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Impact of mono or polyculture systems on water quality, growth performance and economic efficiency of *Oreochromis niloticus* (Linnaeus, 1758) and *Hypophthalmichthys molitrix* (Valenciennes, 1844)

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ABSTRACT

The aim of this study was to investigate the effect of the graded replacement of stocking density rate (0, 4, 8 and 12%) of the monosex *Oreochromis niloticus* by the silver carp, *Hypophthalmichthys molitrix* as a mono (T_1) or poly-culture systems (T_2, T_3, and T_4, respectively) for 124 days (4 months) on water quality parameters, growth performance and feed efficiency parameters, condition factor, fish organs indices, fish body composition. The total production of *O. niloticus* and economic efficiency parameters were evaluated in each treatment. An experimental field study was conducted in covered floating net cages in the Lake Manzala. The obtained results revealed the positive effects of rearing *O. niloticus* in poly-culture systems with *H. molitrix* compared to mono-culture system of *O. niloticus* (T_1). *O. niloticus* reared in poly-culture system at stocking rate 4% (T_2) or 8% (T_3) with *H. molitrix* significantly ($P \leq 0.05$) improved the growth rate, feed efficiency (feed intake, feed conversion ratio, protein and energy utilization), and chemical composition of the fish body (crude protein, ether extract, energy content) parameters of both fish species. While, *O. niloticus* reared in poly-culture system with 12% silver carp (T_4) gave the highest total output, total profit, and economic efficiency (%) among all the experimental mono (T_1) or poly-culture systems with silver carp (T_2 and T_3). Thus, it could be concluded that monosex *O. niloticus* reared with *H. molitrix* at 4% (T_2), and 8% (T_3) in poly-culture systems are the best aquaculture systems among the experimental mono (T_1) or other poly-culture system with 12% *H. molitrix* (T_4). But economically, *O. niloticus* reared in poly-culture system with 12% silver carp (T_4) is the best aquaculture system among all the experimental systems.

Keywords: Nile tilapia, Silver carp, Aquaculture, Growth performance, Lake Manzala

INTRODUCTION

Aquaculture is currently the largest single source of fish supply in Egypt accounting for almost 77% (1.1 million ton) of the total fish production of the country with over 99% produced from privately owned farms (GAFRD, 2014). This sector is exhibiting the strongest growth of any fisheries related activity in the country and as a result aquaculture is considered as the only viable option for reducing the gap between production and consumption of fish in Egypt. Partially, fish cage culture system also widely used especially in the Nile Delta region where semi-intensive and intensive farming is practiced with a total production in 2014 reaching to 176266 tonnes (as 11.89% of the total fish production, GAFRD, 2014). Intensive fish cage culture is rapidly developing and now contributes to around 10% of total aquaculture production in Egypt. Nile tilapia, *Oreochromis niloticus* is the principal cage culture species. The sizes of the cages vary from small cages of around 32 m^3 to larger cages of around

600 m^3. Smaller cages (2-4 m^3) suspended in drainage canals are also used in rural areas. The yield varies between 5 to 35 kg/m^3 (El-Sayed, 2007).

Lake Manzala has gradually transformed, with time, from a brackish environment (Bishai and Yossef, 1977) to eutrophic fresh water in response to increased drainage water inputs, nutrient loading associated with agricultural land reclamation processes and due to the urban waste disposal. Polyculture of species combinations with compatible feeding habits can help in maximizing primary productivity and reducing nutrient discharges. It may be possible in suitable situations to use minimum water exchange systems successfully (Avnilmech, 1998) in intensive fish farming. Nile tilapia and silver carp are cultured and stocked in commercial ponds and known to be effective in managing nuisance phytoplankton blooms in both eutrophic lakes (Starling, 1993; Fukushima *et al*., 1999) and aquaculture ponds (Brune *et al*., 2001; Mueller, 2001). Both species are reported to selectively filter water based on particle size. Hence, the present study was designed as an attempt to improve monosex Nile tilapia, *O. niloticus* production in Lake Manzala, through the graded replacement of stocking density rate (0, 4, 8 and 12%) of *O. niloticus* by silver carp, *Hypophthalmichthys molitrix* as a mono (T_1) or poly-culture systems (T_2, T_3, and T_4, respectively) in floating net cages for 124 days (4 months). The impacts of these aquaculture systems were studied on water quality parameters, growth and feed efficiency parameters, condition factor, fish organs indices, fish body composition. The total production of *O. niloticus* through the graded of their body size, as well as the total production, total output, and the economic efficiency parameters of each treatment were evaluated.

MATERIALS AND METHODS

Experimental management:

The present study was carried in a private fish cages farm in Lake Manzala, (Raswah Lisa Al-Gamaliah), Dakahlia Governorate, Egypt. Mono-sex Nile tilapia, *O. niloticus*, (Linnaeus, 1758) with an average initial body weight (19.30 ± 3.81 g) and / or silver carp, *H. molitrix* (Valenciennes, 1844) with an average initial body weight (73.67 ± 10.11 g) were used in this experiment. *O. niloticus* fingerlings were purchased from El-Manzala hatchery, Integrated Fish Farm at El-Manzala (General Authority for Fish Resources Development-Ministry of Agriculture), Dakahlia Governorate, Egypt. While, silver carp were purchased from a private Fish Farm of Yousef Asal, Raswah, Lisa Al-Gamaliah, Dakahlia Governorate, Egypt.

The experimental fish were adapted for two weeks in floating covered net-cages and fed on the basal diet during this adaptation period. Fish randomly distributed into four floating covered net-cages (10 m length × 10 m Width × 2 m depth), as four experimental groups as shown in Table 1 and Figure 1.

Table 1: The design of the experimental treatment (Aquaculture systems)

Treatment (cage)	No. of Nile tilapia	No. of Silver carp	Total biomass of cage (kg)
1st (Nile tilapia mono aquaculture system)	6000	------	115.50
2nd (Nile tilapia and 4% silver carp in poly-culture system)	5760	240	129.00
3rd (Nile tilapia and 8% silver carp in poly-culture system)	5520	480	142.00
4th (Nile tilapia and 12% silver carp in poly-culture system)	5280	720	155.50

Fig. 1: Site of the experimental cages in Manzala Lake, Dakahlia Governorate, Egypt

All fish groups were fed on the same artificial pelleted diet (about 25% crude protein), which purchased from AboAbbas Animal Feed Factory, the industrial zone El-Asafra, Al-Matariah, Dakahlia Governorate, Egypt. The ingredients of the artificial diet and its chemical composition are illustrated in Table 2. The artificial diet was offered manually to the fish in all treatment twice daily at 9.00 a.m. and 15.00 p.m. The feeding rate was 4% for the three months of the experiment and decreased to 3% of body weight mass till the end of the experiment. The feed quantity was adjusted biweekly on the basis of the actual changes on biomass of the fish in each cage.

