treatments, respectively (Table 3). There was a significant difference (p = 0.011) in SGR between the 28% CP treatment and the 25% and 30% CP treatments. The 28% treatment had an SGR of 1.21 ± 0.17%/day, 1.27 ± 0.01%/day for the 25% protein and 1.31 ± 0.15%/day for the 30% protein. Mean weight gain also followed the same trend as the specific growth rate with a recorded value of 363.90 ± 60% for the 28% protein, 401.18 ± 18.06% for the 25% protein and 410.90 ± 5.01% for the 30% protein as shown in Table 4.1. The Daily weight gain however, had a different trend from the other growth indices assessed with a significant difference existing only between the 28% and the 30% crude protein treatment. The values for the 25%, 28% and 30% treatments were 1.89± 0.09, 1.74 ± 0.03 and 1.94 ± 0.02, respectively. The FCR averaged 2.06 and protein efficiency ratio average 1.81; both metrics were not significantly different across treatments. Summary of weekly monitored water quality variables are presented in Table A6.

Table 3.- Means ± SD of the growth performance of Nile Tilapia *Oreochromis niloticus*

Variables	**25% CP(n=3)**	**28% CP(n=3)**	**30% CP (n=2)**
Initial Weight (g)	59.78 ± 9.52	59.78 ± 9.52	59.78 ± 9.52
Weight Gain(g)	239.8 ± 10.8^{a}	217.3 ± 2.04^{b}	245.60 ± 3.04^{a}
Weight Gain (%)	401.1 ±18.06^{a}	363.60 ± 3.41^{b}	410.90 ± 5.01^{a}
Final weight (g)	299.58 ±20.32^{a}	277 ±11.56^{b}	305 ± 12.56^{a}
Specific Growth Rate (%/day)	1.27 ± 0.03^{a}	1.21 ± 0.01^{b}	1.29 ± 0.01^{a}
Daily Weight Gain (g)	1.89± 0.09^{ab}	1.74 ± 0.03^{a}	1.94 ± 0.02^{b}
Survival Rate (%)	93.67 ± 3.79^{a}	93.67 ± 5.03^{a}	93.00 ± 0.00^{a}

^{abc}mean values in the same row with different superscripts are significantly different (p<0.05)

The production cost which included cost of feed, labor inputs for pond preparation, pond rental and cost of fingerlings showed that the 28% protein had the highest cost of GH¢12.26 per kg of fish produced. This was followed by the 30% protein which also incurred a production cost per kg of fish at GH¢10.89. The least was the 25% protein which was GH¢9.57. The total cost of production, the revenue generated after sale of fish, and the profit or loss incurred after the trial for both treatments is shown in Table A7. The 28% crude protein treatment also had the highest revenue despite recording the least growth as a result of the proceeds realized from reproduction in the experiment.

Experiment E3
Feed reduction strategies generally did not negatively affect fish growth and nutrient conversion efficiency over the 15 week culture period. Growth was similar among the treatments although fish on control recorded relatively better growth (211.3g) compared to fish that were fed on alternative days (173.3g) (Table 4). Fish in all the treatments had final mean weight that was about four times

their initial mean weight which did not differ significantly ($p>0.05$). Other growth performance indices (SGR, FI, SR and DGR) did not show significant differences ($p> 0.05$) among the three treatments. However, the control group recorded the slightly higher performance values. Cumulative feed intake (FI $gfish^{-1}$) over the culture period was significantly higher ($p< 0.05$) for fish fed the control treatment (full ration) but similar for the group on half ration and alternate day full ration (Table 4). Feed conversion efficiency ranged from least efficiency of 1.25 for the control treatment to highest efficiency of 0.86 for the alternate day feeding group. FCRs recorded, however, did not differ among the treatments. Associated water quality data monitored biweekly are presented in Table A8.

Table 4.- Growth performance and feed utilization of *Oreochromis niloticus* fed different feeding strategies culture period of 15 weeks.

Variable	Full Ration	Half Ration	Alternate Day Full Ration
Initial mean weight (g)	35.01 ± 14.81	35.01 ± 14.81	35.01 ± 14.81
Final mean weight (g)	211.29 ± 17.09	185.62 ± 42.53	173.31 ± 20.43
Weight Gain (%)	503.55 ± 48.83	416.37 ± 128.70	380.18 ± 68.12
DGR (g fish-1 day-1)	2.05 ± 0.20	1.75 ± 0.49	1.61 ± 0.24
SGR (%.day-1)	2.09 ± 0.09	1.89 ± 0.27	1.85 ± 0.14
Survival (%)	91.48 ± 6.99	90.71 ± 5.02	91.62 ± 6.76
FCR	1.25 ± 0.23	0.94 ± 0.20	0.86 ± 0.21
FI (g/fish)	219.11 ± 28.98b	134.32 ± 7.38a	116.64 ± 20.69a
Fish yield (kg)	406.43 ± 17.60	350.75 ± 20.55	334.35 ± 18.88
Fish yield (kg/hectare)	3870.81 ± 410.67	3340.47 ± 479.42	3184.28 ± 440.29
Feed given (kg)	418.10 ± 7.42b	255.38 ± 0.00a	222.50 ± 7.39a
Feed given (kg/hectare)	3981.90 ± 173.16 b	2432.14 ± 0.00 a	2119.05 ± 172.40 a

