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Oxygen Dynamics and Growth Performances of the Nile Tilapia Under Different Areal Feed Inputs

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ABSTRACT

The aim of the current experiment was to examine the economic efficiency, growth and feed costs of the Nile tilapia subjected to different levels of areal feed inputs during the production cycle. Four feeding strategies were employed; the control treatment included continuous feeding of 8 grams commercial diet/m^2/day for 155 days. T1, T2 and T3 included feeding corn at 1.5, 3 and 5 % of biomass, respectively for 60 days, followed by feeding commercial diet at 4, 6 and 8 g/m^2/day for additional 95 days, respectively. Data of daytime net primary production (dNNP) among treatments nearly balanced nighttime community respiration (nCR) values. The similar average of dNPP and nCR values recorded in T3 treatment tanks indicated that the feed input of T3 treatment was approximately the maximum safe areal feed input limit without affecting oxygen demand. Daily algal production in rearing units constituted approximately 40% of total combined natural and artificial food available for fish in the control and T3 treatments during the growing season. The feed conversion ratio (1.12:1) and the daily weight gain (0.77 g/fish/day) were significantly improved in the control treatment compared to all other treatments ($P<0.05$). Consequently, it is recommended to feed Nile tilapia at 8 g diet/m^2/day when rearing during the production cycle in order to obtain acceptable growth with higher economic returns.

INTRODUCTION

The determination of feed management in terms of economic efficiency and feed costs along with suitable fish growth is important in farm management **(Huang *et al*., 2015)**. Moreover, supplemental feeding in algal-based pond system contributed to higher growth and larger yields than chemical fertilization alone **(Green, 1992 & Diana *et al*., 1994)**. Optimal feeding rates for Nile tilapia fingerlings in intensive systems are supposed to range 4-5% of biomass during the fingerlings stage when tilapia are raised in clear water system according to **(Muir *et al*., 2000)**. **Robinson and Li (1999)** pointed out that fish cannot be fed at optimal rates during the pre- harvest time when fish biomass is high since high level of feed inputs will deteriorate water quality in terms of negative oxygen budget and high toxic ammonia levels.

In order to maintain recommended water quality, **Rowland *et al*. (1995)** reported that total feed inputs in larger ponds along with artificial aeration should not exceed 40 kg/acre/day (i.e. 10 grams diet/m²/day). **Tucker (2003)** indicated that daily feed inputs in static-water ponds should not exceed the upper critical limits of 45 kg/acre/ day (i.e. 11 grams diet/m²/day) when artificial aeration are used during nighttime hours. **Boyd (1982, 1990)** and **Boyd and Tucker (2012)** indicated that maximum safe daily feed inputs in earthen ponds should not exceed 20 kg/acre/day (i.e. 5 grams diet/m²/day) without nighttime artificial aeration and 40 kg/acre/day (i.e. 10 grams diet/m²/day) in case of artificial aeration during nighttime in order to avoid water quality deterioration and oxygen depletion in farmed ponds.

Hargreaves and Tucker (2003) reported that farmers should not feed fish above 40-50 kg diet /acre/ day (i.e. 10-12 grams diet/m²/day) when using artificial aeration to avoid water quality deterioration. Moreover, **Yakupitiyage (1993)** explained that feed input of 40 Kg /acre/day (i.e. 10 grams diet/m²/day) could be used under nighttime artificial aeration for a short period (3-6 months) during the production cycle of tilapia and carp. **Elnady *et al*. (2011)** reported that negative oxygen budgets, and deterioration of growth performance of Nile tilapia coincided with feeding Nile tilapia at 10-15 grams diet/m²/day, without artificial aeration.

Borski *et al*. (2011) reported that the cost of commercial feeds for Nile tilapia are sharply escalated. Moreover, fish farmers aim at producing larger yield at least costs since feed comprise 50-60% of operating costs in economically efficient farms (**Tacon, 1997 & Essa *et al*., 2004).** Reductions in feed costs could be accomplished through the decrease in quantity of feed employed to grow out fish **(Borski *et al*., 2011). Cheunbarn and Cheunbarn (2015)** indicated that plankton and natural food could be used to reduce feed inputs required to produce fish. Economic efficiency of Nile tilapia culture in semi-intensive ponds depends on natural food abundance (i.e. algal protein) which determines the free-cost nutrition available for Nile tilapia **(Ikpi *et al*., 2013 & Mbonde *et al*., 2017).**

El-Sayed (2017) indicated that some fish farmers in Egypt feed tilapia in ponds at a pre-determined level and do not use feeding tables based on a feeding program. The current research was designed to test the effect of pre-determined areal feed inputs not exceeding the maximum safe feeding rate on oxygen dynamics and growth performance of Nile tilapia raised in algal-based system, without artificial aeration. The aim of the current experiment was to examine the economic efficiency and feed costs of Nile tilapia subjected to restricted feeding during the production cycle, when supported by extra nutrition from natural food abundance.

