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Assessment of production and profitability of stocking sizes and densities of Nile tilapia (*Oreochromis niloticus*) for small–scale pond culture in Ghana

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ABSTRACT

The present study evaluated growth and profitability of culturing monosex male Nile tilapia (*Oreochromis niloticus*) at different stocking densities and sizes in ponds. Two stocking sizes (2 and 10 g) and densities (3 and 6 fish/m^2) were evaluated at Aquaculture Research and Development Centre of CSIR-Water Research Institute, Akosombo, Ghana. Two factorial designs had four treatments (T), each replicated two times, as follows: 2 grams at 3 fish/m^2 (T_1), 2 g at 6 fish/m^2 (T_2), 10 g at 3 fish/m^2 (T_3) and 10 g at 6 fish/m^2 (T_4). Results show that both stocking size and density independently had significant effects on final weight, condition factor, weight gain, specific growth rate and fish survival. Evaluated 154 days after stocking, highest to least final mean weights were 195.0 ± 18.5 g (T_3), 181.7 ± 16.3 g (T_1), 153.3 ± 27.5 g (T_4), and 152.2 ± 18.8 g (T_2). These mean final weights among the treatments were significantly different ($P < 0.05$) except for T_2 and T_4. The four options are ranked from the most to least profitable based on profitability and scenario analysis using different assumptions for market demand and price premiums for bigger tilapia: (1) rearing fingerlings at 2 g at 3 fish/m^2 (T_1) giving 38-76% profit margin or return to variable costs; (2) 2 g at 6 fish/m^2 (T_2) giving 50% profit margin; (3) 10 g at 3 fish/m^2 (T_3) giving 12 – 42% profit margin; and (4) 10 g at 6 fish /m^2 (T_4) giving 9 % profit margin.

KEY WORDS: Nile tilapia, profitability, stocking size, stocking density, small–scale pond culture

1.0 Introduction

Ghana's aquaculture keeps on growing faster at an annual rate of 28% from 2006 to 2019 (Agyakwah et al. 2020) because of the decline in marine fisheries and inland fisheries production (MOFAD, 2016). Aquaculture indeed is the alternate way to fill the fish shortfall in Ghana. For the past years in Ghana, the aquaculture industry has experienced a tremendous growth in both cage and pond culture (Ragasa *et al.* 2022). Aquaculture in Ghana has amounted to 76.6 thousand metric tons in 2018, representing a dramatic increase from 2008 (Ragasa *et al.* 2022) of which 11,069 metric tons were produced by small scale fish farmers (Fishery Commission, 2020). According to Kassam and Dorward (2017), pond aquaculture has a larger multiple of effect on the growth of the local economy as well as reduction of poverty as compare to commercial cage culture. Majority (90 %) small-scale farms are private sector-led and has the potential to contribute significantly to fish food and nutritional security, employment generation, increased incomes and economic growth (Fishery Commission, 2020).

Stocking size is an important factor that determines the growth and production of Nile tilapia culture in a farm (El-Sayed, 2006). Stocking size of tilapia for grow-out in pond is dictated by fingerlings available from tilapia hatcheries. The regular size of the fingerlings sold by most hatcheries in Ghana is 2.5 g (Konyim, 2018). According to Beveridge (2004), the majority (85%) of small - scale farmers stocked their cage and ponds with tilapia fry of sizes 2 g instead of the recommended fingerlings size of at least 15 g. Karikari *et al.* (2016) and Asmah *et al*. (2014) also reported smaller stocking size, ranging from 2 to 5 g, were used by tilapia farmers in Ghana. They reported that the majority of farmers stocked 2 g fingerlings and only few farmers stocked 5 g fingerlings. Recent surveys under the Ghana Tilapia Seed Project shows that 2, 5 and 10 g fingerlings are most commonly stocked by small–scale farmers (Ragasa *et al*., 2022).

Stocking density influences survival, growth, health, water quality, feeding and production system of aquaculture (Lesvia, 2014). It is also one of the most important factors in determining the production of a fish farm (El-Sayed, 2006). In ponds that are only supplemented with manures, grains or grain by–products, fish is usually stocked at a maximum rate of 1 per square meter of pond area but where tilapia are fed on pelleted feed the stocking density could be as high as 3 – 4 fingerlings per square meter (Williams, 2000).

Although many works had been done which involved government farms, large-scale farms and other NGOs, it is however unclear the type of stocking size and density small – scale tilapia pond farmers should use to maximize yield and profits in a production cycle (Konyim, 2018). There is also inadequate information on stocking size and density that will give small-scale tilapia pond farmers higher production levels and profits. So, looking at the management practices, including combination of size of fingerling and stocking density on which one could grow bigger tilapia faster and satisfy market, will therefore be important to guide small – scale farmers. The present study investigated the effects of two stocking sizes of Nile Tilapia (*O. niloticus*) at two different stocking densities in ponds on final production at harvest and production cost and benefit for small-scale aquaculture.

2.0 Materials and methods

2.1 Study area

The study was carried out at the Aquaculture Research and Development Centre (ARDEC) of CSIR-Water Research Institute (CSIR-WRI), Ghana (6017′00″ N; 0003′29″ E) at Akosombo in the Eastern Region of Ghana between December 2019 and August 2020.

2.2 Experimental set-up

Eight ponds, each of size 200 m^2 was used in the study. All ponds were prepared by clearing and allowing the bottom to dry prior to use. Lime ($CaCO_3$) of 0.1 kg/m^2 was used to condition each pond prior to filling with water. The ponds were supplied with water screened from the Volta Lake. Water levels of ponds were topped up to replace losses due to evaporation and seepage.

2.3 Experimental design and stocking of fingerlings

Mono sex male of *O. niloticus* fingerlings of the eleventh generation (G11) of "Akosombo Strain" developed by CSIR-WRI at ARDEC, Akosombo through selective breeding (Attipoe, 2006) were stocked in the experimental ponds. The 2 × 2 factorial study design involved a total of 7200 fingerlings of two different stocking sizes (2 and 10 g) that were stocked at two different stocking densities (3 and 6 fish/m^2) in eight ponds (Table 1). The fingerlings were allowed to acclimatize for five days before the trial commenced. Mortalities encountered during this period were replaced. All stocked fingerlings were cultured for 154 days.