Table 2: Formulation and chemical analysis (% on dry matter basis) of the experimental diet

Ingredient	Gram per kg diet
Moroccan fish meal (65% CP)	60.00
Corn gluten (60% CP)	40.00
Soybean meal (48% CP)	250.00
Wheat bran (14% CP)	200.00
Rice bran (14% CP)	250.00
Yellow corn (9% CP)	180.00
Salts	20.00
Total	1000.0
Nutrient composition	
Dry matter (DM%)	90.50
Crude protein (CP %)	24.05
Ether extract (EE %)	5.55
Crude fiber (%)	7.55
Ash (%)	8.75
Nitrogen free extract (%)	54.10
Total carbohydrates (%)	61.65
Gross energy (GE)[1] (Kcal / 1000 g DM)	441.41
Protein / energy (P/E)[2] ratio (mg CP / Kcal GE)	54.48

[1] GE (Kcal / 100 g DM) = CP × 5.64 + EE × 9.44 + Total carbohydrates × 4.11 calculated according to (Macdonald *et al.*, 1973).
[2] P/E ratio (mg protein / Kcal GE) = (CP × 1000) / GE.

Criteria measured:

Some of water quality parameters were measured in all experimental cages as following; water temperature, dissolved oxygen (DO), ammonia and pH values at the start and weekly in all the experimental period. Whereas, water temperature in degree centigrade was recorded using a thermometer and DO concentration was determined using the Winkler method (APHA, 1971). Ammonia and pH values of water was measured by direct Nesslerization methods using a CHEMETS® test kits (CHEMETRICS, INC, USA) according to APHA (1992).

Body weight of monosex *O. niloticus* in each cage were measured biweekly, while the body weight of *H. molitrix* were measured at the start and the end of the experiment to limited feed quantity and to calculate the growth performance and feed utilization according to Halver and Hardy (2002). Also, at the start and the end of the experiment, all fish species (*O. niloticus* and *H. molitrix*) were sampled from each cage and kept frozen (– 20°C) until the chemical analysis was done. The chemical analysis of the experimental diet and the whole fish body was carried out according to AOAC (2004).

At the end of the experiment, ten *O. niloticus* were randomly taken from each treatment and anaesthetized then individually weighed and their total length was measured to calculated the condition factor (K_f) according to the following equation; K_f = (fish weight (g) × 100) / total length^3 (cm) (Lagler, 1956). Also, at the end of the study the same ten fish used for determination K_f-values were anaesthetized by pure clove oil. Then fish were individually weighed, sacrificed, and the internal organs livers, spleen, and intestine were individually removed and weighed also to calculate the organs indices according to the following equations; hepato-somatic index (HSI) = (liver weight/ fish weight) × 100 (Jangaard *et al*., 1967), spleen-somatic index (SSI) = (spleen weight / fish weight) × 100, and intestine-somatic index (ISI) = (intestine weight / fish weight) × 100 (Tseng and Chan, 1982).

At the end of the experiment, total production of all fish species (kg) and total output (LE) parameters were calculated according to the total weight gain costs (as output) and food consumption costs (as input) regardless to any other costs. While, the graded of *O. niloticus* according their body size in each cage was done, where the fish size was consider as; size 1: 300 – 500g, size 2: 200 – 250g, size 3: 100 – 150g, and size 4: 50 - 100g.

Statistical analysis:

The obtained data was subjected to one-way analysis of variance (ANOVA) using professional statistical analysis system (SAS, 2006) software version 9.1.3. All ratios and percentages were arcsine-transformed prior to statistical analyses. Mean of each treatment were statistically compared for the significance ($P \leq 0.05$) using Duncan's multiple range test (Duncan, 1955), evaluated by the following model:

$$Y_{ij} = \mu + T_i + e_{ij}$$

Where:

Y_{ij} = the data of growth performance, feed efficiency, K_f and organs indices, and fish body composition parameters; μ = the overall means; T_i = the fixed effect of treatments; e_{ij}= is the random error.

While, all data of the water quality parameters in different treatments and in different times were statistically analyzed using SAS (2006), with factorial design (4×4) and evaluated using the following model:

$$Y_{ijk} = \mu + L_i + P_j + LP_{ij} + e_{ijk}$$

Where:

Y_{ijK} = the data of water quality parameters; μ = the overall means; L_i = the fixed effect of the different treatments (four treatments); P_j= the fixed effect of different times (Four months); LP_{ij}= the interaction effect between the effect of treatments (four treatments) and / or different times (Four months) on water quality parameters; e_{ijk} = is the random error.

RESULTS AND DISCUSSION

Water quality parameters:

No significant ($P \geq 0.05$) effects of mono or polyculture systems (treatments, Table 3) or the interaction between mono or poly-culture systems and different experimental times were found on all water quality parameters. In the 3rd period (September - October), water pH-value, and water temperature have significantly ($P \leq 0.05$) increased, while water-NH_3, and dissolved oxygen (DO) were significantly ($P \leq 0.05$) decreased comparing to other experimental periods. Although, these significant differences of water quality parameters were within the suitable range for fish culture (Abdelhamid, 2011), except water DO. Where, DO seriously decreased in all cages and in all experimental period, especially in summer. Additionally, the discharge of agricultural, domestic and industrial wastes with high biological oxygen demand, nutrient, heavy metals, and pesticides have led to a deterioration in water quality and eutrophicated conditions in large areas of Lake Manzala (**Ayache *et al*., 2009**). Moreover, cages sites that are strongly stratified for much of the year, and/or where algal blooms carry risks of periodically poor oxygen condition, should be avoided if possible. Marine sites which have good bottom currents and which disperse sedimenting wastes are desirable. Warm-water fish survive at DO levels as low as 1 mg / L, but their growth is slowed down by prolonged exposure, whereas the desirable range of DO is above 5 mg / L.