MATERIALS AND METHODS

The current experiment was carried out at the Fish Research Unit, Faculty of Agriculture, Cairo University, Egypt during summer and fall of 2019. A still water outdoor rearing tanks were used to perform the experiment. Twelve concrete tanks (2.2 ×

1.2 × 1.0 m) were filled with water to a depth of 80 cm and were used as rearing units. One week prior to stocking fingerlings, all rearing tanks were fertilized with urea and superphosphate to enhance algal blooms. After the start of the experiment, rearing tanks were fertilized only when secchi disk readings increase above 25 cm. The fertilization rate was fixed at a rate of 1 gram NH_4-N and 0.25 gram P_2O_5-P per square meter area. Nile tilapia fingerlings (17.0 grams each) were randomly distributed among experimental units at 20 tilapia juveniles per tank, with triplicate tanks per treatment.

Experimental design:

Four feeding strategies were employed in the current experiment which lasted 155 days as follows: 1) The control treatment included feeding fish with artificial diet (30% crude protein) at 8 grams diet/m^2/day from the start to the end of the experiment for 155 days without chemical fertilization; 2) T1 treatment included feeding fish with corn flour at 1.5% of initial biomass per day for 60 days (period 1), followed by feeding fish with artificial diet (30% crude protein) at 4 grams diet/m^2/day for additional 95 days (period 2); 3) T2 treatment included feeding fish with corn flour at 3% of initial biomass per day for 60 days (period 1), followed by feeding fish with artificial diet (30% crude protein) at 6 grams diet/m^2/day for additional 95 days (period 2); 4) T3 treatment included feeding fish with corn flour at 5% of initial biomass per day for 60 days (period 1), followed by feeding fish with artificial diet (30% crude protein) at 8 grams diet/m^2/day for additional 95 days (period 2).

T1, T2 and T3 were fertilized with urea and superphosphate (at a rate of 1 gram NH_4-N and 0.25 gram P_2O_5-P/m^2/week) during period 1 of the experiment, while the control treatment did not receive any chemical fertilization during the whole experiment. During period 2 of the experiment, T1 and T2 received the same dose of chemical fertilization, while T3 and the control treatment did not receive any chemical fertilization. Fish were feeding on both diet material and natural food generated by direct and indirect fertilization in rearing tanks. Artificial diet contained 31.1% crude protein, 4% crude fat, 44.7% NFE, 3.7% crude fiber, 7.5% ash and 9% moisture were used.

Water Quality Parameters:

Water quality determinations were carried out according to Boyd and Tucker (1992). Water temperature and dissolved oxygen were measured using dissolved oxygen meter (Hanna Model 55). Oxygen concentration in water was transformed from mg/L units to grams O_2/m^2 by multiplying average water column oxygen concentration (mg/L) by water volume in liters under square meter surface area divided by 1000. The pH was measured by pH digital meter, while visibility was measured using a wooden apparatus. Gross photosynthesis of algae was calculated according to **Szeper (1996)** as follows:

Algal gross productivity (g O_2/m^2/day) = (Net daytime production of dissolved oxygen + nighttime community respiration).

Total ammonia concentration was measured by phenate method. Nitrite- nitrogen concentration was measured by the diazotizing method, using Photometer (Lovibond Multi Direct Photometer, Germany). Water samples were filtered through 0.45 micron filter membrane before analysis. Water Temperature, dissolved oxygen and pH values were measured bi-weekly at early morning, sunset time and next-early morning during the experimental period. Dissolved oxygen readings were taken by integrating the oxygen prob over the depth of tank water up to the bottom of whole tank.

Oxygen dynamics calculations:

- Calculations of oxygen dynamics was based on areal oxygen dynamics model proposed by **Szyper (1996)** for the estimation of daily areal primary production.
- In calculations daily net algal production, phytoplankton respiration was assumed to consume 50% of gross primary production on a 24-hours basis. To convert carbon matter to dry matter, carbon matter was multiplied by a factor of 2.0.
- Oxygen concentration (gram O_2/m^2) = oxygen concentration (mg/L) * water volume under surface water area of square meter (liters) / 1000.
- Daytime oxygen gain (dNNP: g O_2/m^2/daytime) = sunset oxygen concentration - early morning oxygen concentration.
- Nighttime oxygen community respiration (nCR: g O_2/m^2/nighttime) = sunset oxygen concentration - next early morning oxygen concentration.
- Gross primary production (grams O_2/m^2/day) = dNNP + nCR
- Early morning oxygen budget (grams O_2/m^2) = daytime oxygen gain - nighttime community respiration.
- Daily net algal production (dry matter/m^2/day) = Gross primary production (in terms of O_2) ÷ 2.66 (assuming algal respiration equal 50% of GPP).

Growth and Feed Performance:

Growth performance of cultured fish was measured in terms of final individual fish weight (g), weight gain (g/fish), daily weight gain (g /fish/ day), daily weight gain /m^2, specific growth rate (SGR % / day) and daily biomass gain per square meter of rearing tank. Feed performance was measured in terms of feed conversion ratio (FCR) and protein efficiency ratio (PER) and feed costs.

Body weight

Individual body weight of fish was measured on monthly basis during the experimental period using digital balance to the nearest 0.1 g, then growth performance parameters were calculated as follows:

- **Weight gain (WG)** = Final weight (W_f) – Initial weight (W_i)

- **Daily weight gain (**DWG) = (final weight - initial weight)/experimental period (days).