Each value is the mean ± SD of data from three replicates. Mean values with different superscripts in the same row are significantly different at $P < 0.05$. Absence of letters indicates no significant difference between all the treatments. FCR = Feed conversion ratio, FI (g) = Feed intake, SGR (%.day $^{-1}$) = Specific growth rate, DGR (g $fish^{-1}$ day^{-1}) = Daily growth rate.

Economic analysis was based on the experimental and market data and on-farm sale of fish. Variable costs incurred were constant across treatments except feed and labor cost that varied with feeding strategy. Feed cost was significantly ($p < 0.05$) higher in full ration feeding strategy contributing about 43% to operational cost while half ration and alternative day full ration contributed 31% and 34%, respectively. The second largest cost component was labor. The largest labor expenditure contribution to variable cost was realized in the half ration (36%), followed by full ration (30%) whiles the alternate day full ration strategy contributed 25% to total variable cost. Other costs of producing Nile tilapia in fertilized ponds are relatively the same with no regard to a particular feeding strategy. Tilapia produced under alternate day treatment (GH₵ 5.39/kg) resulted in the lowest breakeven price and the full ration was the highest (GH₵ 7.87/kg) (Table A9). Average breakeven prices for all treatments were below the selling price (GH₵ 10.0/kg) of Nile tilapia (at 250g). The average fish yields recorded were above the breakeven yields for all treatments (Table 4). Revenue accrued from fish sale was similar among the three feeding strategies. Net returns above the total cost was significantly higher ($p < 0.05$) in fish fed on alternate day full ration compared to the half ration and full ration. Alternate day full ration recorded a profit of GH₵ 2269.41 representing about 75% profit returns on total money invested, an amount that exceeds the net returns in the full ration by 53%. The half ration feeding strategy recorded a profit of GH₵ 1,582.04 also representing about 42% net returns on investment while the full ration recorded GH₵ 995.88 which represents about 22% returns on investment. None of the feeding strategy however recorded negative returns on investment.

DISCUSSION AND CONCLUSION

The reduced protein and feeding strategies other than full ration for grow-out of tilapia both showed opportunities for substantial reduction in cost and improvement profitability of small-scale, semi-intensive tilapia farming in Ghana. In particular, considering reduced feed cost, the 25% CP feed was substantially more profitable than the 30% CP feed. Similarly, alternate day feeding at full ration, followed by daily feeding at half ration both were more profitable than the full ration feeding of twice daily at 5-2% ABW (depending on size at stocking).

Any reduction in growth associated with reduced protein is more than compensated by the reduced cost of feed. According to the feed manufacturer, opportunities exist for further feed price reduction through decreased vitamin and other supplements as effective pond fertilization provides the necessary nutrients through the phytoplankton and zooplankton. The 28% feed available on local market is designed primarily as a maintenance feed for cage farmers after fish attain market size and before harvest. It is therefore not surprising that this feed formulation appeared to be worse than the 25% feed formulated specifically for pond grow-out of tilapia. The 25% feed is the predominant feed used in Egypt, for example, (El-Sayed 2017) for tilapia grow-out. Farmers need to be educated to understand that slight growth differences due to higher protein content may not be worth the extra cost of feed if profit is to be maximized. Better understanding will increase the acceptability of reduced protein feeds to farmers and consequently motivate its production by the feed manufacturers at a scale that is beneficial to both feed producers and farmers.

Additionally, the opportunity to reduce cost and increase profitability through reduced feeding is well demonstrated by this study. Alternate day feeding at full ration, followed by daily feeding at half ration both were more profitable than the full ration feeding. Farmers might look at the slight differences in growth observed over the study period while missing the economic efficiency associated with the reduced feed input. Increased education of farmers is necessary to draw attention to profitability as the bottom-line to focus on rather than growth. There is also a need to educate farmers to produce for the appropriate market. For example, premium pricing of larger tilapia by the restaurant sector in Ghana pushes small-scale farmers to target production of larger fish which may not necessarily feasible with the strain of tilapia under cultivation in the country but is nevertheless tempting as more feeding appears to result in better growth.

The nursery trial with commercial feed showed profitability at a high stocking density of approximately 100 fry/m^3, without incurring costly high mortalities. Survival rates were quite high across the experimental stocking densities, ranging from 77% at the highest (110/m^3) to 85% at the lowest (25/m^3). Furthermore, it is possible that stocking density could have been increased further to increase profitability even at the risk of slightly increased mortality. Future studies should consider testing higher stocking densities. Based on the current study, a viable tilapia nursery business model is available in Ghana that should be developed.