Table 3: Effect of experimental mono or poly-culture systems in cages and times (month) on the rearing water quality parameters

	pH	NH_3 (mg / L)	DO (mg / L)	Temperature (°C)
Treatment (cage)				
1	7.25 ± 0.13	0.0016 ± 0.00	2.40 ± 0.16	26.60 ± 0.81
2	7.25 ± 0.13	0.0016 ± 0.00	2.66 ± 0.20	26.60 ± 0.81
3	7.25 ± 0.13	0.0017 ± 0.00	2.30 ± 0.17	26.60 ± 0.81
4	7.25 ± 0.13	0.0013 ± 0.00	2.66 ± 0.18	26.60 ± 0.81
P-value	1.00	0.1999	0.2350	1.00
Time (month)				
1st (July - August)	7.00^b ± 0.00	0.0010^c ± 0.00	2.62^{ab} ± 0.13	25.00^d ± 0.00
2nd (August - September)	7.00^b ± 0.00	0.0010^c ± 0.00	2.37^b ± 0.19	28.00^b ± 0.00
3rd (September - October)	8.00^a ± 0.00	0.0016^b ± 0.00	2.00^c ± 0.15	30.00^a ± 0.25
4th (October - November)	7.00^b ± 0.00	0.0027^a ± 0.00	3.03^a ± 0.10	23.60^c ± 0.56
P-value	0.0001	0.0001	0.0002	0.0001

Mean in the same column having different small letters are significantly different ($P \leq 0.05$). DO: Dissolved oxygen

Fish growth performance:

All growth performance parameters of *O. niloticus* reared in poly-culture systems (T_2, T_3 and T_4) were significantly ($P \leq 0.05$) increased comparing to the *O. niloticus* reared in mono-culture system (T_1), where the highest growth performance parameters were recorded in T_2 compared to other groups (Table 4). Regarding the growth performance of *H. molitrix* reared in poly-culture systems, the same treatment T_2 (4% *H. molitrix*) had a significant ($P \leq 0.05$) increased of all growth performance parameters of *H. molitrix* among other poly-culture systems 8% (T_3) and 12% (T_4) of *H. molitrix*, respectively (Table 4).

Growth is an important component of the ecology of fishes (Wootton, 1992). In the present study, the growth performance of *O. niloticus* or *H. molitrix* has been improved ($P \leq 0.05$) in poly-culture systems than mono-culture system. As the current findings also, Sweilum (1995) found that the body length and weight of Nile tilapia and silver carp slightly increased by decreasing the stocking density rate. In addition, Sweilum (2001) obtained better growth rate and production for *O. niloticus* in poly-culture combination (*Sarotherodon galilaeus* and *Clarias gariepinus*) than in duo-culture and mono-culture systems. On other hand, Sweilum (1998 a) reported that growth and production of *O. niloticus* are related to stocking density, since they increase at low density. Also, El-Saidy and Gaber (2002) confirmed the same conclusion for *O. niloticus*, which were significantly ($P \leq 0.01$) the best growth performance at the lower stocking density; while, total production and net production exhibited significantly the opposite trend. In this respect, Hassan *et al*. (2006) noticed also that increasing the stocking density significantly decreased body weight and length of tilapia aurea. Inversely, Abdelhamid (2011) recommended that the best treatment is the monoculture of all males monosex *O. niloticus* reared in net cages followed by that of poly-culture for their superiority in growth and feed efficiency parameters.

Due to their rapid growth rate and worldwide popularity, silver carp is not considered threatened. They are often sold for human consumption and are also used for cleaning waters of algael blooms (Smith, 1989). In general, silver carp can adapt to many different environments and can grow very quickly, as well as silver carp gained 2.7 g / day when fed on a large diet. Similarly with the obtained results herein, Bakeer *et al*. (2003) revealed that silver carp cultured in cages gave pronounced ($P \leq 0.05$) increases in body weights at lower stocking density. In addition, Sweilum (1998 b) noticed that the silver carp was the best species in tilapia rearing ponds, where weight gain of *O. niloticus* reached its maximum value.

Table 4: Effect of the experimental mono or poly-culture systems in cages on growth performance parameters of *Oreochromis niloticus* and *Hypophthalmichthys molitrix*

Treatment (cage)	Final weight (g)	Average weight gain (g)	ADG (g/fish/day)	RGR (g)	SGR (%/day)
O. niloticus					
1	$84.13^{b} \pm 1.20$	$64.83^{b} \pm 1.20$	$0.52^{b} \pm 0.01$	$335.90^{b} \pm 6.19$	$1.18^{b} \pm 0.01$
2	$100.58^{a} \pm 0.59$	$81.28^{a} \pm 0.58$	$0.65^{a} \pm 0.00$	$421.10^{a} \pm 2.97$	$1.33^{a} \pm 0.00$
3	$96.67^{a} \pm 1.84$	$77.36^{a} \pm 1.83$	$0.62^{a} \pm 0.01$	$400.80^{a} \pm 9.49$	$1.29^{a} \pm 0.02$
4	$97.46^{a} \pm 0.98$	$78.16^{a} \pm 0.98$	$0.63^{a} \pm 0.01$	$405.00^{a} \pm 5.07$	$1.31^{a} \pm 0.01$
P-value	0.0001	0.0001	0.0001	0.0001	0.0001
H. molitrix					
2	$227.50^{a} \pm 2.65$	$153.80^{a} \pm 2.65$	$1.24^{a} \pm 0.02$	$208.80^{a} \pm 3.59$	$0.90^{a} \pm 0.01$
3	$219.20^{a} \pm 5.27$	$145.50^{a} \pm 5.27$	$1.17^{a} \pm 0.04$	$197.60^{a} \pm 7.16$	$0.87^{a} \pm 0.02$
4	$179.50^{b} \pm 1.02$	$105.80^{b} \pm 1.02$	$0.85^{b} \pm 0.01$	$143.70^{b} \pm 1.39$	$0.71^{b} \pm 0.00$
P-value	0.0001	0.0001	0.0001	00.0001	0.0001

Mean in the same column having different small letters are significantly different ($P \leq 0.05$). ADG: average daily gain, RGR: relative growth rate, and SGR = specific growth rate

Chemical composition of fish body:

Results in Table 5 revealed that *O. niloticus* reared in poly-culture system with 8% silver carp (T_3) had a significant ($P \leq 0.05$) highest DM content among the experimental fish reared under mono (T_1) or poly-culture systems (T_2, and T_4). Also, fish in T_2 group (4% poly-culture system by silver carp) gave the highest ($P \leq 0.05$) EE and EC among all fish groups. However, *O. niloticus* reared in mono-culture system (T_1) had highest ($P \leq 0.05$) CP and ash contents compared to fish reared under the poly-culture systems (T_2, T_3, and T_4). Also, data in Table 5 illustrated the body composition of *H. molitrix* reared under poly-culture systems (T_2, T_3, and T_4). *H. molitrix* reared under 8% poly-culture system (T_3) had significant ($P \leq 0.05$) highest DM and ash contents among fish reared under other poly-culture systems (T_2, and T_4). While, fish reared in 4% poly-culture system (T_2) gave highest ($P \leq 0.05$) CP and EC compared to fish reared in other poly-culture systems (T_3, and T_4). No significant ($P \geq 0.05$) effects on EE content of fish reared in all poly-culture systems.