- **Specific Growth rate (**SGRW) = [Ln W_f– Ln W_i /duration time (days)] *100

- **Feed Conversion Ratio (FCR)** = dry weight of feed fed (g)/Fish weight gain (g).

- **Protein Efficiency Ratio (PER)** = Fish weight gain (g) / protein fed (g)

Feed Costs

The economic efficiency expressed as the feed cost per unit production, was calculated as a function of feed conversion ratio and the price per kilogram of test diet for the different dietary treatments.

- **Feed costs of production** = FCR * price per kilogram diet.

- **Initial biomass (g/m^2)** = initial count * average initial body weight

- **Harvest biomass (g/m^2)** = harvest count * average harvest body weight

- **Daily biomass gain ($g/m^2/day$)** = (harvest biomass - initial biomass)/ growth period (days)

- **Survival (%)** = (harvest count / initial count) * 100

Statistical Analysis:

Growth and feed performances of cultured fish as well as water quality parameters in culture tanks were subjected to one - way analysis of variance to determine statistically significant differences among treatments. Differences among means were assessed by Duncan multiple range test (Duncan, 1955). Statistically significant differences were determined by setting the aggregate type I error at 5% ($P< 0.05$) for each comparison. These statistical analyses were performed using the software package SPSS for windows, Release 8.0 (SPSS 1997).

RESULTS AND DISCUSSION

Water quality parameters:

Water temperature during period 1 were approximately constant (30.6-31.7°C) overtime coinciding with summer season (Table 1). Water temperature during the period 2 decreased gradually to an average range of 24.4 -26.5°C during fall season. The gradual decrease of water temperature overtime during fall season was due to the natural decrease in air temperature. The overall average sunset pH values ranged 9.48 - 10.43 units during period 1 and decreased to 8.9-9.7 units during the period 2, reflecting the positive effect of seasonal water temperature on algal productivity which induced higher pH values during summer season. The overall range of total ammonia concentrations were very low during the experimental period, while near-zero nitrite concentrations were observed.

Oxygen dynamics:

Dissolved oxygen dynamics and algal productivity in rearing tanks are shown in Table 2. Early morning dissolved oxygen concentrations were significantly higher (7.11–11.78 g O_2/m^2) during period 1 compared to the control treatment (5.8 g O_2/m^2)

Table 1. Water Quality Parameters under different areal feed input treatments

Parameter	Feeding Strategies			
	Control	**T1**	**T2**	**T3**
Period 1 (60 days):				
Sunset Temperature (°C)	31.6	30.6	31.7	31.6
Sunset PH	9.48^{b}	10.43^{a}	10.26^{ab}	10.03^{ab}
Ammonia concentration (TAN: mg/L)	0.243^{b}	0.450^{a}	0.330^{ab}	0.293^{b}
Nitrite concentration (NO_2-N: mg/L)	0.00	0.00	0.00	0.003
Period 2 (95 days):				
Sunset Temperature (°C)	26.52	24.4	26.0	25.7
Sunset PH	8.90^{c}	9.32^{b}	9.70^{a}	9.21^{b}
Ammonia concentration (TAN: mg/L)	0.145	0.133	0.131	0.193
Nitrite concentration (NO_2-N: mg/L)	0.010	0.008	0.013	0.003

Means in the same row with different superscript letters are significantly different ($p<0.05$).

due to the higher metabolic activities on the diet material compared to the corn flour material ($P<0.05$). The mean sunset oxygen concentrations during period 1 ranged 12.67 – 15.6 g O_2 /m^2 among treatments, with the control treatment being significantly lowest than other treatments ($P<0.05$). The higher feed load in the control treatment was accompanied by higher biological activities in terms of community respiration rates compared to T1, T2 and T3 treatments that had lower metabolic activities on corn flour matter.

The average early morning dissolved oxygen concentrations during period 2 were higher (4.92 – 5.0 g O_2 /m^2) in T1 and T2 treatments and decreased to 1.45 – 3.04 g O_2 /m^2 in T3 and the control treatments when the diet input was increased to 8 grams /m^2/ day. The negative relationship between daily diet inputs and early morning oxygen concentrations was due to the positive relationship between the daily diet inputs and respiration activities during nighttime period from sunset to dawn time. Higher feed inputs in pond water is always accompanied by higher feed oxygen demand (FOD) which is correlated with dissolved oxygen deterioration **(Boyd, 2008 & Boyd and Tucker, 2012).** However, **Saeiam *et al*. (2020)** reported that dense algal blooms consumed huge quantities of DO during nighttime hours, inducing oxygen depletion. The lower oxygen concentrations in the control and T3 treatments may be due to the higher biological oxygen demand needed for feed metabolism by fish and biota as well as the decomposition of feed wastes and feces by aerobic bacterial activities.

During period 2, the sunset oxygen concentrations ranged 8.6 – 11.96 g O_2 /m^2 among treatments, with no significant relationship between diet input and sunset DO concentration ($P>0.05$). When dissolved oxygen concentrations during early morning and sunset time were compared, the dusk DO concentrations were higher, representing oxygen gain during daytime (dNPP). **Ghosh and Tiwari (2008)** indicated that the sunset dissolved oxygen concentration increased as algae generated more oxygen during the process of photosynthesis than was consumed by daytime respiration. **Boyd (2008)** indicated that areal feed inputs can lead to higher feed oxygen demand as each gram of feed demands an oxygen amount of 1.3 grams during feed metabolism.