The experimental nursery feeds also produced highly promising results, considering relatively lower costs associated with production of these feeds from local ingredients. Compared to the commercial feed, survival rates were good in all three experiments with an average overall rate exceeding 75%. The field experiments with 100/m^3 had survival as high as 92%. Combined with the good FCRs (<1) recorded in the field experiments, it is very likely that the conditions under which the fish were grown in this investigation were suitable for juvenile Nile tilapia. Low FCR could also be attributed to the fingerlings feeding on natural foods and this was confirmed by the gut content analysis that showed that plankton was an important part of the fish diet. The importance of plankton in the diet of fingerling has been previously established (Abdel-Tawwab and El-Marakby, 2004; Gupta et al. 2012). Higher survival rates have been associated with feeding with live foods (Hassan 2011). This is further supported by the fact that higher FCR was recorded in the recirculation tanks. In recirculation tanks with bio-filters, bacteria tend to be a more important microorganism than plankton (Hargreaves 2013). All water quality parameters measured in the tanks were within favorable range for tilapia culture with mean dissolved oxygen levels remaining above 6mg/L.

Although, the experimental Diet 1 had good fecal output and good nutrient digestibility, it did not perform as well as the other two experimental diets. Higher fiber content in diets 2 and 3 could account for the higher fecal load from the two treatments. Ammonia excretion rates peaked six hours after feeding, this means that the last feeding of the day should be time such that phytoplankton are still active and can help with the elimination of the ammonia produced. Based on the ammonia excretion rates, survival rates, digestibility and growth performance Diet 2 was the best experimental Diet. This assessment was confirmed during the third experiment where Diet 2 performed better than Diet 3. In addition to the Diet 2 being more digestible than Diet 3, the fish in that treatment eat more zooplankton to supplement their diets than did those fed Diet 3. The experimental diets especially the Diet 2 compared favorably to the control and, given the lower cost, will result in higher profits than that of the control. Stocking densities used had no significant effect on weight gain; similar results were reported by Brown and Bolivar (2005) and did not negatively affect FCR. This might indicate that optimum stocking density is yet to be reached. Collectively, the experiments and economic analyses conducted under this investigation show numerous opportunities still exist from nursery through grow-out in the practice of tilapia production in Ghana, to reduce feed and feeding cost, increase profitability, and sustainably increase tilapia production in the country.

ACKNOWLEDGEMENT

We are grateful to the following individuals, including thesis students and technicians of KNUST who assisted with the field and laboratory studies: Nathaniel Gyasi Adjei, Abigail Ebachie Tarchie, Anthony Aliebe, Emmanuel Nyamekye, Grace Nikoi-Olai, Francis Adjei, Stephen Gyamfi, Maame E. Goode. We would also like to sincerely thank the Pilot Aquaculture Centre of the Fisheries Commission and Mr Joshua Enin (private farmer) for providing additional sites and ponds for the experiments, and Jacques Magnee and Raanan Fish Feed - West Africa Ltd for formulating the entire 25% protein commercial feed used in the experiments.

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ADDITIONAL TABLES AND FIGURES

Table A1.- Weight of formulated diets (g kg-1) and proximate composition (% dry weight basis) of feedstuff used for the formulation of the different experimental diets

TEST DIETS			
Ingredients	**DI**	**D2**	**D3**
Fishmeal	486.00	403.00	324.50
Soybean meal	325.00	425.00	509.80
Fermented copra meal	81.00	74.50	71.50
Wheat bran	68.00	57.80	54.20
Binder (starch)	10.00	10.00	10.00
Palm oil	20.00	20.00	20.00
Vit. Supplements	10.00	10.00	10.00

Ingredients	DM		CP		CL		ASH		NFE	
Fishmeal	90.40	91.00	60.80	61.20	5.30	5.60	12.70	13.0		
Soybean meal	90.39	90.26	44.02	44.77	15.09	17.83	9.03	9.15	22.25	18.51
Wheat bran	88.86	88.44	19.73	19.05	9.74	8.51	5.72	5.86	53.67	55.02
Copra meal	83.91	83.72	24.36	23.71	19.45	19.74	8.78	9.08	31.38	31.19
Fermented Copra meal	79.84	80.25	30.10	32.62	11.24	12.13	14.08	14.24	24.42	21.26