The obtained results regarding the body composition of the experimental fish (*O. niloticus* or *H. molitrix*) revealed that the poly-culture systems of fish at 8% (T_3) followed by 4% (T_2) significantly improved the body composition of fish compared to mono-culture system (T_1) or the poly-culture system (12%, T_4). These results were confirmed by the markedly significant effects of these poly-culture systems (T_2 and T_3) on all growth performance parameters of *O. niloticus* or *H. molitrix* (Table 4) among all groups. *O. niloticus* have the ability to filter-feed on phytoplankton (Turker *et al*., 2003 a,b), and concomitantly produce a second crop of marketable animal in poly-culture systems (Dos Santos and Valenti, 2002). In this respect, tilapias are considered filter feeders because they can efficiently harvest plankton from the water. They can digest more efficiently the plant protein (Popma and Masser, 1999). Under the poly-culture system of Nile tilapia and silver carp, Soltan (1998) had the same results for Nile tilapia and the opposite results were obtained with silver carp stocked with Nile tilapia in the same pond. Also, the current findings agree with those obtained by Shaker and Mahmoud (2007) in case of silver carp reared in cages in River Nile.

Table 5: Effect of the experimental mono or poly-culture systems in cages on body chemical composition parameters (% on dry matter basis) of *Oreochromis niloticus* and *Hypophthalmichthys molitrix*

Treatment (cage)	DM (%)	CP (%)	EE (%)	Ash (%)	EC (kcal / 100 g)
O. niloticus					
At the start:					
	20.86	59.47	13.61	26.92	463.88
At the end:					
1	$22.72^b \pm 0.17$	$58.19^a \pm 0.40$	$21.54^d \pm 0.14$	$20.26^a \pm 0.53$	$531.6^c \pm 3.51$
2	$22.27^b \pm 0.63$	$55.64^c \pm 0.08$	$28.55^a \pm 0.28$	$15.80^b \pm 0.36$	$583.4^a \pm 3.07$
3	$24.30^a \pm 0.28$	$57.04^b \pm 0.32$	$26.19^c \pm 0.13$	$16.76^b \pm 0.29$	$569.0^b \pm 1.65$
4	$22.74^b \pm 0.39$	$55.50^c \pm 0.32$	$27.49^b \pm 0.18$	$17.00^b \pm 0.16$	$572.6^b \pm 0.50$
P-value	0.033	0.0008	0.0001	0.0001	0.0001
H. molitrix					
At the start:					
	19.49	68.20	9.75	22.05	476.68
At the end:					
2	$16.09^{ab} \pm 0.14$	$70.33^a \pm 0.23$	7.73 ± 0.07	$21.94^c \pm 0.22$	$469.60^a \pm 1.27$
3	$17.23^a \pm 0.53$	$67.31^b \pm 0.32$	7.40 ± 0.26	$25.28^a \pm 0.20$	$449.50^c \pm 1.55$
4	$15.64^b \pm 0.22$	$68.47^b \pm 0.53$	7.45 ± 0.35	$24.08^b \pm 0.22$	$456.50^b \pm 1.01$
P-value	0.038	0.003	0.640	0.0001	0.0001

Mean in the same column having different small letters are significantly different ($P \leq 0.05$). DM: Dry matter, CP: Crude protein, EE: Ether extract, and EC: Energy content.

Condition factor (K_f) and internal organs indices:

Condition factor (K_f) and organs indices, now usual practice in fisheries biology, and have also been used to evaluate the fitness of fish populations (Bolger and Connolly, 1989). In the present study, no significant ($P \geq 0.05$) effects were detected on K_f or the organs indices (HSI%, SSI%, and ISI%) parameters of *O. niloticus* reared in mono or poly-culture systems (Table 6). Additionally, knowledge of some quantitative characteristics in fishes is an important tool for the study of biological fundamentals such as viscerosomatic and hepatosomatic indices, because measurement and analysis of these indices are very important in assessing food value (Ighwela *et al.*, 2014), and fish health (Sadekarpawar and Parikh, 2013). Although, the poly-culture systems significantly improved of all growth performance parameters (Table 4) of *O. niloticus*, but no significant ($P \geq 0.05$) effects were detected on K_f or the organs indices of *O. niloticus* reared in the poly-culture systems. The rate of growth of fish is highly variable because it is greatly dependent on a variety of interacting environmental factors such as water temperature, levels of DO and ammonia, salinity, and photoperiod (Brogowski *et al.*, 2005). Generally, the growth-dependent variations of trace element levels are known to be influenced by various factors such as metabolic rate, and growth dilution of the elements (Langston and Spence, 1995).

Length-weight relationship is widely used procedure to assess the growth performances of fish (Morato *et al.*, 2001). According to Mendes *et al.* (2004), length-weight relationship is one of the most commonly used analyses of fisheries data. Along with length-weight relationship, studies on K_f provide a robust indication of fish health. As in the present findings herein, when K_f was greater than 1, it can be concluded that fish reared in cages were in good condition and healthy (Gupta *et al.*, 2012). It also means that the growth of tilapia in cages was good as K_f has been used as an index for growth studies (Fagade, 1979).

Table 6: Effect of the experimental mono or poly-culture systems in cages on condition factor (K_f) and different organs indices parameters of *Oreochromis niloticus*

Treatment (cage)	K_f (%)	HSI (%)	SSI (%)	ISI (%)
1	1.69 ± 0.08	2.49 ± 0.24	0.33 ± 0.10	5.44 ± 0.71
2	1.72 ± 0.02	1.82 ± 0.40	0.25 ± 0.07	4.41 ± 0.23
3	1.79 ± 0.05	2.91 ± 0.02	0.34 ± 0.12	5.79 ± 1.39
4	1.60 ± 0.05	2.55 ± 0.15	0.32 ± 0.08	4.08 ± 0.31
P-value	0.200	0.072	0.904	0.430

Kf: Condition factor, HSI: hepato-somatic index, SSI: spleen-somatic index, and ISI: intestine-somatic index.