The gap in DO concentrations between sunset time and early morning among treatments ranged 3.82 – 7.39 g O_2 /m^2 during period 1, while the gap in DO concentrations ranged 6.1 – 7.15 g O_2 /m^2 during period 2, which indicated a large gap in oxygen concentrations between sunset and dawn time. The rearing environment in the current experiment are considered as hypereutrophic aquaculture systems, with intensive algal growth. The daytime dissolved oxygen concentrations in the current experiment ranged from saturated to super-saturated. **Ghosh and Tiwari (2008)** reported that best balanced ponds allow oscillation in oxygen concentrations between sunrise and sunset that produce sufficient oxygen concentration in water that sustain fish respiration during nighttime hours. Maximum difference in DO concentrations between daytime and nighttime hours within a single day was reported as high as 10 mg/L **(Chang and Ouyang, 1988).**

dNPP and nCR values:

The daytime net primary production (dNPP) during period 1 ranged 4.47-7.39 g O_2/m^2/daytime among treatments ($P<0.05$). While the daytime net primary production during period 2 ranged 6.1- 7.19 g O_2/m^2/daytime among means ($P>0.05$). The overall averages nighttime community respiration (nCR) ranged 4.81-8.25 g O_2/m^2/nighttime during period 1, with higher nCR in the control and T3 treatments ($P<0.5$). While nighttime community respiration during period 2 ranged 5.3 – 7.19 g O_2/m^2/nighttime, with no significant differences among treatments ($P>0.05$).

Data of nCR and dNPP values among treatments during period 1 indicated dNPP values were slightly less nCR values, with slight differences between dNPP and nCR values indicating slight heterotrophy. While, during period 2 of the experiment, dNPP values among treatments were nearly balanced or slightly higher than nCR values, suggesting net autotrophy.

Hargreaves and Steeby (1999) indicated that when net primary production (dNPP) is more than whole pond respiration (WPR) by a factor of (1.3), net autotrophy is reported to occur, which results in positive oxygen budget at dawn time **(Tucker, 1996).** Oxygen production by algal photosynthesis increased oxygen content of water during daylight hours (dNPP) while nighttime community respiration decreased oxygen content of water during nighttime hours (nCR). Respiration rate of phytoplankton and zooplankton communities in water column was reported to be approximately 50% of gross algal production on a daily basis **(Guo-Cai *et al*., 2000).**

Algal respiration during nighttime hours was reported to make a huge part of oxygen budget in green water ponds, constituting a large share of oxygen depletion **(Teichert-Coddington and Green, 1993).** Similar average daytime net oxygen production (dNPP) and nighttime community respiration (nCR) during period 2, indicated that the correct feed input (8 g diet /m^2/day) resulted in a condition where the feed load was just equal to the assimilative capacity of water in terms of oxygen availability required for the oxidative metabolism of the feed input. **Elnady *et al*. (2011)** indicated that areal feed inputs above 10 g diet /m^2/day made water quality deteriorate to anoxic conditions in the pre-dawn hours, which reduced growth performance of Nile tilapia.

Algal blooms and oxygen budget:

Early morning oxygen deficits were observed during period 1 (-0.45 to - 1.38 g O_2/m^2), indicating slight net heterotrophy. However early morning oxygen surpluses were observed in period 2 where oxygen budget ranged -0.05 to +0.8 g O_2/m^2, indicating slight net autotrophy. There was a negative relationship between oxygen budget at early morning and the amount of feed input (g diet/m^2/day) during period 2 where oxygen surpluses increased from -0.05 to +0.8 g O_2/m^2 as the diet inputs decreased.

During period 2 of the experiment, it seemed that the feed input of 8-gram diet /m^2/day employed in T3 and the control treatments, was approximately the maximum safe areal feed input limit, beyond which a negative oxygen budged occurs and water quality deteriorates in terms of metabolic activities. The daily feed input should be optimal at 8 grams diet /m^2/day (extrapolated to 32 kg diet/acre/day), when growth performance of Nile tilapia was compared among treatments. It can be concluded that the areal feed input limit should not exceed 8 gram dry matter/m^2/day in order to obtain normal fish growth, with positive oxygen budget at early morning, without exceeding the waste assimilative capacity of static water.

During period 2, dense algal bloom in water column negatively affected oxygen budget in rearing tanks in T3 treatment, resulting in a near zero oxygen budget at early morning hours. This coincided with the low secchi disk reading of 15.6 cm. The lower daily diet inputs in T1 and T2 treatments, induced higher secchi disk readings (20.1-25.2 cm) and algal blooms decreased. The lower algal blooms observed in T1 and T2 treatments during period 2, resulted in positive oxygen budgets at early morning in water. The current experiment indicated a negative relationship between the daily areal feed inputs and secchi disk readings that reflected algal bloom. **Hargreaves and Tucker (2003)** indicated that the presence of dense phytoplankton bloom in the water column in culture tanks negatively influenced the waste assimilative capacity in stillwater as the bulk of dissolved oxygen concentration in water is used in algal respiration. Moreover, **Hargreaves and Steeby (1999)** reported that algal blooms comprise most part of whole pond respiration. **Pawar *et al*. (2009)** indicated that phytoplankton produce most dissolved oxygen content in culture ponds and use up major oxygen content during nighttime period.