DM: Dry Matter; CP: Crude Protein; CL: Crude Lipid; NFE: Nitrogen Free Extract

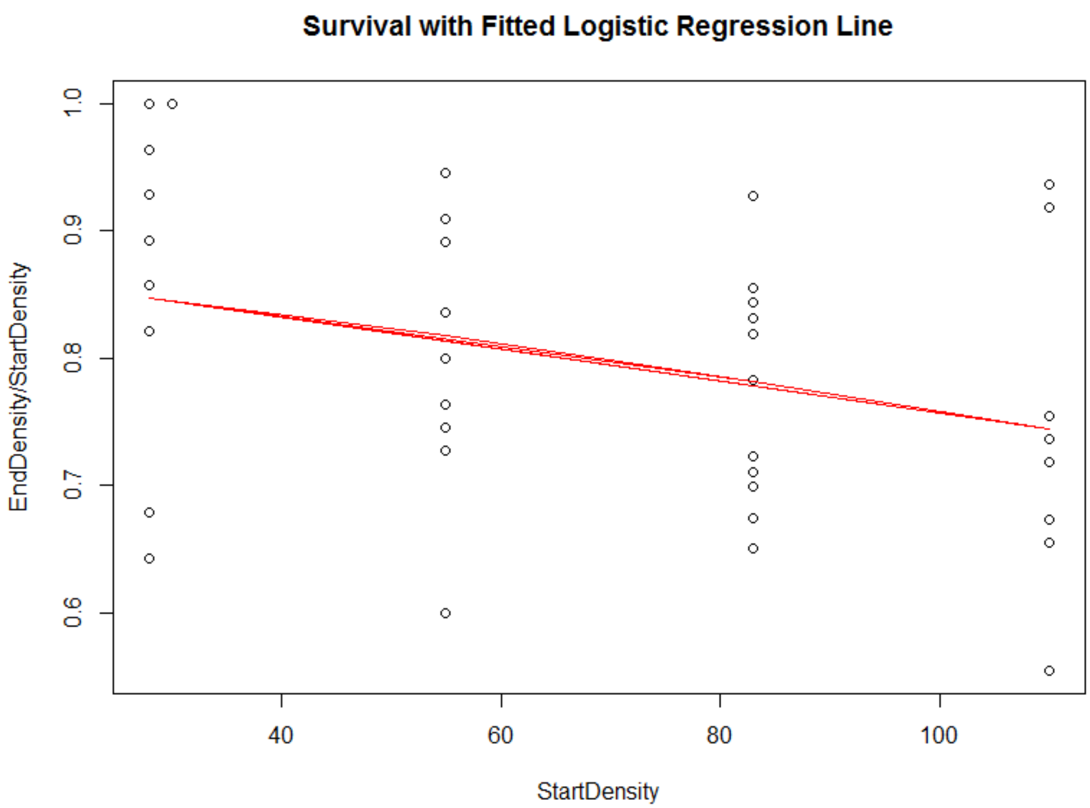

Figure A1.- Survival as a function of FCR in nursery trials. Stocking density in hapas is in number/m^3.8