2.4 Feeding and growth monitoring

Fish were fed with commercial extruded feed (Raanan). Forty percent (40%) crude protein of feed with pellet size 2.5 mm at an initial rate of 8% of fish body weight (BW) were administered to experimental ponds (A1, A2, C1 and C2) (Table 1) for the first two weeks. While 40% crude protein feed (2.5 mm) at an initial rate of 6% of fish body weight (BW) as suggested by MOALF (2014), were administered to experimental ponds B1, B2, D1 and D2 (Table 1) for the first two weeks. The fish were fed three times daily (8:00 a.m., 12:00 p.m. and 4:00 p.m.) and was done by hand broadcasting.

Feeding rate (FR) was determined as $FR = \%\ body\ weight \times biomass$, where biomass = average weight × total number of fish. (MOALF, 2014). Average weights were obtained from random sample of 100 individual fishes from each pond per treatment. These was done due to limited labour support, to measure all the surviving fish. Adjustment of the amount of feed was done every two weeks as fishes increased in size.

2.5 Water quality monitoring

Water quality parameters such as temperature (°C), dissolve oxygen (mg/l), ammonia - nitrogen (mg/l), hydrogen ion concentration (pH), turbidity (NTU) and total alkalinity (mg/l) of ponds were monitored prior to stocking and bi-weekly thereafter. All analyses for water quality parameters were done at ARDEC Lab at Akosombo with the exception of temperature that was taken on the field. The samples were taken between 9:00 to 9:30 a.m. in the morning.

2.6 Determination of growth parameters

Growth parameters of the fingerlings were monitored bi-weekly from sampled fish of each pond using drag net. The data collected on the fish weight and length after each sampling were used to determine growth parameters Weight gain (WG, in grams) was calculated as $\left(\frac{pond\ final\ weight}{number\ of\ fish} - \frac{pond\ initial\ weight}{number\ of\ fish}\right)$ (Ricker, 1975). where 'pond final weight' is the final average weight per pond (g/fish) and 'pond initial weight' is average initial weight per pond (g/fish). Specific growth rate (SGR, g/day) was calculated as SGR (g/day) = $100 \times \left(\frac{\ln(pond\ final\ weight)}{number\ of\ fish} - \frac{\ln(pond\ initial\ weight)}{number\ of\ fish}\right) \div \Delta T,$ where, ΔT = culture period in days. (Pillay, 1990). Individual condition factor (CF, g/cm^3) was calculated as $\frac{weight\ of\ fish}{length\ of\ fish^3} \times 100$

where weight of fish is the final individual weight and length of fish is final individual total length. (Pillay, 1990). Feed conversion ratio (FCR) was calculated as $FCR = \frac{\frac{dry\ feed\ intake}{number\ of\ fish}}{\frac{pond\ final\ weight}{number\ of\ fish} - \frac{pond\ initial\ weight}{number\ of\ fish}}$ (Pillay, 1990). Feed efficiency ratio (FE, in %) = $\frac{live\ weight\ gain\ per\ pond}{total\ feed\ fed\ per\ pond} \times 100$ (Pillay, 1990). At the end of the experiment, all surviving fish were harvested and the total weight were recorded for all treatments.

2.7 Determination of profitability of fish production

At the end of the study, revenue was calculated from sale of fish produced. To arrive at sales revenue in cash, the total quantity of fish sold was multiplied by the unit price of harvested fish. It was then computed as $TR_i = P_i Q_i$ where P_i = price of fish in kilograms (kg), Q_i = quantity of fish harvested in kilogram (kg), TR_i = total revenue (Wood, 1999). It was assumed that other fixed costs such as salaries, utilities (electricity, water, telephone, and general maintenance costs), and pond construction are the same for all treatments. The net income which is the difference between the total revenue and total cost for production results in net income or profit was computed as $\Pi = TR_i - TC_i$ where TR_i = total revenue, TC_i = total cost, Π = profit. The return on variable cost (ROC) was determine as (Profit /Variable cost) × 100% (Wood, 1999). Different assumptions of the tilapia sales price were used depending on market demand and premium put on bigger tilapia based on location:

(1) all treatments valued at GH¢11 (which is the average farmgate price for 'Rejects' of size 100-200 g) (Table 6);

(2) GH¢11 for tilapia weighing 150 – 160 g (T2 and T4) and GH¢ 12 for tilapia weighing 180 – 190 g (T1 and T3) (Table 7);

(3) GH¢11 for tilapia weighing 150 – 160 g (T2 and T4) and GH¢ 13 for tilapia weighing 180 – 190 g (T1 and T3) (Table 8); and

(4) GH¢11 for tilapia weighing 150 – 160 g (T2 and T4) and GH¢ 14 for tilapia Weighing 180 – 190 g (T1 and T3) (Table 9).

2.8 Data analysis

Data were analyzed using R software version 4.0.3 (R Core Team, 2021). Individual data were used to determine some parameters (initial weight, final weight, and condition factor), while for other parameters only the mean (average) value for each pond was used (WG, SGR, FCR, and FE). All data information on individual fish were included in the analyses. For all parameters, *p*-values in type III Sum of Square as calculated using package 'car' (Fox and Weisberg, 2019). Differences were deemed statistically significant at $p < 0.05$. Growth curves of fish for both treatments were presented in line graph using Microsoft Excel, 2019.

All parameters were analyzed using the following linear model (Model 1) $\boldsymbol{y_{ijk}} = \boldsymbol{\mu} + \boldsymbol{stocking\ weight_i} + \boldsymbol{stocking\ density_j} + (\boldsymbol{stocking\ weight} \times \boldsymbol{stocking\ density})_{ij} + \boldsymbol{e_{ijk}}$ **(Model 1)** where, $\boldsymbol{y_{ijk}}$ is individual value for final weight and CF of the $\boldsymbol{k^{th}}$ fish or mean values for WG, SGR, FCR, and FE of the $\boldsymbol{k^{th}}$ pond, $\boldsymbol{\mu}$ is the population mean, $\boldsymbol{stocking\ weight_i}$ is the fixed effect of the two stocking weight (2 g and 10 g), $\boldsymbol{stocking\ density_j}$ is the fixed effect of the two stocking density (3 and 6 fish/m^2), $(\boldsymbol{stocking\ weight} \times \boldsymbol{stocking\ density})_{\boldsymbol{ij}}$ is the fixed effect of the $\boldsymbol{ij}$ interaction of stocking weight (2 and 10 g) and stocking density (3 and 6 fish/m^2), and $\boldsymbol{e_{ijk}}$ is the random residual term.