Gross primary productivity and algal production:

During period 1, gross primary production in terms of daily oxygen production ranged 10.17 – 15.23 g O_2/m^2/day among treatments ($P<0.05$). There was a trend towards decreasing the gross primary productivity (oxygen production) with decreasing feeding rates from T3 to T1 treatments. However gross primary productivity during period 2 ranged 11.4 – 14.39 g O_2/m^2/day among treatments, with no significant differences among means ($P>0.05$). Gross primary productivity during period 2 tended to decrease from 13.82 – 17.73 g O_2/m^2/day at the start of fall season to 6.91 – 8.84 g O_2/m^2/day by the end of fall season, which was negatively affected by water temperature. Gross primary production was progressively reduced overtime during fall season in all treatments. Lower water temperature during autumn season had a negative effect on phytoplankton productivity, while warm water temperature during summer season enhanced algal productivity. Algal primary productivity is always positively correlated with water temperature **(Boyd, 2000 & Boyd and Tucker, 2012).** The net algal production was estimated from gross primary production, assuming that algal respiration constitutes 50% of total algal productivity.

The overall net algal production (D.M. basis) available for fish nutrition during period 1 ranged 3.82 – 5.72 grams/m^2/day among treatments, with significant differences ($P<0.05$). However, the overall net algal production available for fish consumption ranged 4.35 – 5.43 grams D.M./m^2/day among treatments during period 2 of the experiment.

Tucker (2003) reported that Nile tilapia feeding on phytoplankton and zooplankton could constitute 50% or more of total nutritional requirements particularly during early growth stage, therefore, employing low-cost fertilizer plans could decrease feed requirements for normal growth of fish **(Abbas and Hafeez-Rehman, 2005). Robson (2005)** indicated that algal abundance in water column in his model averaged 30 mg dry weigh/L.

Net algal production available for fish nutrition in water column averaged 4.99 – 5.43 grams (D.M.)/m^2/day in T3 and the control treatments. Assuming that the maximum safe feeding rate is at 8 grams diet/m^2/day, it can be concluded that daily algal production in rearing units constituted approximately 40% of total combined natural and artificial food available for Nile tilapia nutrition during the growing season. Algal dry matter could contain up to 35% crude protein according to **Kamgombe *et al*. (2006).**

Growth performance:

Average Final body weight:

Growth performance data of Nile tilapia are illustrated in Table 3. Starting with initial weight of 17.0 grams / fish during period 1, Nile tilapia juveniles grew to 25.8 - 29.6 g/fish compared to 63.38 g/fish in the control treatment, with significant differences

Table 2. Oxygen dynamics and algal productivity under different areal feed inputs treatments

Parameter	**Feeding Strategies**			
	Control	**T1**	**T2**	**T3**
Period 1 (60 days):				
Early morning DO (g O_2/m^2)	5.8^{c}	11.78^{a}	9.61^{b}	7.11^{c}
Sunset DO (g O_2/m^2)	12.67^{c}	15.60^{a}	14.08^{ab}	14.50^{ab}
Next early morning DO (g O_2/m^2)	4.42^{d}	10.79^{a}	8.38^{b}	6.66^{c}
Oxygen budget (g O_2/m^2)	-1.38	+0.99	-1.23	-0.45
Daytime DO gain (dNPP: g O_2/m^2)	6.87^{b}	6.36^{b}	4.47^{bc}	7.39^{a}
Nighttime community respiration (nCR: g O_2/m^2)	8.25^{a}	4.81^{b}	5.7^{ab}	7.84^{a}
Gross primary productivity (GPP: g O_2/m^2 /day)	15.12 ^{a}	11.16^{b}	10.17^{c}	15.23^{a}
Algal DM production (g dry matter/m^2/day)	5.68^{a}	4.19^{b}	3.82^{c}	5.72^{a}
Secchi disk readings (cm)	16.88^{b}	24.77^{ab}	27.33^{a}	17.16^{b}
Period 2 (95 days):				
Early morning DO (g O_2/m^2)	1.45^{c}	4.92^{a}	5.0^{a}	3.04^{ab}
Sunset DO (g O_2/m^2)	8.60	11.02	11.96	9.77
Next early morning DO (g O_2/m^2)	1.49^{c}	5.72^{a}	5.17^{ab}	2.99^{bc}
Oxygen budget (g O_2/m^2)	0.04	0.8	0.17	-0.05
Daytime DO gain (dNPP: g O_2/m^2)	7.19	6.1	6.96	6.80
Nighttime community respiration (nCR: g O_2/m^2)	7.19	5.3	6.79	6.73
Gross primary productivity (GPP: g O_2/m^2 /day)	14.39	11.4	13.75	13.53
Algal DM production (g dry matter/m^2/day)	5.43	4.35	4.70	4.99
Secchi disk readings (cm)	14.80	25.28	20.18	15.61

Means in the same row with different superscript letters are significantly different ($p<0.05$).
among treatments ($P<0.05$).