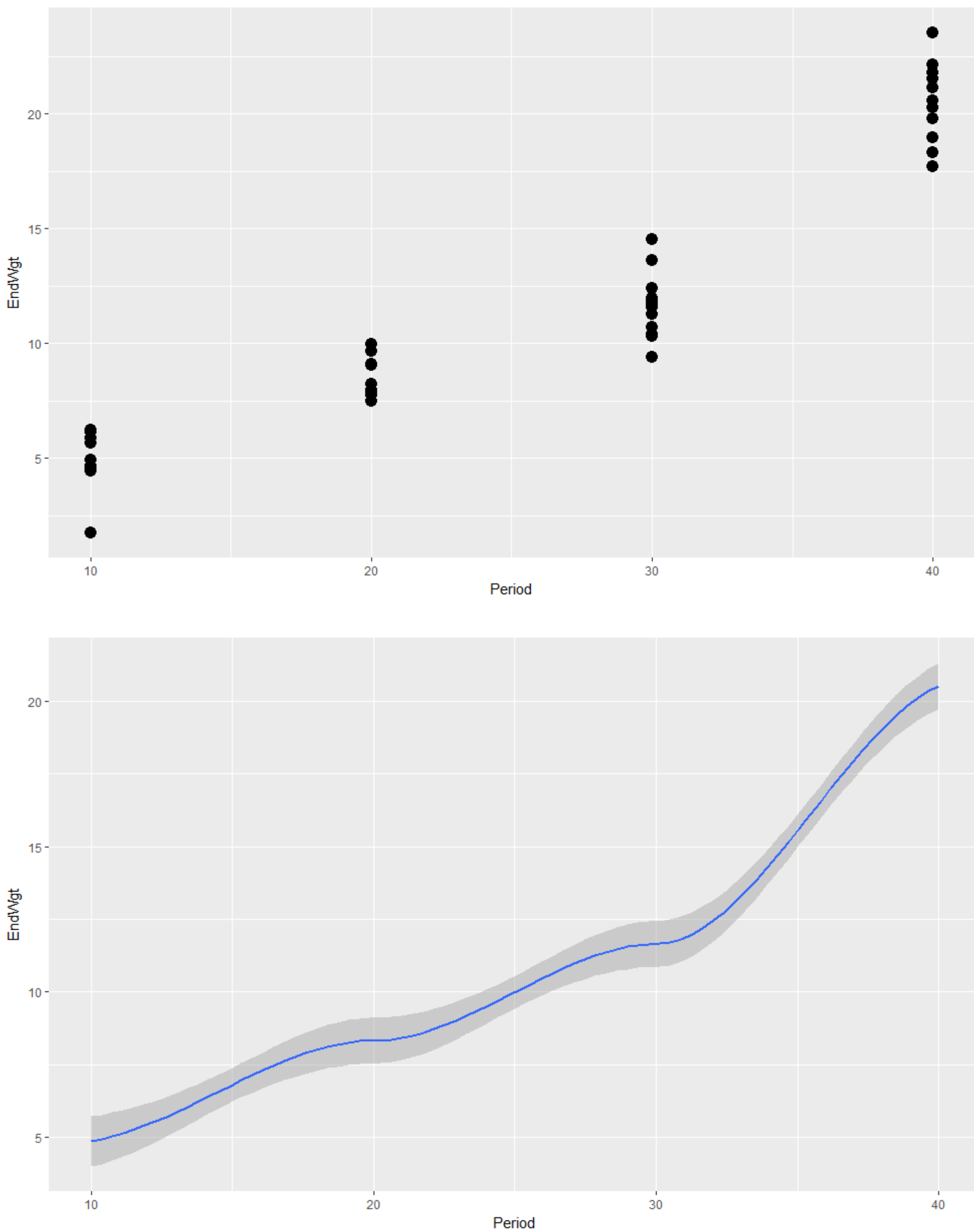

Figure A2.- Weight gain attained in different intervals as influenced by growth rate, **Top**: Scatter plot of end weights (g) against number of days (period) fry/fingerlings are kept in hapas and **Bottom**: A loess smoothing interpolation of end weight (g) by period showing growth stanzas likely caused by differing feeding rates.

Table A2.- Annualized enterprise budget of treatment 110 fish/m^3 for 40-day period at estimated harvest weight of 20g.

ITEM	DESCRIPTION	UNIT	QUANTITY	UNIT COST (¢)	TOTAL (¢)
Gross Receipts					
Tilapia fingerlings	Live (20g) (24% mortality included)	#	1003	1	1003
Total Gross Receipts					1003
Variable Costs					
Tilapia fry	From hatchery(2g)	#	1320	0.17	224.4
Hapa			12	3.08	36.96
Feed	48% CP commercial feed	(kg)	12	10.28	123.36
Fuel		Liter	12	0.95	11.40
Liming		kg	12	2.08	24.96
Labour				3.02	36.24
Fertilizer	MAP & Urea	kg	12	0.1	1.2
Total Variable Cost					458.46
Fixed Cost					
Pond Rent		1m^3		2.08	24.96
Total Cost					482.36
Cost per fingerling		¢/#		0.28	0.28
Fingerling sales		#/¢	0.80	802.56	802.56
Profitability					
Total Revenue					802.56
Gross profit		¢			319.08
Profit Margin					1.08
Profit per fingerling		¢/#			0.52
Breakeven price/fish					
Above TVC		¢/#			0.46
Above TC		¢/#			0.48
Break-even production					
Above TVC		¢/#			458.46
Above TC		¢/#			482.36
Benefit/Cost Ratio		(%)			2.08

Table A3.- Physicochemical variables (mean ± SD) measured throughout the short-term growth trial with experimental feed (n=3 for each diet)

Parameters	Diet 1	Diet 2	Diet 3	Control
DO	6.18 ± 0.52	6.51 ± 0.36	6.76±0.42	6.51±0.48
pH	5.70-7.68	5.76-7.73	5.79-7.83	5.58-7.74
% DO	86.21±4.69	88.26±1.30	84.68±1.98	88.33±1.87
Temperature	28.09±0.63	28.01±0.60	27.98±0.68	28.08±0.64

Table A4.- Physicochemical parameters in field experiments using the experimental; experimental period was 40 days

Parameters	Control	Diet 2	Diet 3
DO (mg/l)	5.07±2.45	3.85±2.08	3.70±1.90
pH	7.19-9.28	6.75-8.63	6.86-8.97
Temperature(°C)	28.43±0.73	28.40±1.11	28.39±0.070
Secchi depth(cm)	19.47±7.96	34.13±6.90	24.38±11.11
Conductivity(µS/cm)	162.50±26.42	145.8±26.26	133.7±23.14

Table A5. Zooplankton identified in fish gut at days 10, 20 and 40 days after the feeding with three different diets