Survival rate per pond (pond survival) was analyzed using the following logistic regression model (Model 2) $\boldsymbol{y_{ijk}} = \boldsymbol{\mu} + \boldsymbol{stocking\ weight_i} + \boldsymbol{stocking\ density_j}$ $(\boldsymbol{Model}\ 2)$ where, $\boldsymbol{y_{ijk}}$ is the logit link function of survival in the $\boldsymbol{k^{th}}$ pond, and other effects are the same as in Model 1. All output values were back-transformed from the logit scale to the response scale.

3. Results and discussions

3.1 Fish growth parameters

The growth curve showed a steady growth of fingerlings from the initial stages in all treatments toward the end of experiment (Figure 1). Irrespective of size of fish stocked (2 or 10 g), the final fish weight were significantly higher at 3 fish/m^2 stocking density compared to 6/m^2 stocking density for either 2 or 10 g at stocking (Table 2). This could be attributed to social interaction through competition for food and space leading to increase energy requirement, which could have contributed to a reduction in growth rate and food utilization by fish stocked at higher density (6 fish/m^2) as noted by Mensah *et al*. (2013).

There were significant differences between 2 g at 3 fish/m^2 and 2 g at 6 fish/m^2 with the 3 fish/m^2 spacing having the highest final weight (Table 2). This was in line with Yousif (2002), who reported that increasing the number of fish (stocking density) will adversely affect fish growth. Abdel-Hakim *et al*. (2001), also confirm that lower stocking densities usually result in significantly higher final weight and length in fish. Generally, the 10 g at 3 fish/m^2 recorded the highest average final weight than all other treatments (Table 2). This agrees with report of Zannatal *et al*. (2014), which indicated that when the initial weight (stocking size) of fish is high, it influences the body weight during the growth period.

The mean condition factor values recorded for the sizes 2 and 10 g (Table 2), were within the range of 2 – 4 as recommended by Golam and Al-Misned (2013) as appropriate for fresh water fishes. The 6 fish/m^2 stocking density recorded a higher significant mean condition factor value (2.1 ± 0.3) than the 3 fish/m^2 stocking density (Table 2). This was contrary to statement by Duodu (2014), that high stocking density has been considered as aquaculture related chronic stressor which causes growth suppression. This could be the cause of variation in water quality and sample size as well as length range. Time of year and stages of maturity may also be a contributing factor.

Generally, the mean weight gain was significantly higher at 3 fish/m^2 as compared to 6 fish/m^2 stocking density at 10 g stocking size (Table 4). The weight gain appears to be a function of stocking density but independent of stocking size. The significantly lower weight gain at 6 fish/m^2 stocking density could be attributed to the early spawning that was observed (T4) during the fourth week sampling. This is was in agreement with the statement made by De Graaf, *et al*. (1996), that early spawning in pond affects the growth rate of adult tilapia because the recruits competed for the feed intended for the stocked adult, thereby reducing the weight gain of the stocked adults. Similarly, the difference between the 3 and 6 fish/m^2 stocking densities at 2 g stocking size (Table

4) may be attributed to the high stocking density which is an inhibitory factor for fish growth due to competition for food and space (Islam, 2002).

The specific growth rate (SGR) in this study was significantly and independently affected by the stocking sizes and densities (Table 4). The 2 g stocking size, was significantly higher than the 10 g stocking size. This was contrary to what Zannatal *et al.* (2014) and Abdel-Hakim *et al.* (2001) reported that when the initial weight (stocking size) of fish is high it influences the body weight during the growth period, thus resulting in a higher specific growth rate. Similarly, fish stocked at density of 3 fish/m^2 recorded a better mean SGR compared to fish stocked at density of 6 fish/m^2 (Table 4). This was in line with Islam (2002), who reported that lower stocking densities usually lead to higher SGR.

Though there were no significant differences on the mean feed conversion ratio of all the treatments (Table 4), however, they were within the recommendation made by Bag *et al*. (2016) that, an FCR value that is less than 2.0 is considered "good" in aquaculture industry. Apparently, all the treatments had appreciable mean feed efficiency values as recorded in Table 4. However higher feed efficiency did not reflect much in their body weight gain. This could be due to the spawning that occurred in all the ponds since most of the energy obtained from the feed was used for the formation of gonads instead of weight gain (Miura *et al*., 2012).

Survival rate of fish reported in the various ponds (Table 4) were appreciable and this could be the rearing period and the water temperature as stated by Hernandez–Llamas (1996). The 6 fish/m^2 having the least pond survival of fish could be attributed to overcrowding which could had led to competition for space and food. Hence weaker ones could have been eliminated from the population as suggested by Mensah *et al*. (2013).

The weight of recruits recorded in the various ponds (Figure 3) was high though the ponds were stocked with sex-reversed male *O. niloticus*. This affected the growth of the stocked fish making them stunted confirming what Lovshin *et al.* (1990) reported that excessive recruitment and subsequent stunting of *O. niloticus* in grow-out ponds is often seen as a major problem in tilapia farming. The massive numbers of fingerlings spawned during the rearing period, utilized part of the feed intended for the stocked adults. Consequently, the growth rate of adult tilapia slowed resulting in reduced harvest yield (De Graaf *et al*. 1996).

3.2 Water quality parameters

Temperature recordings in the various treatment ponds (Table 5) were within the optimal range (26 – 30 °C) required by tilapia for growth as stated by Boyd (1990) and Lazur (2007). There were wider variations in dissolved oxygen concentrations during the study in all the treatments (Table 5). This could be because of relatively high green algae which usually occurs in wider fluctuations in dissolved oxygen concentration as observed in all the ponds. Diana *et al*. (1994), suggested that wide variation in dissolved oxygen levels could be as a result of the high oxygen demand and nutrient loading at the pond bottom. According to Peterman (2011), the suitable level of dissolved oxygen for Nile tilapia fry and fingerling production should be above 2 mg/l. Generally, all the dissolved oxygen value obtained from the treatments was acceptable for the growth of fry and fingerlings but it appeared lower than the optimum (Boyd, 1990; Makori *et al.* 2017). The earthen ponds used for the study did not have aerators, neither was there regular water exchange, except topping up to maintain threshold water levels.

The average pH value for all the treatments as shown in Table 5 were in agreement with Peterman (2011), and Nandlal and Pickering, (2004), whose independent reports indicated that the pH values for optimal growth of Nile tilapia should be within the ranges of 6 and 9. Further studies conducted by Crane (2006) and Makori *et al*. (2017) also stated that pH values should be within the ranges of 6.1 – 8 for survival of Nile tilapia.