The lower average final weights of Nile tilapia obtained in the corn fed treatments during period 1 were due to the lower nutritive value of corn flour material compared to that of the artificial diet employed in the control treatment. When fingerlings were fed on algae and corn flour during period 1, lower growth and feed efficiencies were obtained compared to those feeding on artificial diet in the control treatment.

Muir *et al*. (2000) reported that Nile tilapia within 50-100 grams size range had optimal growth rates when were fed at 5% of fish biomass in clear water intensive systems. While the feeding rates employed in the current experiment were significantly lower. Moreover, growth rates of Nile tilapia were always lower when fed on natural food as a sole source of nutrition when compared to using supplementary feed. Typical commercial farms of tilapia usually implement high fish densities and depend heavily on using commercial feeds instead of natural food **(Kunlasak *et al*., 2013).** Moreover, **Pant *et al*. (2002)** indicated that it is expected to get slower growth rates when only plankton is fed to fish even when high densities of plankton are existing in the pond. In fertilized ponds, supplementary feeding led to considerably higher growth rates and better yields than fertilization alone **(Green 1992 & Diana *et al*., 1994).** Fish grown solely on fertilizer-based system reached a slower growth and production, whereas supplemental feeding resulted in fast growth and higher output **(Abdelghany *et al*., 2002).**

When corn flour as a single ingredient diet during period 1 was followed by artificial diet during period 2 of the experiment, different growth patterns were observed among treatments. Nile tilapia fingerlings in the T1, T2 and T3 treatments grew from 25.8-29.6 grams to 68.7-99.5 g/fish by the end of period 2, with lower harvest weights in the low feed input treatments due to under-feeding. The highest harvest weight of Nile tilapia was obtained in the T3 and control treatments above those obtained with the low and medium areal feed input (T1 and T2) treatments.

The T3 and the control treatments were most effective in increasing harvest weight of fish to 99.5 – 141.8 g/fish above other low feed input treatments which averaged 68.7 – 78.5 g/fish, respectively. Increasing dietary input from T2 level to T3 level, improved final harvest weight by 26.7% during period 2. Doubling the feeding rate from 4 g/m^2/day (T1) to 8 g/m^2/day (T3), during period 2 only increased harvest weight by 44.8%. Nutrition is a critical factor that should be considered to improve aquaculture management since fish need enough energy to enhance its fast growth **(Gaylord and Gatlin, 2001 & Ali *et al*., 2003 & Wu *et al*., 2006).**

Daily weight gain:

During period 1 of the experiment, the overall daily weight gains of the corn fed treatments (T1, T2 and T3) ranged 0.14 – 0.21 g/fish/day, being significantly lower than that of the control treatment which averaged 0. 77 g/fish/day ($P<0.05$). The lower daily weight gains observed in the corn fed treatments could be justified by the lower protein content in the corn flour and the lower algal abundances compared to that of the control as indicated by secchi disk data. In contrast, the control treatment had a dietary protein content of 30% and higher algal abundance.

The overall daily weight gains during period 2 ranged 0.45 – 0.82 g/fish/day among treatments. During period 2, the daily weight gains of Nile tilapia in the T3 and control treatments were significantly higher (0.73 – 0.82 g/fish/day) than those subjected to T1 and T2 treatments. **Borski *et al.* (2011)** reported that during a 120-day growth period, Nile tilapia increased in size from 0.35 g/fish to 99.7 g/fish, with an average daily weight gain of 0.82 g/fish.

It can be concluded that natural food organisms were important sources in tilapia nutrition when fish were fed at restricted levels. The successful cultivation of O. niloticus in semi-intensive farms relies mainly on the availability of natural food, including algae and abiotic factors among other factors **(Mbonde *et al.*, 2017).** Phytoplankton is considered as the foundation of food webs and food chains in semi-intensive O. niloticus ponds **(Shil *et al.*, 2013).**

Table 3. Growth Performance of Nile tilapia fingerlings under different areal feed input treatments.

Parameter	**Feeding Strategies**			
	Control	**T1**	**T2**	**T3**
Period 1 (60 days):				
Initial body weight (g/fish)	17.0	17.0	17.0	17.0
Final body weight (g/fish)	63.38^{a}	25.89^{b}	27.45^{b}	29.69^{b}
SGR (% per day)	2.19^{a}	0.697^{c}	0.798^{b}	0.926^{b}
Daily weight gain (g/fish/day)	0.773^{a}	0. 148^{b}	0.174^{b}	0. 211^{b}
Initial biomass (g/m^{2})	136	136	136	136
Harvest biomass (g/m^{2})	473.6^{a}	179.6 ^{c}	219.6^{b}	216.93^{b}
Daily Biomass gain (g/m^{2}/day)	5.62^{a}	0.72^{c}	1.39^{b}	1.34^{ab}
Period 2 (95 days):				
Final body weight (g/fish)	141.88^{a}	68.72^{c}	78.50^{c}	99.53^{b}
SGR (% per day)	0.842^{c}	1.02^{b}	1.10^{b}	1.27^{a}
Daily weight gain (g/fish/day)	0.826^{a}	0.45^{c}	0.537^{bc}	0.735^{ab}
Initial Biomass (g/m^{2})	473.6^{a}	179.6 ^{c}	219.6^{b}	216.93^{b}
Harvest biomass (g/m^{2})	917.6^{a}	393.32^{c}	565.2^{b}	689.6^{b}
Daily Biomass gain (g/m^{2}/day)	4.67^{a}	2.25^{c}	3.63^{b}	4.97^{a}

Means in the same row with different superscript letters are significantly different ($p<0.05$).