DIET	GROUP	ZOOPLANKTON SPP	FREQUENCY OF O CCURANCE
1ST SAMPLING – DAY 10			
CONTROL	*Ostracod*	*Cypria* sp.	2
	Rotifera	*Trichocerca* sp.	12
	Copepod	*Cyclops* sp.	2
		Diaptomus sp.	1
	Rotifera	*Brachionus* sp.	19
Diet 2	*Ostracod*	*Cypridopsis* sp.	9
	Rotifera	*Brachionus* sp.	35
		Trichocerca sp.	17
Diet 3	*Copepod*	*Limnocalanus* sp.	1
	Ostracod	*Cypridopsis* sp.	5
	Rotifera	*Trichocerca* sp.	8
		Brachionus sp	11
	Copepod	*Diaptomus* sp.	1
2ND SAMPLING – DAY 20			
CONTROL	Rotifera	*Trichotria sp.*	1
		Trichocerca sp.	6
		Brachionus sp.	8
	Copepod	*Cyclops* sp.	2
Diet 2	Rotifera	*Trichocerca* sp.	9
		Brachionus sp.	15
Diet 3	Rotifera	*Trichocerca* sp.	18
		Brachionus sp.	4
3RD SAMPLING – DAY 40			
CONTROL	Cladoceran	*Daphnia* sp.	1
	Rotifera	*Trichocerca* sp.	8
	cladoceran	*Cyclocypris* sp.	8
	rotifer	*Asplachna* sp.	1
	Ostracod	*Darwinula sp.*	1
Diet 2	Rotifera	*Asplachna* sp.	3
		Trichotria sp.	1
		Trichocerca sp.	7
		Brachionus sp.	5
		Worm	2
	Cladoceran	*Polyphemus* sp.	1
	Rotifera	*Rotaria* sp.	2
	Ostracod	*Cypridopsis* sp.	1
Diet 3	Rotifera	*Macrochaetus* sp.	1
		Worm	1
	Ostracod	*Cypridopsis* sp	5
	Rotifera	*Trichocerca* sp.	1
		Asplachna sp.	1
	Ostracod	*Limnocythere* sp.	1
	Ostracod	*Darwinula* sp.	1
	Rotifera	*Brachionus* sp	1

