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Impact of Mono- and Polyculture Systems on Growth Performance, Feed Utilization, and Economic Efficiency of *Oreochromis niloticus*, *Mugil cephalus*, and *Mugil capito*

Mehrim, A. I.; M. M. Refaey; F. F. Khalil and Zohour E. M. Shaban
Animal Production Department, Faculty of Agriculture, Mansoura University, Mansoura, Egypt.

ABSTRACT

A field study was conducted to assess the effect of mono- and polyculture systems in net Hapas of monosex Nile tilapia (*Oreochromis niloticus*), striped mullet (*Mugil cephalus)* and /or thin-lipped mullet (*M. capito*) at different stocking ratios on growth performance, feed efficiency, chemical composition of the whole body, and economic efficiency parameters of experimental fish for 107 days rearing period. Five experimental treatments were represented as 100% Nile tilapia (T_1, monoculture); 75% Nile tilapia: 25% striped mullet (T_2, polyculture); 75% Nile tilapia: 13% striped mullet: 12% thin-lipped mullet (T_3, polyculture); 50% Nile tilapia: 50% striped mullet (T_4, polyculture) and 100% striped mullet (T_5, monoculture). Fish of T_2 showed the highest significant of all growth performance, feed utilization, and economic efficiency parameters followed by the same fish species reared in polyculture system (T_4) at stocking ratio (50%: 50%) compared to other experimental fish-culture systems. Generally, it could be recommended that rearing monosex *O. niloticus* in polyculture system with *M. cephalus* at stocking ratio 75%: 25%, respectively (T_2) is more effective than other aquaculture systems under the experimental conditions of the present study.

Keywords: Nile tilapia, Striped mullet, Polyculture, Growth performance, Economic efficiency.

INTRODUCTION

In recent years, aquaculture is the main resource of increasing fish production to meet the increasing demand for fish protein, especially after the stability of productivity from capture fisheries (FAO, 2009). Based on FAO statistics, the increase of fish production from aquaculture led to an increase in per capita consumption of fish to 20.3 kg in 2016 compared to 9 kg in 1961 (FAO, 2018). The growing of aquaculture in Egypt has gradually increased over the past few years (Suloma and Ogata, 2006). Egypt's national development strategy includes the objectives of increasing the annual per-capita consumption of fish and confirming the accessibility of affordable fish to the consumer by increasing the national production (Suloma and Ogata, 2006). In Egypt, aquaculture has become the main source of fish protein to cope with the country's growing population. Currently, the total fish production in Egypt increased from 724,300 ton in 2000 to 1,762,174 ton in 2016 (GAFRD, 2016).

The development of aquaculture systems and technology aims to increase productivity and minimizing the environmental impacts of aquaculture to ensure food safety and sustainability (Bakeer *et al*., 2008). Also, due to limited sources of freshwater in Egypt, the development and increase of the aquaculture production can be achieved through higher fish stocking density, the application of artificial feeding, and especially through the popularly applicable the polyculture system of different fish species (Abdel-Hakim *et al*., 2012). Earthen ponds are the major fish-farming system in Egypt. Most ponds are supplied by water with irrigation drainage canals and cultured using semi-intensive methods either as monocultures of Nile tilapia or polyculture of tilapia and other fish species such as mullet and carp (GAFRD, 2014). Polyculture is one strategy can considerably enhance fish production yields by optimizing the use of available resources (Landau, 1992 and Ponce-Marbán *et al*., 2006). Polyculture is also referred to as multi-trophic aquaculture, coculture or simply integrated aquaculture, which consists of adding one or more fish species to the culture system of the main species (Lanza-Espino *et al*., 1991 and Bunting, 2008). In addition, polyculture can provide benefits impacts related to progressive ecological stability and function (Gooley and Gavine, 2003). Additionally, polyculture is one approach to developing aquaculture. Most of the aquaculture production in Egypt is pond-based using polyculture farming techniques (GAFRD, 2010).