Feed conversion and protein efficiency ratios:

Significant differences were observed among treatments during period 1, with better FCR (2.6: 1) at T2 feeding rate than either T1 or T3 feeding rates ($P<0.05$) (Table 4). The most efficient FCR (1.12:1) was obtained in the control treatment when fish were fed artificial diet at 5% of initial fish biomass. The feed conversion ratio (1.12:1) and the daily weight gain (0.77 g/fish/day) were significantly improved in the control treatment compared to all other treatments during period 1 ($P<0.05$). The better natural food abundance and optimum dietary protein level improved the control treatment performance in terms of daily weight gain and feed conversion ratio.

The deterioration in feed conversion ratios in corn flour fed fish during period 1 compared to that of the control may be due to the low quality and palatability of the corn flour compared to that of the control diet which produced the better FCR. During period 2, feed conversion ratios were similar in T2 treatment (1.29:1) compared to T3 treatment that averaged (1.37:1) ($P>0.05$). Improved FCR ratios obtained in all treatments during period 2 (1.29 – 1.51:1) could be justified by the supply of extra nutrition obtained from natural food in all treatments. Slightly lower FCR efficiencies were obtained in the lowest feed input (T1) treatment due to under-feeding.

During the period 2 of the experiment, PER ratios ranged 2.2 – 2.57 among treatments, with significant differences among means ($P<0.05$). The PER ratio observed in the T1 treatment was slightly lower than those of higher feed input treatments (T2 and T3) due to under-feeding. The overall PER ratios observed during the whole experiment was significantly higher in T2 and control treatments (2.82 and 2.54, respectively), compared to those of T1 (2.31) and T3 (2.42) treatments ($P<0.05$).

Feed performances in terms of FCR and daily biomass gain (gain/m^2/day) were improved during period 2, except T1 treatment which represented under-feeding. Consequently, it is recommended to feed Nile tilapia at 8 g diet/m^2/day (i.e.32 kilograms feed/acre/day) when rearing during the production cycle in order to obtain acceptable growth with economic returns. Reducing dietary input to T1 level during period 2, also reduced fish harvest volume to 57.0% compared to the T3, with no significant improvement in FCR ratio, indicating that natural food did not compensate growth when fish were under-fed. The feed conversion ratios did not deteriorate with increasing areal feed inputs during period 2, indicating economical use when diet input was increased to 8 g/m^2/day regarding feeding Nile tilapia.

The employed areal feeding inputs during period 2 enabled Nile tilapia to grow at acceptable FCR which ranged 1.29-1.51:1 compared to normal FCR (2.0:1) obtained by several authors in clear water. Tilapia culture using the floating net cage system had FCR of 2.0:1 **(Djunaidah, 1995).** The employed pre-determined feed inputs during period 2 yielded economical feed costs compared to those observed in clear water systems.

Feeding rates during period 2 of the experiment:

Feeding rates at the start of period 2 ranged 1.68 – 3.68% of initial fish biomass on a daily basis. As tilapia grew in size during period 2, the feeding rates were gradually reduced to 0.87 – 1.16% of biomass at harvest time since daily feed inputs were held constant, with fish obtaining extra nutrition from feeding on natural food.

Survival rate:

Although non-significant, the lowest feed input treatment (T1) had the lowest survival rates (86.6% and 82.6%) during both period 1 and 2 of the experiment, respectively. Higher survival rates were observed in all other treatments. This indicated a non-significant negative effect of reduced feeding rates on Nile tilapia health conditions. The reduced survival rate in T1 treatment (82.8%) was accompanied by lower daily weight gain (0.45 g/fish/day) compared to other treatments. Nile tilapia fingerlings grew at lower rate when fish were under-fed at the lowest rate. Consequently, shortage of adequate feed can negatively affect daily weight gain and survival.

Sufficient feeding should be provided to allow for adequate feed intake which results in remarkable growth and survival rate of fish **(Wang *et al*., 2007).** In contrast, insufficient diet supply is also unwanted as it negatively affects growth and survival of fish **(Mihelakakis *et al*., 2002).** As a result, setting the best plan for feeding management is crucial to attain best fish growth while restricting wastage **(Huang *et al*., 2015).**

Biomass harvest and daily biomass gain:

At the start of the experiment, feeding rates in the control treatment was 5% of initial fingerlings biomass which was gradually reduced to 1.68% of biomass by the end of period 1 as fish grew in size. Harvest biomass were significantly lowest in T1, T2 and T3 treatments (179.6 – 219.6 g/m²) compared to the control treatment (473.6 g/m²) that received artificial diet as food material ($P<0.05$). The control treatment had significantly higher harvest volume compared to all other treatments, which indicated the high efficiency of artificial diet in promoting algal fertility and fish growth, without the need to apply supplemental chemical fertilizer.