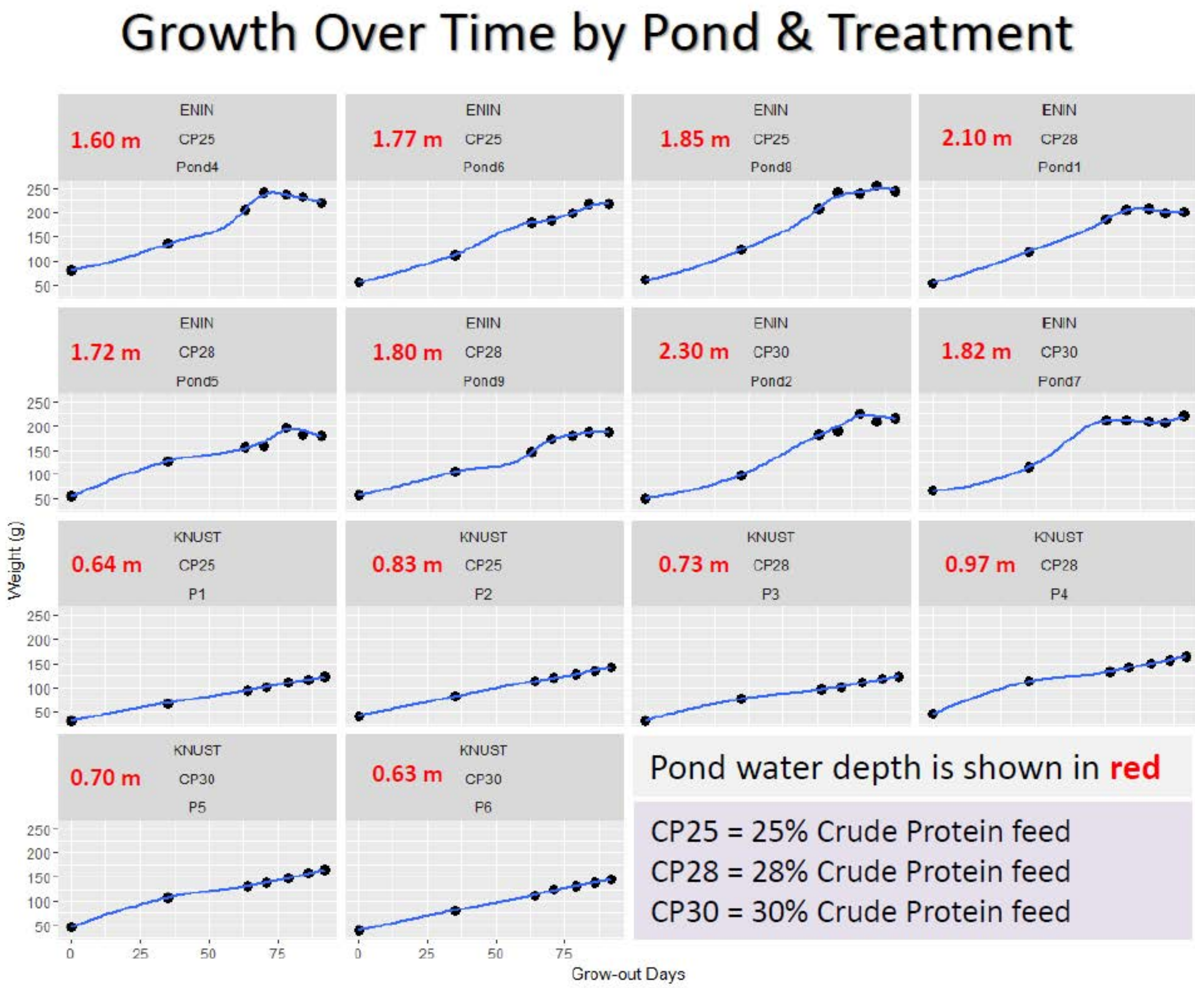

Figure A3.- Fish growth over time in individual ponds at two trial sites.

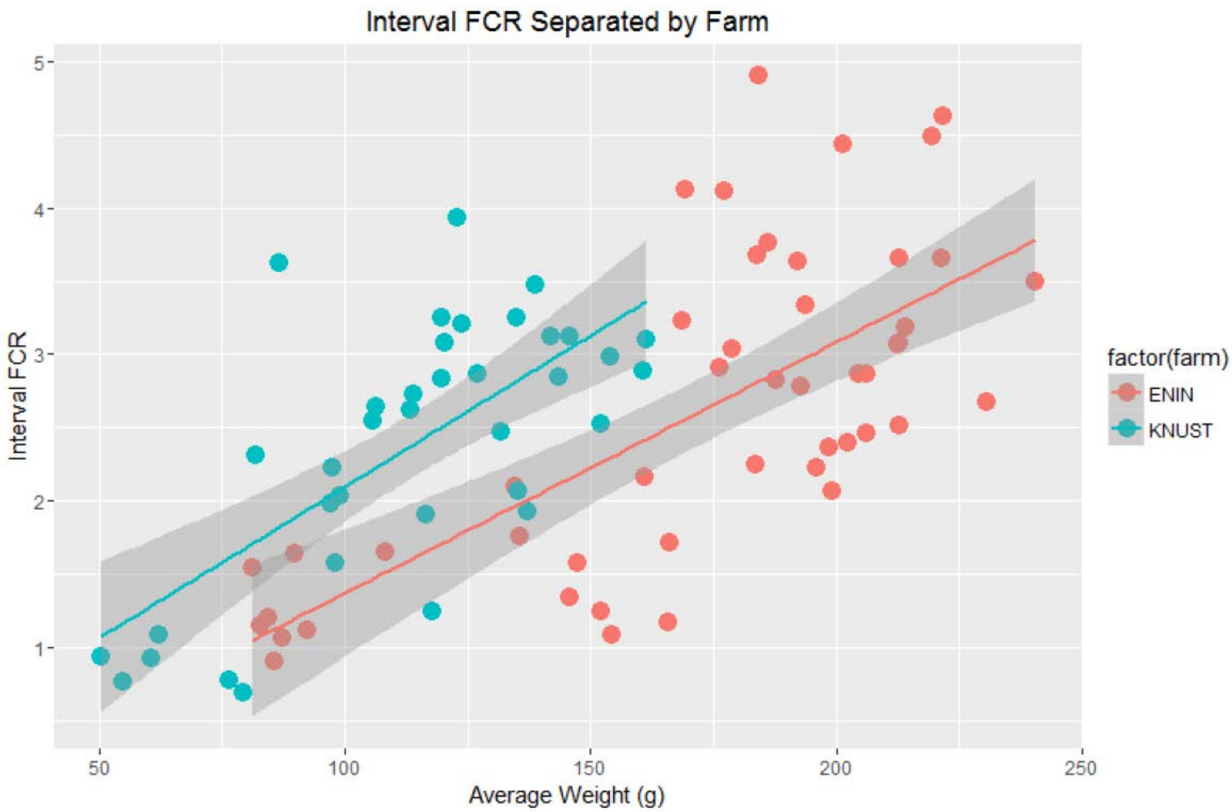

Figure A4.- Interval FCR as a function of fish size (i.e., average weight over the interval) and trial site or farm

Table A5- Proximate analysis results for experimental feeds.