The 10 g at 6 fish/m^2 treatment recorded the highest turbidity mean value while the 2 g at 6 fish/m^2 recorded the lowest (Table 5). This may also be the possible cause of low mean final weight recorded by the 10 g at 6 fish/m^2 (Table 2) as stated by Boyd *et al.* (2016), that an increase in turbidity may affects light penetration in pond and therefore, can affect primary production, hence oxygen concentration, and temperature. These, in turn, can have sub-lethal effects on fish growth. This may be the possible cause of the low mean final weight for the 10 g at 6 fish/m^2 treatment.

All the average total alkalinity value recorded in the various treatment were below the range (Table 5) recommended by Boyd *et al*. (2016) that the total alkalinity for fish culture may range from 75 – 200 mg/l $CaCO_3$. This may be attribute to nitrification processes leading to higher ammonia levels in all ponds (above 0.4mg/l, which is far higher than recommended 0.1mg/l). Due to the low alkalinity, the water system could not be buffered enough, hence the low range of pH in all ponds (6.2 to 6.6 mg/l - Table 5).

The average ammonia – nitrogen mean value recorded in the various treatment as shown in Table 5 were above the recommended range stated by Santhosh and Singh (2007) that the upper limit of ammonia concentration for aquatic organisms may be 0.1 mg/l. Bhatnagar and Singh (2010) and Makori *et al.* (2017) also cited that ammonia levels of < 0.2 mg/l could be suitable for pond culture. This affected the feeding of the fish as observed in the 10g at 6m^2 treatment pond during the study.

3.3 Economic profitability

The total cost of production, the revenue generated after sale of fish, and the profit or loss incurred as well as return to variable cost were calculated for the various treatments (Table 6 -9). The costs of all basic inputs as well as the prices of fish were based on local market prices at Akosombo as at the study period. The harvested tilapia weighed 150-190g across the treatments at 154 days after the experiment. These are considered "Reject" size (100 - 200 g) and fetch an average farm-gate price of GH¢11 per kg. The next size grouping is Regular (200-300g) and fetches about GH¢12-14 per kg. T_1 and T_3 are close to growing to Regular size after a few additional weeks. Using these different price premiums for tilapia size, we computed for the profitability of the different treatments. At GH¢11 tilapia price across all treatments, 2 g at 6 fish/m^2 (T_2) gave the highest profits, followed by 2 g at 3 fish/m^2 (T_1), and third, 10 g at 3 fish/m^2 (Table 6). At GH¢11 tilapia price for 150-160g and GH¢12, GH¢13, or GH¢14 for 180-190 g (Table 7, 8 and 9), 2 g at 3 fish/m^2 (T_1) gave the highest profits, followed by 2 g at 6 fish/m^2 (T_2), and third 10 g at 3/m^2 (T_3). Rearing fingerlings at 10 g at 6 fish /m^2 (T_4) consistently gave the lowest profits, giving only roughly 9 % profit margin.

The four treatments are ranked from the most to least profitable based on profitability and scenario analysis using different assumptions for market demand and price premiums for bigger tilapia: (1) rearing fingerlings at 2 g at 3 fish/m^2 (T_1) giving 38-76% profit margin or return to variable costs; (2) 2 g at 6 fish/m^2 (T_2) giving 50% profit margin; (3) 10 g at 3 fish/m^2 (T_3) giving 12 – 42% profit margin; and (4) 10 g at 6 fish /m^2 (T_4) giving 9 % profit margin.

4 Conclusions

The present study evaluated growth and profitability of culturing monosex male Nile tilapia (*Oreochromis niloticus*) at different stocking densities and sizes in ponds. Two stocking sizes (2 and 10 g) and densities (3 and 6 fish/m^2) were evaluated using a two-factorial design with four treatments (T): 2 grams at 3 fish/m^2 (T_1), 2 g at 6 fish/m^2 (T_2), 10 g at 3 fish/m^2 (T_3), and 10 g at 6 fish/m^2 (T_4). The different treatments showed different growth rates, with 2 g at 3 fish/m^2 (T_1) and 10 g at 3/m^2 (T_3) growing the fastest by 154 days of rearing. The four treatments are ranked from the most to least profitable based on profitability and scenario analysis using different assumptions for market demand and price premiums for bigger tilapia: (1) rearing fingerlings at 2 g at 3 fish/m^2 (T_1) giving 38-76% profit margin or return to variable costs; (2) 2 g at 6 fish/m^2 (T_2) giving 50% profit margin; (3) 10 g at 3 fish/m^2 (T_3) giving 12 – 42% profit margin; and (4) 10 g at 6 fish /m^2 (T_4) giving 9 % profit margin.

These results show that tilapia farming is profitable and growing bigger tilapia is possible with adjustments in stocking density and fingerling size. Nonetheless, the results also show that current practices have not produced much bigger tilapia to sizes 300-500g or more, which can capture much higher price premiums. This shows that much research, training, and capacity strengthening are needed on good aquaculture practices to maximize tilapia growth, feed use efficiency, and profits of small-scale farmers. This study illustrates that by simple adjustment in stocking density and fingerling size, faster growth, bigger tilapia, and higher profits can be achieved. More research on evaluating performance of different management practices is warranted.

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References

Abdel-Hakim, N. F., Amar, A. A., & Abd-Elgawad, A. S. (2008). Effect of initial stocking size and production cycle on growth performance of monosex tilapia reared in earthen ponds. *8th International Symposium on Tilapia in Aquaculture*, p. 55-269.

Abdel-Hakim, N. F., Hilali, I. A., Khalil, M. H., & Al-Azab, A. A. (2001). Effect of stocking density and feeding rate on performance of Nile tilapia (*Oreochromis niloticus*) reared in Tanks. *Egyptian J. Nutrition and Feeds (Special Issue)*, 705-717.

Agyakwah, S.K., R. Asmah, E.T.D. Mensah, C. Ragasa, S. Amewu, N. Tran, M. Oyih and P. Ziddah (2020). Farmers' manual on small-scale tilapia cage farming in Ghana. ISBN: 9964-85-286-X. CSIR-Water Research Institute, CSIR/WRI/MA/SKA/2020/1. Accra, Ghana. 28pp.