During period 2 of the experiment, under-feeding at T1 and T2 treatments, yielded lower harvest biomass (393.3 – 565.2 g/m²) compared to that of T3 treatment (689.6 g/m²). The highest biomass harvest was observed in the control (917.6 g/m^2). **Chen *et al*. (1995)** indicated that on worldwide, the possible harvest of cultured fish in static-water without nighttime aeration averaged 500 g/m², which can be extrapolated 2000 kg/acre. While **El-Sayed (2017)** indicated that possible fish harvest in Egypt could range 3-4 tons/acre (i.e. 0.75-1 kg/m^2). Fish harvest in the current experiment averaged 0.68 – 0.91 kg/m^2 in the T3 and control treatments which approached Egyptian harvest according to **El-Sayed (2017).**

During period 2 of the experiment, the high feed input treatment (T3 and the control) had better environment that improved treatment performance in terms of harvest volume compared to those of lower feed input treatments (T1 and T2) which could be considered as under-feeding treatments. Feeding rates during period 2 started at 1.68 – 3.68% of initial biomass and were gradually reduced to 0.87 – 1.16% by the end of the experiment as fish grew in size. Optimal feeding rates which maximize fish yield is considered cost-effective aquaculture routines, which could be achieved if the applied feed rates were under the satiation level **(Van der Meer *et al*., 1997).** Annual production of fish in ponds using artificial diet supplied Nile tilapia yields of 3 tons/acre/year **(Liti and Munguti, 2007).**

The harvest biomass tripled during period 2 of the experiment within approximately 3-month rearing period in both T2 and T3 treatments. Based on world literature, standing stock biomass of Nile tilapia doubles in earthen ponds during the last 3 months of the production cycle of the pre-harvest period.

Table 4. Feed Performance of Nile tilapia fingerlings under different areal feed input treatments

Parameter	Feeding Strategies			
	Control	T1	T2	T3
Period 1 (60 days):				
FCR	1.12^{c}	3.67^{b}	2.60^{b}	4.65^{a}
PER	2.98^{bc}	3.13^{ab}	4.39^{a}	2.38^{c}
Feeding cost (L.E./kg fish)	11.24^{b}	18.38^{a}	13.01^{b}	23.29^{a}
Survival (%)	93.33^{ab}	86.66^{a}	100^{a}	91.66^{ab}
Initial feeding rate (%)	5%	1.5%	3%	5%
Feeding rate at harvest (%)	1.68%	2.2%	2.5%	3.7%
Period 2 (95 days):				
FCR	1.46^{a}	1.51^{a}	1.29^{b}	1.37^{ab}
PER	2.28^{b}	2.2^{b}	2.57^{a}	2.43^{ab}
Feeding cost (L.E./kg fish)	14.66^{a}	15.13^{a}	12.98^{b}	13.7^{ab}
Survival (%)	87.62	82.67	90.80	94.81
Initial feeding rate (%)	1.68%	2.23%	2.52%	3.68 %
Feeding rate at harvest (%)	0.87%	1.01%	0.97%	1.16%

Means in the same row with different superscript letters are significantly different ($p<0.05$).

Economic efficiency and feed costs:

During period 1, the feed costs for producing one kilogram of Nile tilapia was lowest for the artificial diet (control) treatment (11.2 L.E./kg). Higher feed costs were obtained when other treatments were used. During period 2, feed costs obtained in T2 and T3 treatments (12.98 -13.7 L.E./kg), were slightly lower than the control and T1 treatments (14.6 – 15.1 L.E./kg) indicating better use of diet during period 2 which produced economically efficient production costs.

Most profitable fish harvest and harvest volume were obtained when Nile tilapia were reared at daily feed input of 8-g diet/m^{2}/day during period 2 of the experiment, indicating improved production parameters as regards to harvest volume and economic performances. The overall feed costs for producing one kilogram of Nile tilapia during the whole experiment were significantly lower in the control (13.1 L.E./kg) and T2 (12.9 L.E./kg) treatments, compared to the T1 and T3 treatments, while averaged 15.5 and 15.1 L.E./kg, respectively. As primarily herbivores and omnivores species, tilapia can achieve up to half of their requirements of amino acid from natural food if grown in a semi-intensive system **(Chowdhury *et al*., 2006)**

CONCLUSION

Superior growth performance was obtained when fish were fed on artificial diet, as compared to feeding on corn flour and natural food enhanced by chemical fertilizers. Nile tilapia juveniles fed corn flour were exposed to limited feed resources in water which depressed growth performance. Artificial diet enhanced growth performance with positive effect on natural food and fertility of water in the rearing tanks. The increase of natural food availability in the T3 and the control treatments indicated a positive effect of artificial diet on algal abundance as indicated by secchi disk readings, without the need for chemical fertilization. Chemical fertilizer supplementation was unnecessary for optimal growth of Nile tilapia when high feed inputs were used since metabolic ammonia and phosphate excretion by fish could act in lieu of chemical fertilizers. It is recommended to use T3 treatment in producing fish for small scale farmers, since lower feed costs and higher growth rates were observed.

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