Variable	25% protein	28% protein	30% protein
Protein (%)	25.66	28.56	29.16
Lipid (%)	14.10	16.3	16.90
Fiber (%)	6.00	5.80	5.37
Ash (%)	9.85	10.52	10.55
Moisture (%)	8.55	9.15	9.17

Table A6.- Summary of weekly monitoring of physico-chemical variables of ponds in differing protein content studies

VARIABLE	25% CP	28% CP	30% CP
Temperature (°C)	28.89 ± 1.20	29.31 ± 2.26	28.82 ± 1.88
Dissolved Oxygen (mg/l)	5.28 ± 1.08	4.96 ± 1.43	4.38 ± 1.01
pH (range)	6.13- 6.91	6.40-7.10	6.15-6.80
Conductivity (µS/cm)	23.00 ± 9.96^{a}	39.38 ± 11.38^{b}	14.25 ± 12.21^{a}
Total Dissolved Solids (mg/l)	13.75 ± 10.22^{a}	19.63 ± 5.83^{b}	6.88 ± 6.49^{a}
Secchi Depth (cm)	14.43 ± 2.92^{a}	14.81 ± 3.16^{a}	15.55 ± 4.40^{a}
Chlorophyll-a (µg/L)	495 ± 41.74^{a}	427.40 ± 18.26^{b}	440.60±13.19^{a}
Ammonia (ppm)	0.09 ± 0.05^{a}	0.15 ± 0.11^{a}	0.14 ± 0.08^{a}

^{ab}Mean values in the same row with different superscripts are significantly different (P<0.05)

Table A7.- Fish production and economic efficiency of experimental diets per hectare

Variables	**25% CP**	**28% CP**	**30% CP**
Total Production Cost (GHC)	35,017.73	42,966.01	46,479.96
Fish Yield (Kg)			
Table Size (~ 300g)	3709.20 ± 12.35	3503.97± 35.37	4260.42 ± 35.76
Reproduction (kg)	749.26 ± 12.16	1729.20 ± 4.86	1317.24 ± 24.32
Total yield	4458.46 ± 24.51	5233.16 ± 40.23	5577. 66 ± 60.08
Revenue (GH¢)	41,654.30	45,403.05	50,562.50
Profit (GH¢)	6636.57	2437.04	4083.33

Table A8.- Mean values of biweekly monitored physico-chemical variables in the different treatments over the 15 week trial period for ponds under different feeding strategies.

	Feeding Strategies		
Variable	Full Ration (n=3)	Half Ration (n=3)	Alternate Day Full Ration (n=3)
Temperature (°C)	27.54 ± 1.03	27.71 ± 1.23	27.52 ± 0.96
DO (mg/L)	2.91 ± 2.04	2.45 ± 1.63	2.65 ± 1.73
pH (range)	6.80 ± 0.34	6.72 ± 0.34	6.77 ± 0.33
NH_3 (mg/L)	0 ± 0.00	0 ± 0.00	0 ± 0.00
Secchi Depth (cm)	15.49 ± 1.91	16.40 ± 2.22	16.61 ± 4.10
Chlorophyll-a (µg/L)	806.40 ± 489.50	817.32 ± 547.46	897.54 ± 604.17
Nitrite (mg/L)	0.03 ± 0.07	0.04 ± 0.07	0.02 ± 0.04
Phosphate (mg/L)	12.48 ± 16.69	13.19 ± 10.46	23.24 ± 22.04
Water depth (m)	0.97 ± 0.11	0.82 ± 0.08	1.01 ± 0.18
Pond depth (m)	1.37 ± 0.06	1.22 ± 0.06	1.43 ± 0.10

Each value is the mean ± SD of data from three replicates. Mean values with different superscripts in the same row are significantly different at $P < 0.05$. Absence of letters indicates no significant difference between all the treatments. DO – Dissolved Oxygen. Data represents 7 weeks of measurements averaged over 3 replicates per treatment.

Table A9.- Economic analyses of *O. niloticus* fed at different feeding strategies.

Parameters	Unit	Full Ration	Half Ration	Alternate Day Full Ration
Yield	kg	548.63 ± 19.40	535.63 ± 25.62	529.89 ± 24.42
Gross revenue	GH₵	5,486.25 ±194.02	5,356.25 ± 256.24	5,298.9 ± 244.23
Total Variable cost (TVC)	GH₵	4,316.54	3,600.38	2,855.65
Fixed costs (FC)	GH₵	173.83	173.83	173.83
Total costs (TC)	GH₵	4,490.37	3,774.21	3,029.49
Breakeven				
Yield above TC	GH₵	449.04	377.42	302.95
price above TC	GH₵	8.18	7.05	5.72
price above TVC	GH₵	7.87	6.72	5.39
Net return				
above TVC	GH₵	1,169.71	1,755.87	2,443.25
above TC	GH₵	995.88	1,582.04	2,269.41
Per Pond	GH₵	331.96	527.35	756.47
Economic Efficiency	%	22.18	41.92	74.91