Asmah, R., Asmah, A. Y., Abban, E. K., Ofori, J. K., & Awity, L. K. (2014). Cage fish farming in the Volta Lake and the lower Volta: Practices and potential impacts on water quality Ghana. *Journal of Science*, *54.* https://www.ajol.info/index.php/gjs/article/view/115827

Attipoe, F. Y. K. (2006). *Breeding and selection for faster growth strains of the Nile tilapia, Oreochromis niloticus in Ghana*. Unpublished doctoral dissertation submitted to Department of Zoology, Faculty of Science, University of Cape Coast, Ghana.

Bag, N. S., & Moulick, B. C. M. (2016). Effect of stocking density on water and soil quality, growth, production and profitability of farming Indian major carps. *Indian J. Fish*, *63*, 39-46.

Bagenal, T. B., & Tesch, F. W. (1978). Age and Growth. In Bagenal, T., Ed., *Methods for assessment of fish production in fresh waters*, (3rd Ed.), IBP Handbook No. 3, Blackwell Science Publications, Oxford.

Beveridge, M. (2004). *Cage aquaculture* (3rd ed.). Wiley-Blackwell Publishing, Oxford, UK. p. 380.

Boyd, C. E. (1990). Water *quality in ponds for aquaculture. Alabama Agriculture Experiment Station Auburn University*, Alabama, pp. 482

Boyd, C. E., Tucker, C. S, & Somridhivej, B. (2016). Alkalinity and hardness: Critical but elusive concepts in aquaculture. *Journal World Aquaculture Soc. 1(47)*, 6 – 41.

Crane B (2006). Results of Water quality Measurements in Messer Pond. 2006. Available at http://www.messerpond.org/Ecology/WaterSamplingSummary. pdf.

De Graaf, G. J., Galemoni, F., & Banzoussi, B. (1996). Successful recruitment control of Nile tilapia, *Oreochromis niloticus* by the African catfish, *Clarias gariepinus* (Burchell 1822) and the African snakehead, *Ophiocephalus obscuris*. A biological analysis. *Aquaculture*, *146*, 85-100.

Diana, J. S., Lin, C. K., & Jaiyen K. (1994). Supplemental feeding of tilapia in fertilized ponds. *Journal of the World Aquaculture Society*, *25*, 497-506

Duodu, P. C. (2014). Effect of pond fertilization and feeding level on productivity of Nile Tilapia (*Oreochromis Niloticus*) in Ghana. Kwame Nkrumah University of Science and Technology, Kumasi.

El-Sayed, A. F. M. (2006). *Tilapia culture*. Cambridge: CABI Publishing, pp. 4.

Fisheries Commission **(**2020). Enhancing small-scale aquaculture towards agribusiness development*:* Accra, Fisheries Commission, Ministry of Food and Agriculture.

Fox, J., & Weisberg, S. (2019). *An R companion to applied regression* (3rd Ed.). Sage.

Golam, M. M and Al-Misned, F. A. (2013). Length-weight relationships, condition factor and sex-ratio of Nile tilapia, Oreochromis niloticus in Wadi Hanifah, Riyadh. *World J Zool. 2013; 8(1):106-109*. Saudi Arabia.

Hernandez – Llamas, A., & Gómez Muñoz, V. M. (1996). Growth and survival response of the catarina scallop *Argopecten circularis* (Sowerby) to stocking density and length or culture period. *Aquaculture Research*, *27*(9), 711-719. DOI: 10.1111/j.1365-2109.1996.tb01306.x.

Islam, M. S. (2002). Evaluation of supplementary feeds for semi-intensive pond culture of mahseer, Tor putitora (Hamilton). *Aquaculture 4(212),* 263 – 276.

Karikari, A. Y., & Asmah, R. (2016). Fish farm surveys. In R. Asmah, A. Karikari, L. Falconer, T. C. Telfer & L. G. Ross, *Cage aquaculture in Lake Volta, Ghana*: *Guidelines for a sustainable future*. CSIR Water Research Institute, Ghana and University of Stirling, Stirling, UK, p. 112.

Kassam, Laila, Dorward, Andrew, 2017. A comparative assessment of the poverty impacts of pond and cage aquaculture in Ghana. Aquaculture 470, 110–122.

Konyim, E. O. (2018). *Why pond producers struggle to meet tilapia production goals in Ghana.* Retrieved from: https://thefishsite.com/articles/why-pond-producers-struggle-to-meet-tilapia-production-goals-in-ghana

Lazur, A. (2007). JIFSAN Good Aquacultural Practices Manual: Grow-out Pond and Water Quality Management. Section 6. University of Maryland. 18pp.

Lesvia, C. H. (2014). *The effect of stocking density on growth rate, survival and yield of gift tilapia (Oreochromis niloticus) in Cubav: Case study fish farm La Juventud*. Retrieved from https://www.grocentre.is/static/gro/publication/321/document/lesvia17prf.pdf.

Lovshin, L. L., DA Silva, A. B., Carneiro-Sobrinho, A., & Melo, F. R. (1990). Effects of *Oreochromis niloticus* females on growth and yield of male hybrids (*O. niloticus* female × *O. hornorum* male) culture in earthen ponds. *Aquaculture*, *88*, 55–60.

Makori, A. J., Abuom, P. l, Kapiyo, O. R., Anyona, D. N., & Dida, O. G. (2017). *Effects of water physico-chemical parameters on tilapia (Oreochromis niloticus) growth in earthen ponds in Teso North Sub-County*. Busia County.

Mensah, E. T. D., Attipoe, F. K., & Mercy, A. J. (2013). Effect of different stocking densities on growth performance and profitability of *Oreochromis niloticus* fry reared in hapa-in-pond system. *International Journal of Fisheries and Aquaculture, 5(8),* 204-209.

Miura, T., Yoshimasa, Y., Takehiko, U., Hiroaki, I. O., Masa-Toshi, Y., & Kohji K. (2012). Homologous recombination via synthesis-dependent strand annealing in yeast requires the Irc20 and Srs2 DNA helicases. *Genetics*, *191*(1), 65-78.

MOALF, (2014). Quick guide to farming tilapia in ponds module: Pond management. State Department of Fisheries. Nairobi, Kenya, pp 4.

MOFAD, (2016). *Annual report-2017*, Ministry of Fisheries and Aquaculture Development. Ghana, pp 5.

Nandlal, S. & Pickering, T., (2004). *Tilapia fish farming in Pacific Island countries, vol. 2, Tilapia grow-out in ponds*. Secretariat of the Pacific Community, Noumea, New Caledonia.