Feed and nutrients utilization:

O. niloticus reared in the poly-culture system with silver carp at 8% (T_3) revealed the highest values of feed intake (FI, g), protein productive value (PPV), and energy utilization (EU, %) and the differences among all groups were significant ($P \leq 0.05$). Also, *O. niloticus* reared in the poly-culture system with silver carp at 4% (T_2) revealed the best ($P \leq 0.05$) value of feed conversion ratio (FCR) and the highest ($P \leq 0.05$) protein efficiency ratio (PER) among all groups (Figure 2 a, b). Where, the positive effects of T_2 and T_3 on feed and nutrients utilization confirmed by their superiority effects on the growth performance (Table 4) and body composition (Table 5) of the experimental fish than of *O. niloticus* reared on mono-culture system (T_1) or in poly- culture system with silver carp at 12% (T_4).

Poly-culture and/or integrated culture have been widely used in freshwater and marine aquaculture to improve yield and nutrient utilization efficiency (Neori *et al.*, 2004). In this respect, carp poly-culture food inputs used worldwide are whole food items, farm-made aqua foods and commercial balanced food (Tacon and Hasan, 2007). Also, El-Saidy and Gaber (2002) confirmed that mean final weight and length, weight and length gain, SGR, and FCR of *O. niloticus* were significantly ($P \leq 0.01$) the best at the lower stocking density; while, total production and net production exhibited significantly the opposite trend. Additionally, Kheir and Saad (2003) proved that the least stocking rate attained the highest significant ($P \leq 0.05$) final weight, weight gain, SGR, FCR, and PER for *O. niloticus*. Inversely with the obtained results herein, Adewolu *et al*. (2008) reported that the two species of the Clariid catfish and their hybrid performed best in terms of growth and feed utilization in monoculture than in duo-culture and trio-culture systems. Also, the same conclusion was detected by Abdelhamid (2011) of monosex *O. niloticus* reared in mono-culture system in net cages followed by that of poly-culture for their superiority in feed and nutrients efficiency parameters.

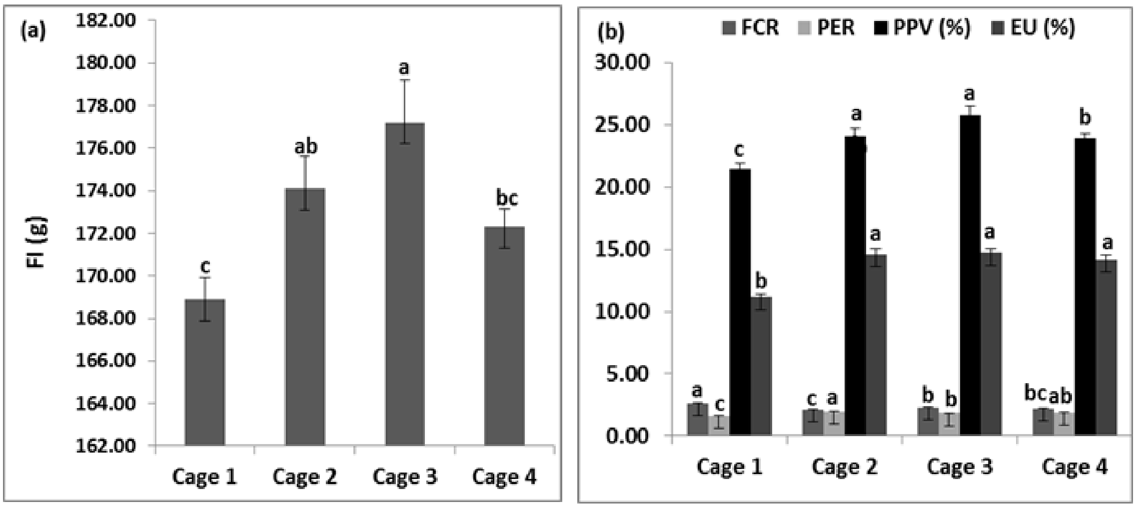

Fig. 2(a-b): Effect of the experimental mono or poly-culture systems in cages on feed efficiency parameters (a) FI and (b) FCR, PER, PPV, and EU of *Oreochromis niloticus*

Total production of *O. niloticus*:

Although, *O. niloticus* reared in mono-culture system, they gave the highest total production (735 kg) compared to the poly-culture systems, but this treatment (T_1) and the poly-culture system with 12% silver carp (T_4) gave the lowest total output of *O. niloticus* (6210, and 5820 LE, respectively) compared to the other poly-culture systems with 4% silver carp (T_2), and 8% silver carp (T_3), which gave the highest total output of tilapia (6590 LE) and (6240 LE), respectively (Table 7). These confusion about the total production and total output of *O. niloticus* reared in different experimental culture systems are related to the difference in their size among all treatments (Table 7). Where, in case of *O. niloticus* reared in poly-culture system with 4% silver carp (T_2) and with 8% silver carp recorded the highest size 1 and size 2 of *O. niloticus* than those the size of fish in both T_1 and T_4, which reflected in increasing the total output of T_2 and T_3 than of T_1 and T_4, respectively (Table 7).

Economic efficiency (%) parameters:

Intensive production is growing fast and takes two forms. Around 10% of total aquaculture production is from cage culture, principally of Nile tilapia. Fish farmers in rural area sometimes use very small cages suspended in drainage canals (GAFRD, 2012). In the present study, *O. niloticus* reared in poly-culture system with 12% silver carp (T_4) gave the highest total output (LE), total profit (LE), and economic efficiency (%) among all the experimental mono (T_1) or poly-culture systems with silver carp (T_2 and T_3, Table 8). Although, the best growth performance and feed efficiency, total output, as well as the differentiation of the size were recorded of monosex *O. niloticus* reared in poly-culture system with 4% and 8% silver carp (T_2 and T_3, respectively) compared to those monosex *O. niloticus* reared in poly-culture with silver carp at high rate 12% (T_4).

These superiority in economic efficiency parameters of T_4 may be potentially related to the addition value of silver carp, which increased by increasing the stocking rate of T_4 (12% silver carp) than other experimental aquaculture systems. Where, silver carp can adapt to many different environments and can grow very quickly, as well as they can consume 2 to 3 times their body weight in plankton each day and gained 2.7 g / day when fed a large diet. Because of their large size and voracious appetite, silver carp are able to out-compete many other species of fish (Cremer and Smitherman, 1980). Additionally, Avnilmech (1998) reported that poly-culture of species combinations with compatible feeding habits can help in maximizing primary productivity and reducing nutrient discharges. Also, Milstein *et al*. (2002) suggested that stocking two or more complimentary fish species can increase the maximum standing crop of a pond by allowing a wide range of available food items and the pond volume to be utilized.