Nile tilapia (*Oreochromis niloticus*) are usually reared in polyculture systems with different species such as common carp *Cyprinus carpio* (Papoutsoglou *et al*., 1992; Karplus *et al*., 1996 and Abdel-Hakim *et al*., 2012), striped mullet *Mugil cephalus* (Abou Zied *et al*., 2005; Abdel-Hakim *et al*., 2006; El-Dahhar *et al*., 2006 and Tahoun *et al*., 2013), African catfish (Liti *et al*., 2002; Ibrahim and El Naggar, 2010 and Shoko *et al*., 2014), milkfish *Chanos chanos* (Cruz and Laudencia, 1980), shrimp (Yi *et al*., 2002; Kotiya Anil *et al*., 2010 and Hernández-Barraza *et al*., 2012), and European eel, *Anguilla anguilla* (Abdel-Hakim *et al*., 2000 & 2001). However, the polyculture systems of Nile tilapia, with striped mullet and thin-lipped mullet are rarely studied. Therefore, the present study was designed to assess the effect of mono- and polyculture systems in net Hapas of monosex Nile tilapia (*O. niloticus*), striped mullet (*M. cephalus)* and / or thin-lipped mullet (*M. capito*) at different stocking ratio for 107 days, regarding the growth performance, feed efficiency, chemical composition of the whole body fish, and economic efficiency parameters.

MATERIALS AND METHODS

The experimental fish:

Six hundred monosex Nile tilapia fingerlings with an average initial body weight 110 ± 3.55 g were purchased from the private fish farm, San El-Baharia, Egypt. While, striped mullet and thin-lipped mullet were purchased from a private fish farm of El-hajj Eid Shaban at the same district (San El-baharia, El-hosania, Al-Sharqia governorate, Egypt), with an average initial body weights 66 ± 1.62 g and 70 ± 2.49 g, respectively. The experimental fish of the three species were adapted in net Hapas for two weeks.

After the adaptation period, each fish species was weighed and then randomly distributed and stocked at 100 fish in each net Hapas (3 m length × 2 m width × 1.5 m depth; total volume 9 m^3) at different stocking ratios of fish species. Hapas were constructed and implanted in 1 Feddan (Egyptian area unit = 4200 m^2) earthen pond in a private fish farm (of El-hajj Eid Shaban). This study was designed to include five experimental treatments as described in Table 1; each treatment comprised two net Hapas.

Table 1. Details of the experimental treatments

Treatment	Fish Species
T_1	100 Tilapia
T_2	75 Tilapia + 25 Striped mullet
T_3	75 Tilapia + 13 Striped mullet + 12 Thin-lipped mullet
T_4	50 Tilapia + 50 Striped mullet
T_5	100 Striped mullet

Feeding system:

Fish in all treatments were fed the same commercial pelleted diet contains (30.95% crude protein and 4.35% crude fat), which purchased from Zoo Control Industrialization and Trade Factory belonging to the industrial zone 6 of October, Cairo, Egypt. This commercial diet consisted of soybean meal (44%), yellow corn, wheatgrass grinders, herring fish meal (72%), corn gluten (60%), lime stone, dicalcium phosphate, a mixture of mineral salts, a mixture of vitamins, fish oil, and soybean oil, according to the manufacturer's formula. The diet was manually offered to experimental fish twice daily at 8.30 a.m. and 15.00 p.m. The percentage of feeding rate was 4 - 3% of the biomass of fish species in each Hapa. The feed amount was adjusted biweekly according to the actual biomass in each Hapa.

The experimental parameters:

Growth performance and feed utilization:

At the end of experiment, body weight of monosex Nile tilapia, striped mullet and thin-lipped mullet in each Hapa were measured to calculate the growth performance and feed utilization such as total weight gain (TWG, g), average weight gain (ADG, g/fish/day), relative growth rate (RGR, %), specific growth rate (SGR, %/day), feed intake (FI, g), feed conversion ratio (FCR), feed efficiency (FE, %), protein efficiency ratio (PER, %), protein productive value (PPV, %) and energy utilization (EU, %) according to Halver and Hardy (2002). For chemical analysis of the whole fish body, fish samples (*n* = 3 / each fish species in each Hapa) were taken from each Hapa 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).

Economic efficiency:

At the end of the experiment, total production of all fish species in each treatment (kg) was calculated according to the total weight gain costs (as output). For input, the cost (LE) of fingerlings and food consumption costs are input, regardless of any other costs. The total yield of *O. niloticus* was classified according to body weight to two sizes; size 1 ranged from 413.8 to 570 g (average = 460.3 g) and size 2 ranged from 250 to 385 g (average = 302.6 g) in each Hapa.