Peterman, A. M. (2011). *Evaluation of production characteristics of four strains of Nile Tilapia Oreochromis Niloticus and a red variety under two sets of intensive culture conditions*. Auburn, Alabama.

Ragasa C., Agyakwah, S. K., Asmah, R., Mensah, E. T., Amewu S., & Oyih, M.. (2022). Accelerating pond aquaculture development and resilience beyond COVID: Ensuring food and jobs in Ghana. Aquaculture 547(January 2022): 737476. https://doi.org/10.1016/j.aquaculture.2021.737476.

Ricker, W.E., (1975). Computation and interpretation of biological statistics of fish populaions. Bull. Fish. Res. Board Can. 191, 382 p.

Ronald, N., Bwanika, G., & Eriku, G. (2014). The Effects of Stocking Density on the Growth and Survival of Nile Tilapia (*Oreochromis niloticus*) Fry at Son Fish Farm, Uganda. *J Aquac Res Development*, *5*(2).

Santhosh, B., & Singh, N. P. (2007). *Guidelines for water quality management for fish culture in Tripura*, ICAR Research Complex for NEH Region, Tripura Center, Publication no. 29.

Williams, K. (2000). *Tilapia culture in cages and open ponds*. Unpublished doctoral thesis submitted to U.S. Langston University.

Wood, F. A. S. (1999). *Business accounting* (28^{th} Ed.). Pearson Education Limited, Edinburgh Gate, Harlow England.

Yousif, O. M. (2002). The effects of stocking density, water exchange rate, feeding frequency and grading on size hierarchy development in juvenile Nile tilapia, *Oreochromis niloticus*. Emir. *J. Agric. Sci*., *14,* 45-53.

Zannatal, F., Masum, A., & Ali, M. (2014). Influence of stocking density on growth performance and survival of monosex tilapia (*Oreochromis niloticus*) fry. p. 34.lp

Table 1. Number of fish stock in eight ponds with two stocking sizes (2 and 10 g) and two stocking density (3 and 6 fish/m^2).

Stocking size (g)	Stocking density (fish/m^2)	Pond number	Number of fish stocked
2	3	A1	600
		A2	600
	6	C1	1,200
		C2	1,200
10	3	B1	600
		B2	600
	6	D1	1,200
		D2	1,200
Total			7,200

Table 2. Mean ± standard deviation for initial weight, final weight and condition factor (CF) of two stocking weights (2 = 2 g, 10 = 10 g) at two stocking densities (3 = 3 fish/m^2, 6 = 6 fish/m^2).

Stocking weight (g)	Stocking density (fish/m^2)	# of fish	Initial weight (g)	Final weight (g)	Condition factor
2	3	100	2.9 ± 0.6^{a}	181.7 ± 16.3^{b}	2.0 ± 0.2^{b}
	6	100	2.9 ± 0.6^{a}	152.2 ± 18.8^{c}	2.1 ± 0.3^{a}
10	3	100	10.2 ± 2.1^{b}	195.0 ± 18.5^{a}	2.0 ± 0.2^{b}
	6	100	10.2 ± 1.7^{b}	153.3 ± 27.5^{c}	2.1 ± 0.3^{a}

Data within the same column with different superscript letters are significantly different ($P < 0.05$).

Table 3. F-values of fixed effects for final weight (FW), condition factor (CF), weight gain (WG), specific growth rate (SGR), feed conversion ratio (FCR), feed efficiency ratio (FE), and pond survival (SUR). Final weight and CF calculated using data from individual fish while WG, SGR, FCR, and FE based on pond data; all analysed using Model 1. Pond survival (SUR), based on pond data, was analysed using Model 2.

Effect[†]	FW	CF	WG	SGR	FCR	FE	SUR
Stocking weight	20.7***	5.6*	14.2***	1,824.3***	1.0^{NS}	0.7^{NS}	8.6*
Stocking density	202.6***	3.5^{NS}	335.6**	33.9**	1.8^{NS}	2.1^{NS}	10.3*
Stocking weight × stocking density interaction	8.8**	1.4^{NS}	29.3**	3.84^{NS}	0.0^{NS}	0.1^{NS}	-

*** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$ and NS = Not significant.

Table 4. Mean ± standard deviation for growth parameters based on average values for experimental ponds of two stocking weight (2 = 2 g, 10 = 10 g) at two stocking densities (3 = 3 fish/m^2, 6 = 6 fish/m^2)

Stocking weight (g)	Stocking density (fish/m^2)	# of pond	WG	SGR	FCR	FE	SUR
2		4	-	2.6 ± 0.1^{a}	1.2 ± 0.1^{a}	85.6 ± 7.4^{a}	85.0^{b}
10		4	-	1.8 ± 0.1^{b}	1.3 ± 0.1^{a}	79.8 ± 5.1^{a}	87.5^{a}
	3	4	-	2.3 ± 0.4^{a}	1.3 ± 0.1^{a}	79.0 ± 4.9^{a}	90.0^{a}
	6	4	-	2.2 ± 0.5^{b}	1.2 ± 0.1^{a}	86.4 ± 6.6^{a}	82.5^{b}
2	3	2	178.8 ± 1.5^{a}	-	-	-	-
	6	2	149.3 ± 1.4^{b}	-	-	-	-
10	3	2	184.8 ± 1.5^{a}	-	-	-	-
	6	2	143.1 ± 2.0^{b}	-	-	-	-

Data within the same column with different superscript letters are significantly different ($p < 0.05$).

Note: FW - Final weight, CF – Condition factor, WG – Weight gain, SGR – Specific growth weight, FCR – Feed conversion ratio, FE – Feed efficiency, SUR - Survival rate. Source: Field data (2020)

Table 5. Water quality parameters (mean ± standard deviation) in the experimental ponds stocked with Nile tilapia at different densities and sizes from April to August 2020.

Parameters	Treatments			
	2 g at 3 fish/m^2	2 g at 6 fish/m^2	10 g at 3 fish/m^2	10 g at 6 fish/m^2
Temperature (°C)	29.5±1.4^{a}	29.6±0.0^{a}	29.5±1.4^{a}	29.7±1.4^{a}
pH	6.3±0.14^{b}	6.2±0.2^{b}	6.4±0.2^{ab}	6.6±0.5^{a}
Dissolve oxygen (mg/l)	3.9±0.8^{b}	3.9±0.9^{b}	4.7±1.1^{ab}	5.4±2.4^{a}
Turbidity (NTU)	84.9±62.1^{a}	70.9±50.3^{a}	85.3±49.1^{a}	109.9±75.1^{a}
Total alkalinity (mg/l)	59.5±7.7^{ab}	49.2±8.2^{b}	61.1±17.5^{ab}	54.7±11.4^{ab}
Ammonia–nitrogen (mg/l)	0.4±0.1^{a}	0.4±0.2^{a}	0.4±0.1^{a}	0.4±0.3^{a}

Treatment means within the same row with different superscript letters are significantly different ($P < 0.05$), n = 2.