Nile tilapia and planktivorous silver carp poly-culture can improve the water quality by grazing down the phytoplankton by the latter species and enhance the growth of former species and their health status. It also helps to gain an extra crop of silver carp without incurring additional cost, making aquaculture more profitable to farmers (Sarkar *et al*., 2006 and 2008). As the current findings herein, Khouraiba *et al*. (1991) reported that the poly-culture system of Nile tilapia at ratios of 1:10 and 2:10 for tilapia and common carp in cages, respectively gave higher (30%) total net production than that of tilapia cultured alone in a mono-culture system. Moreover, Essa *et al*. (2008) revealed that Nile tilapia and silver carp culture in net-enclosures was more productive (12.26 kg / m^3 / 5 months) and economic than mono-culture system of Nile tilapia (5.77 kg / m^3 / 5 months). Inversely with our findings, Abdelhamid (2011) concluded that the best treatment is the mono-culture of monosex Nile tilapia followed by that of poly-culture with silver carp at high or low stocking densities, regarding to their superiority in growth and feed efficiency, besides the economic efficiency parameters.

Table 7: Effect of the experimental mono or poly-culture systems in cages on total production, and total output of *Oreochromis niloticus* and the differentiation of their size

Treatment (cage)		Size 1	Size 2	Size 3	Size 4	Total
1	Total production (kg)	115	160	310	150	735
	Total production (%)	15.65	21.77	42.18	20.41	100.00
	Total output of tilapia (LE)	1380	1600	2480	750	6210
2	Total production (kg)	220	190	200	90	700
	Total production (%)	31.43	27.14	28.57	12.86	100.00
	Total output of tilapia (LE)	2640	1900	1600	450	6590
3	Total production (kg)	170	255	150	90	665
	Total production (%)	25.56	38.35	22.56	13.53	100.00
	Total output of tilapia (LE)	2040	2550	1200	450	6240
4	Total production (kg)	210	195	125	70	600
	Total production (%)	35.00	32.50	20.83	11.67	100.00
	Total output of tilapia (LE)	2520	1950	1000	350	5820

Size 1: 300 – 500g; Size 2: 200 – 250g; Size 3: 100 – 150g, and Size 4: 50 - 100g.

Table 8: Effect of the experimental mono or poly-culture systems in cages on the economic efficiency (%) parameters of each cage

Treatment (cage)	Total output of cage (LE)	Total input of cage (LE)	Total profit of cage (LE)	Economic efficiency (%)
1	6210	4450	1760	39.59
2	7310	4600	2710	58.98
3	7680	4715	2965	60.95
4	7980	4680	3300	70.47

1- Total feed costs per cage (LE / Kg diet) = feed costs per one kg diet × feed intake
2- Total outputs per cage (LE / Kg) = fish price × total fish production*
* Total fish production per cage = final number of fish × fish weight gain
3- Total profit of cage (LE) = total output – total input of cage
4- Economic efficiency per cage (%) = (total profit / total input) × 100
The price of 1 kg ingredient was used in the present study (3.20 LE), as well as the price of fish according to the local market price in Egypt at the time of the study (2013).

CONCLUSION

Based on the biological obtained findings herein, it could be concluded that monosex *O. niloticus* reared with *H. molitrix* at 4% (T_2), and 8% (T_3) in poly-culture systems are the best aquaculture systems among the experimental mono-culture (T_1) system or other poly-culture system with 12% *H. molitrix* (T_4). While, from the economic point of view, it could be recommended that *O. niloticus* reared in poly-culture system with 12% silver carp (T_4) gave the highest total output, total profit, and economic efficiency parameters among all the experimental mono (T_1) or other poly-culture systems with silver carp at 4% (T_2) or 8% (T_3). Accordingly to the present findings, further studies are required for determination the optimal stocking rate of *O. niloticus* and *H. molitrix* in poly-culture system in cages or in other aquaculture systems with other fish species, or in different feeding sources, levels and percentages…etc.

REFERENCES

Abdelhamid, A.M. (2011). Intensive rearing of mono-Sex Nile tilapia and silver carp under mono-or polyculture systems at different stocking densities in floating net cages. J. Animal and Poultry Prod., Mansoura Univ., 2 (7): 277-289.

Adewolu, M. A.; Ogunsanmi, A.O. and Yunusa, A. (2008). Studies on growth performance and feed utilization of two Clariid catfish and their hybrid reared under different culture systems. Eur. J. Sci. Res., 23 (2): 252-260.

AOAC, (2004). Association of Official Analytical Chemists of Official Methods of Analysis. AOAC International, Arlington, Virginia, USA.

APHA, American Public Health Association (1971). Standard Methods., Washington, DC, pp: 874.

APHA, American Public Health Association (1992). Standard Methods for the Examination of Water and Waste water, 18th ed., Washington, DC. pp: 1268.

Avnilmech, Y. (1998). Minimal discharges from intensive fish ponds. World Aquaculture, 29: 32–37.

Ayache, F.; Thompson, J. R., Flower, R. J., Boujarra, A., Rouatbi, F. and Makina, H. (2009). Environmental characteristics, landscape history and pressures on three coastal lagoons in the Southern Mediterranean Region: Merja Zerga (Morocco), Ghar El Melh (Tunisia) and Lake Manzala (Egypt). Hydrobiologia, 622(1):15-43.

Bakeer, M. N.; Abdel-Gawad, A. S., Abdel-Rahman, S. and Nossier, M. I. (2003). Biological and economical investigations of silver carp (*Hypophthalmichthys molitrix*) cultured in cages at different stocking densities and manuring treatments. Intern. Conf. "Fish Wealth and Food Security in Arabic and Islamic Countries", 22-24 Oct., Al-Azhar Univ., pp.19.

Bishai, H.M. and Yosef, S.F. (1977). Some aspects on the hydrography, physico-chemical characteristics and fisheries of Lake Manzalah. Bull. Inst. Oceanogr. and Fish., 7:31-58.

Bolger, T. and Connolly, P.L. (1989). The selection of suitable indices for the measurement and analysis of fish condition. J. Fish Biol., 34:171–182.

Brogowski, Z., Siewert, H. and Keplinger, D. (2005). Feeding and Growth Responses of Bluegill Fish (*Lepomis macrochirus*) at various pH Levels. Pol. J. Environ. Stud., 14 (4): 517-519.