Table 6. Cost and benefit analysis of pond cultured Nile tilapia at different stocking densities and sizes from April to August 2020, assuming tilapia prices at GH¢11 across all treatments.

	Treatments											
	2 g at 3 fish/m^2			2 g at 6 fish/m^2			10 g at 3 fish/m^2			10 g at 6 fish/m^2		
Economic Parameters	**Number**	**Unit price (GH¢)**	**Total (GH¢)**	**Number**	**Unit price (GH¢)**	**Total (GH¢)**	**Number**	**Unit price (GH¢)**	**Total (GH¢)**	**Number**	**Unit price (GH¢)**	**Total (GH¢)**
Revenue (GH¢)												
Fish sales (Kg)	197	11.00	2,170	281	11.00	3,094	212.90	11.00	2,342	319.83	11.00	3,518
Cost of Production (GH¢)												
Fingerlings (g)	1,200	0.15	180	2400	0.15	360	1,200	0.50	600	2400	0.50	1,200
Feed (Kg)	10	104.00	1,040	13	104.00	1,352	11	104.00	1,144	16	104.00	1,664
Lime (Kg)	40	2.00	80	40	2.00	80	40	2.00	80	40	2.00	80
Fuel (liters)	10	4.77	50	10	4.77	50	10	4.77	50	10	4.77	50
Labour (/week)	22	10.00	220	22	10.00	220	22	10.00	220	22	10.00	220
Total cost (GH¢)			1,570			2,062			2,094			3,214
Net income (GH¢)			**600**			**1,033**			**248**			**304**
Profit margin or Return to variable cost (%)			**38**			**50**			**12**			**9**

Table 7. Cost and benefit analysis of pond cultured Nile tilapia at different stocking densities and sizes from April to August 2020, assuming tilapia prices at GH¢11 for tilapia weighing 150 – 160 g (T2 and T4) and GH¢ 12 for tilapia weighing 180 – 190 g (T1 and T3).

Economic Parameters	Treatments											
	2 g at 3 fish/m^2			2 g at 6 fish/m^2			10 g at 3 fish/m^2			10 g at 6 fish/m^2		
	Number	**Unit price (GH¢)**	**Total (GH¢)**	**Number**	**Unit price (GH¢)**	**Total (GH¢)**	**Number**	**Unit price (GH¢)**	**Total (GH¢)**	**Number**	**Unit price (GH¢)**	**Total (GH¢)**
Revenue (GH¢)												
Fish sales (Kg)	197	12.00	2,368	281	11.00	3094	213	12.00	2,555	320	11.00	3518
Cost of production (GH¢)												
Fingerlings (g)	1,200	0.15	180	2,400	0.15	360	1,200	0.50	600	2,400	0.50	1,200
Feed (Kg)	10	104.00	1,040	13	104.00	1,352	11	104.00	1,144	16	104.00	1664
Lime (Kg)	40	2.00	80	40	2.00	80	40	2.00	80	40	2.00	80
Fuel (liters)	10	4.77	50	10	4.77	50	10	4.77	50	10	4.77	50
Labour (/week)	22	10.00	220	22	10.00	220	22	10.00	220	22	10.00	220
Total cost (GH¢)			1,570			2,062			2,094			3,214
Net income (Profit)		**798**			**1032**			**461**			**304**	
Profit margin or Return to variable cost (%)		**51**			**50**			**22**			**9**	

Table 8. Cost and benefit analysis of pond cultured Nile tilapia at different stocking densities and sizes from April to August 2020, assuming tilapia prices at GH¢11 for tilapia weighing 150 – 160 g (T2 and T4) and GH¢ 13 for tilapia weighing 180 – 190 g (T1 and T3).

Economic Parameters	**Treatment**											
	2 g at 3 fish/m²			**2 g at 6 fish/m²**			**10 g at 3 fish/m²**			**10 g at 6 fish/m²**		
	Number	**Unit price (GH¢)**	**Total (GH¢)**	**Number**	**Unit price (GH¢)**	**Total (GH¢)**	**Number**	**Unit price (GH¢)**	**Total (GH¢)**	**Number**	**Unit price (GH¢)**	**Total (GH¢)**
Revenue (GH¢)												
Fish sales (Kg)	197	13	2565	281	11	3094	213	13	2,768	320	11	3,518
Cost of production (GH¢)												
Fingerlings (g)	1,200	0.15	180	2,400	0.15	360	1,200	0.50	600	2,400	0.50	1,200
Feed (Kg)	10	104.00	1,040	13	104.00	1,352	11	104.00	1,144	16	104.00	1,664
Lime (Kg)	40	2.00	80	40	2.00	80	40	2.00	80	40	2.00	80
Fuel (liters)	10	4.77	50	10	4.77	50	10	4.77	50	10	4.77	50
Labour (/week)	22	10.00	220	22	10.00	220	22	10.00	220	22	10.00	220
Total cost (GH¢)			1,570			2,062			2,094			3,214
Net income (Profit)		**995**			**1,032**			**674**			**304**	
Profit margin or Return to variable cost (%)		**63**			**50**			**32**			**9**	

Table 9. Cost and benefit analysis of pond cultured Nile tilapia at different stocking densities and sizes from April to August 2020, assuming tilapia prices at GH¢11 for tilapia weighing 150 – 160 g (T2 and T4) and GH¢ 14 for tilapia weighing 180 – 190 g (T1 and T3).