Brune, D.E.; Reed, S., Schwartz, G., Collier, J.A., Eversole, A. and Schwedler, T. (2001). High rate algal systems for aquaculture, Proceedings from the Aquacultural Engineering Society's Second Issues Forum, Ithaca, NY, NRAES-. 117/129, pp.157.

Cremer, M.C. and Smitherman, R.O. (1980). Food habits and growth of silver carp and bighead carp in cages and ponds. Aquaculture, 20: 57-64.

Dos Santos, M.J.M. and Valenti, W.C. (2002). Production of Nile tilapia, *Oreochromis niloticus*, and freshwater prawn, *Macrobrachium rosenbergii*, stocked at different densities in polyculture systems in Brazil. J. World Aquac. Soc., 33(3): 369–376.

Duncan, D.B. (1955). Multiple ranges and multiple F-tests. Biometrics, 11:1-42.

El-Saidy, D.M.S.D. and Gaber, M.M.A. (2002). Intensive culture of Nile tilapia, *Oreochromis niloticus* in concrete tanks in Egypt: Effect of stocking density and feeding levels on growth performance, production traits, feed conversion and body composition. Proc. 1st Sci. Conf. Aqu., El-Arish,13-15Dec., pp:1-22.

El-Sayed, A-F.M. (2007). Analysis of Feeds and Fertilizers for Sustainable Aquaculture Development in Egypt. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and Analysis of Feeds and Fertilizers for Sustainable Aquaculture Development. FAO Fisheries Technical Paper. No. 497. Rome, FAO.

Essa, M.A.; Goda, A.M.A.S., Hanafy, M.A., El-Shebly, A.A., Mohamed, R.A. and El-Ebiary, E.H. (2008). Small-scale fish culture: guiding models of aquaponics and net-enclosures fish farming in Egypt. Egypt. J. Aqua. Res., 34 (3): 320-337.

Fagade, S.O. (1979). Observation of the biology of two species of tilapia from the Lagos lagoon Nigeria. Bull. Inst. Fond Afr. Nore (Ser. A)., 41: 627-658.

Fukushima, M.; Takamura, N., Sun, L., Nakagawa, M., Matsushige, K. and Xies, P. (1999). Changes in the plankton community following introduction of filter-feeding planktivorous fish. Freshw. Biol., 42: 719-735.

GAFRD, General Authority for Fish Resources Development (2012). Fish Statistics yearbook 2012. Ministry of Agriculture and Land Reclamation, Cairo, Egypt, pp:106.

GAFRD, General Authority for Fish Resources Development (2014). Fish statistics yearbook 2014, 24th Edition, Cairo, Egypt, pp:106.

Gupta, N.; Haque, M.M. and Khan, M. (2012). Growth performance of tilapia fingerling in cage in ponds managed by Adivasi households: An assessment through length-weight relationship. J. Bangladesh Agril. Univ. 10(1): 149-155.

Halver, J.E. and Hardy, R.W. (2002). Fish Nutrition. 3rd edn. Academic Press, Elsevier Science Imprint, California, USA. pp: 824.

Hassan, A.S.; Hassan, A.A. and Mahmoud, S.H. (2006). Effect of stocking rate and organic fertilization on the growth performance of tilapia aurea (*Oreochromis aureus*). J. Agric. Sci. Mansoura Univ., 31 (2): 617-625.

Ighwela, K.A.; Ahmad, A.B. and Abol-Munafi, A.B. (2014). The selection of viscerosomatic and hepatosomatic indices for the measurement and analysis of *Oreochromis niloticus* condition fed with varying dietary maltose levels. Int. J. Fauna Biol. Stud., 1(3): 18-20.

Jangaard, P.M.; Ackman, R.G. and Spios, J.C. (1967). Seasonal studies of the fatty acids composition of cod liver flesh, roe and milt lipids. J. Fish Res. Bd. of Canada, 24: 613-627.

Kheir, M.T. and Saad, A.S. (2003). Growth performance and feed utilization of *Oreochromis niloticus* (Linnaeus, 1757) fingerlings as affected with stocking density and feeding regime. J. Egypt. Acad. Soc. Environ. Develop., (B-Aquaculture), 4 (2): 1-21.

Khouraiba, H.M.; El-Sherif, M.S. and Dansoury, M.A.K. (1991). Enhanced fish production through polyculture system of Nile tilapia (*Tilapia nilotica*) with common carp (*Cyprinus carpio*) in floating cages. Zagazig Vet. J., 19(4): 854-864.

Lagler, K.R. (1956). Freshwater fishery biology (2^{nd} cd.), Dubuque, Iowa, William C. Brown Co., pp: 421.

Langston, W.J. and Spence, S.K. (1995). Biological factors involved in metal concentrations observed in aquatic organisms. In: Tessier, A., Turner, D.R. (Eds.), Metal speciation and bioavailability in aquatic systems. John Wiley, Chichester., pp:407–478.

Macdonald, P.; Edwards, R.A. and Greenhalgh, J.F.D. (1973). Animal Nutrition, 2^{nd} Ed., Longman, London.

Mendes, B.; Fonseca, P. and Campos, A. (2004). Weight-length relationships for 46 fish species of the Portuguese west coast. J. Applied Icht., 20: 355-361.

Milstein A.; Wahab, M.A. and Rahman, M.M. (2002). Environmental effcts of common carp *Cyprinus carpio* (L.) and mrigal *Cirrhinus mrigala* (Hamilton) as bottom feeders in major Indian carp polycultures. Aquac. Res., 33, 1103-1117.

Morato, T.; Afonso, P., Loirinho, P., Barreiros, J.P., Sanstos, R.S. and Nash, R.D.M. (2001). Length-weight relationships for 21 costal fish species of the Azores, North-eastern Atlantic. Fish Res., 50: 297-302.

Mueller, R.C. (2001). Effect of filter feeders on the phytoplankton community of the Partitioned Aquaculture System. M. Sc. Thesis. Clemson University, Clemson, SC, USA.

Neori, A.; Chopin, T., Troell, M., Buschmann, A.H., Kraemer, G.P., Halling, C., Shpigel, M. and Yarish, C. (2004). Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. Aquaculture, 231: 361–391.

Popma, T. and Masser, M. (1999). Tilapia life story and biology. Southern Regional Aquaculture Center Publication No. 283.

Sadekarpawar, S. and Parikh, P. (2013). Gonadosomatic and hepatosomatic indices of freshwater fish *Oreochromis mossambicus* in response to a plant nutrient. World J. Zool., 8 (1): 110-118.

Sarkar, M.R.U.; Khan, S., Haque, M.M. and Haq, M.S. (2006). Evaluation of growth and water quality in pangasiid catfish (*Pangasius hypophthalmus*) monoculture and polyculture with silver carp (*Hypophthalmichthys molitrix*). J. Bangladesh Agril. Univ. 4(2): 339-346.

Sarkar, M.R.U.; Khan, S., Haque, M.M., Khan, M.N.A. and Choi, J. (2008). Comparison of phytoplankton growth and species composition in pangasiid catfish monoculture and pangasiid catfish/silver carp polyculture ponds. J. Fish. Sci. Techno., 11(1): 15-22.

SAS, (2006). SAS procedure user's guide. SAS Institute Inc., Cary, NC, USA.

Shaker, I. M. A. and Mahmoud, A. A. (2007). The biological load of silver carp cages in the River Nile and their effects on water quality and growth performance. Egypt. J. Aquat. Biol. and Fish., 11 (2): 119-143.

Smith, D.W., (1989). The feeding selectivity of silver carp, *Hypophthalmichthys molitrix*. J. Fish Biol., 34: 819–828.

Soltan, M.A. (1998). Productive studies on tilapia fish. Ph.D. Thesis, Faculty of Agriculture, Moshtohor, Zagazig University, Banha branch, Egypt.

Starling, F.L.R.M. (1993). Control of eutrophication by silver carp, *Hypophthalmichthys molitrix*, in the tropical Paranoa Reservoir (Brasilia, Brazil): a mesocosm experiment. Hydrobiologia, 257: 143– 152.

Sweilum, M.A. (1995). Studies on rearing of some available species of carp and tilapia in ponds. Ph.D. Thesis, Faculty of Science, Benha University, Egypt.

Sweilum, M.A. (1998 a). Observations on growth and production of *Oreochromis niloticus* reared in floating cages. Bull. Fac. Sci., Zagazig Univ., 20 (1): 224-238.

Sweilum, M.A. (1998 b). Comparison of silver carp and common carp usefulness as additional fish in tilapia rearing ponds. Bull. Fac. Sci., Zagazig Univ., 20 (2): 288-299.

Sweilum, M.A. (2001). Growth performance and production of *Oreochromis niloticus* using polyculture systems and fertilizers. Egypt. J. Aquat. Biol. and Fish., 5 (2): 105-119.

Tacon, A.G.J. and Hasan, M.R. (2007). Global synthesis of feeds and nutrients for sustainable aquaculture development. In: Hasan, M.R.; Hecht, T., De Silva, S.S. and Tacon, A.G.J. (Eds.). Study and analysis of feeds and fertilizers for sustainable aquaculture development. FAO Fish. Tech. Pap., 497: 3-17.

Tseng, W.Y. and Chan, K.L. (1982). The reproductive biology of the rabbit fish in Hong Kong. J. World Maricul. Soc., 13: 313-321.

Turker, H.; Eversole, A.G. and Brune, D.E. (2003 a). Effect of temperature and phytoplankton concentration on Nile tilapia *Oreochromis niloticus* (L.) filtration rate. Aqua. Res., 34:453–459.

Turker, H.; Eversole, A.G. and Brune, D.E. (2003 b). Effect of Nile tilapia, *Oreochromis niloticus* (L.), size on phytoplankton filtration rate. Aqua. Res., 34:1087–1091.

Wootton, R.J. (1992). Growth in Fish Ecology. Tertiary Biology. Chapman and Hall (Publishers), New York, USA, pp: 124-127.

ARABIC SUMMARY

تأثير نظامي الاستزراع الأحادي أو المتعدد على جودة المياه ، أداء النمو والكفاءة الاقتصادية لأسماك البلطي النيلي والمبروك الفضي

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الهدف من هذه الدراسة هو دراسة تأثير الإحلال المتدرج في كثافة التخزين (صفر ، ٤ ، ٨ و١٢%) لأسماك البلطي النيلي وحيد الجنس بأسماك المبروك الفضي كنظم استزراع آحادي (المعاملة الأولي) أو متعدد (المعاملات الثانية ، الثالثة والرابعة على التوالي) لمدة ١٢٤ يوم (٤ شهور) علي قياسات جودة المياه ، كفاءة النمو والاستفادة من الغذاء ، معامل الحالة ، دلائل الأعضاء ، تركيب الجسم ، بجانب تقييم الإنتاج الكلي للبلطي النيلي ، الكفاءة الاقتصادية في كل معاملة. ُأجريت هذه التجربة الحقلية فى أقفاص شبكية طافية ومغطاة فى بحيرة المنزلة. أوضحت النتائج المتحصل عليها التأثيرات الإيجابية لاستزراع البلطي النيلي في نظم الاستزراع المتعدد مع المبروك الفضي مقارنة بالاستزراع الآحادي للبلطي النيلي. حيث أن الاستزراع المتعدد للبلطي النيلي مع معدل تخزين ٤% (المعاملة الثانية) أو ٨% مبروك فضي (المعاملة الثالثة) كانتا أفضل معنوياً من حيث قياسات كفاءة النمو والاستفادة من الغذاء (الغذاء المستهلك ، كفاءة تحويل الغذاء ، الاستفادة من البروتين والطاقة) و تركيب الجسم (البروتين الخام ، الدهن الخام و محتوى الطاقة) لكلا النوعين من الأسماك. بينما أسماك البلطي النيلي المستزرعة في نظام متعدد مع معدل تخزين ١٢% مبروك فضي (المعاملة الرابعة) حققت أعلى دخل مادي ، صافى ربح وكفاءة اقتصادية بين كل المعاملات التجريبية سواء نظام آحادي الاستزراع (المعاملة الأولي) أو نظم الاستزراع المتعدد (المعاملتين الثانية والثالثة). وبالتالي يمكن التوصية بأن البلطي النيلي المستزرع بالنظام المتعدد مع ٤% (المعاملة الثانية) أو ٨% مبروك فضي (المعاملة الثالثة) كانتا أفضل معاملتين مقارنة بالاستزراع الآحادي للبلطي النيلي (المعاملة الأولي) أو الاستزراع المتعدد مع معدل تخزين ١٢% مبروك فضي (المعاملة الرابعة). لكن اقتصاديًا استزراع البلطي النيلي في نظام متعدد مع معدل تخزين ١٢% مبروك فضي (المعاملة الرابعة) كان أفضل نظام استزراع بين كل النظم التجريبية.