Economic parameters	Treatments											
	2 g at 3 fish/m^2			2 g at 6 fish/m^2			10 g at 3 fish/m^2			10 g at 6 fish/m^2		
	Number	Unit price (GH¢)	Total (GH¢)	Number	Unit price (GH¢)	Total (GH¢)	Number	Unit price (GH¢)	Total (GH¢)	Number	Unit price (GH¢)	Total (GH¢)
Revenue (GH¢)												
Fish sales (Kg)	197	14.00	2,762	281	11.00	3,094	213	14.00	2,981	320	11.00	3,518
Cost of production (GH¢)												
Fingerlings (g)	1,200	0.15	180	2,400	0.15	360	1,200	0.50	600	2,400	0.50	1,200
Feed (Kg)	10	104.00	1,040	13	104.00	1,352	11	104.00	1,144	16	104.00	1,664
Lime (Kg)	40	2.00	80	40	2.00	80	40	2.00	80	40	2.00	80
Fuel (liters)	10	4.77	50	10	4.77	50	10	4.77	50	10	4.77	50
Labour (/week)	22	10.00	220	22	10.00	220	22	10.00	220	22	10.00	220
Total cost (GH¢)			1,570			2,062			2,094			3,214
Net income (Profit)		**1192**			**1032**			**887**			**304**	
Profit margin or Return to variable cost (%)		**76**			**50**			**42**			**9**	

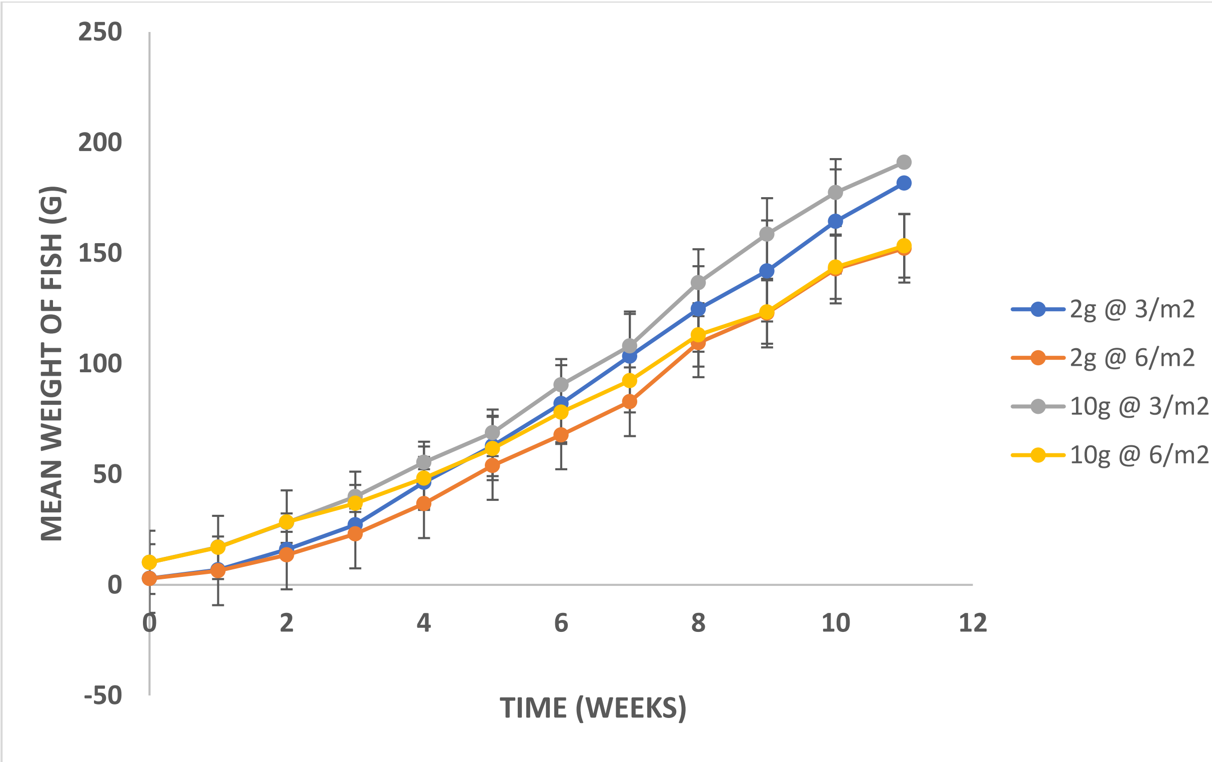

Figure 1. Mean weight of different stocking sizes (2 and 10 g) and stocking densities of Nile tilapia (3 and 6 fish/m^2) cultured for 154 days. Bars indicate standard deviations.

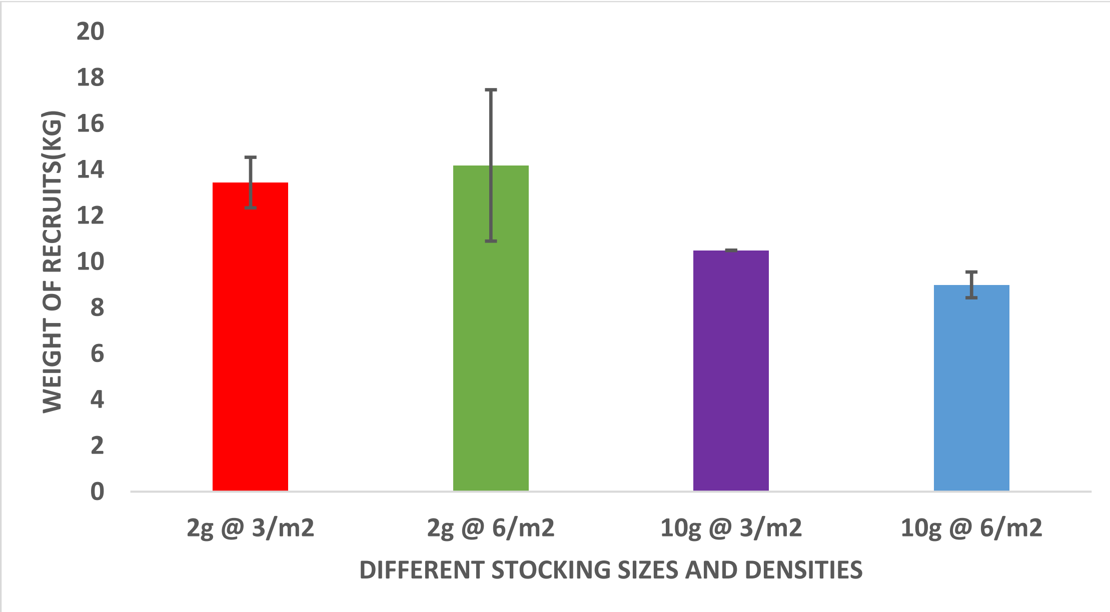

Figure 2. Weight of fish recruits at different stocking sizes and densities during culture of Nile tilapia fingerlings for 154 days in an experimental pond. Bars indicate standard deviations.