Statistical analysis:

The obtained data such as growth performance and chemical composition of the whole fish body in each of Nile tilapia, striped mullet, and thin-lipped mullet , as well as feed utilization and economic efficiency were subjected to one-way analysis of variance (ANOVA) using (SAS, 2006) version 9.1.3. All ratios and percentages were arcsine-transformed earlier to statistical examines. Mean of each treatment were statistically compared for the significance ($P \leq 0.05$) using Duncan's multiple range test (Duncan, 1955).

RESULTS

Growth performance parameters of Nile tilapia:

O. niloticus reared in polyculture system with *M. cephalus* at stocking ratio 75%: 25% (T_2) achieved the highest significant ($P \leq 0.05$) of all tested growth performance parameters followed by the same fish species reared in polyculture system (T_4) at stocking ratio (50%: 50%) compared to other mono- (T_1) and polyculture systems with *M. cephalus,* and *M. capito* at stocking ratio 75%, 13%, and 12%, respectively (T_3) (Table 2).

Table 2. Effect of mono- and polyculture systems on growth performance parameters of Nile tilapia

Treatments	FW (g)	TWG (g)	ADG (g/fish/day)	RGR (%)	SGR (%/day)
T_1	$371.5^c \pm 9.84$	$261.5^c \pm 9.84$	$2.44^c \pm 0.09$	$237.8^c \pm 8.95$	$1.14^c \pm 0.03$
T_2	$486.7^a \pm 18.33$	$376.7^a \pm 18.33$	$3.52^a \pm 0.17$	$342.4^a \pm 16.66$	$1.39^a \pm 0.03$
T_3	$359.4^c \pm 6.96$	$249.3^c \pm 6.96$	$2.33^c \pm 0.06$	$226.8^c \pm 6.33$	$1.11^c \pm 0.02$
T_4	$431.5^b \pm 17.06$	$321.5^b \pm 17.06$	$3.01^b \pm 0.16$	$292.3^b \pm 15.52$	$1.28^b \pm 0.04$

a,b,c: Mean in the same column having different small letters are significantly different ($P \leq 0.05$). FW: Final body weight; TWG: Total weight gain; ADG: Average weight gain; RGR: Relative growth rate; SGR: Specific growth rate.

Feed utilization parameters of Nile tilapia:

Table 3 illustrates the feed utilization parameters of Nile tilapia reared in mono- and polyculture systems. *O. niloticus* reared in polyculture system with *M. cephalus* at stocking ratio (75%: 25%, respectively, T_2) reflected significantly ($P \leq 0.05$) increased FE (%), PER, and PPV (%), as well as it had the better FCR followed by the same fish species reared in polyculture system (T_4) at stocking ratio (50%: 50%) compared to other mono- (T_1) and polyculture (T_3) systems. However, *O. niloticus* reared in polyculture system with *M. cephalus* at stocking ratio (50%: 50%, T_4) was responsible for significantly ($P \leq 0.05$) increased FI and EU followed by the same fish species reared in polyculture system (T_2) at stocking ratio (75% *O. niloticus*: 25% *M. cephalus*) compared to other mono (T_1) -and polyculture (T_3) systems.

Table 3. Effect of mono- and polyculture systems on feed utilization parameters of Nile tilapia

Treatments	FI (g)	FCR	FE (%)	PER	PPV (%)	EU (%)
T_1	$479.7^c \pm 0.00$	$1.84^a \pm 0.07$	$54.52^b \pm 2.05$	$1.46^b \pm 0.05$	$20.42^c \pm 0.80$	$20.34^b \pm 0.74$
T_2	$520.9^b \pm 0.00$	$1.39^b \pm 0.07$	$72.32^a \pm 3.52$	$1.94^a \pm 0.09$	$33.64^a \pm 1.61$	$24.96^b \pm 1.53$
T_3	$464.4^d \pm 0.00$	$1.87^a \pm 0.05$	$53.70^b \pm 1.50$	$1.44^b \pm 0.04$	$25.03^b \pm 0.68$	$32.33^a \pm 0.76$
T_4	$541.5^a \pm 0.00$	$1.70^a \pm 0.09$	$59.38^b \pm 3.15$	$1.59^b \pm 0.08$	$30.44^a \pm 1.55$	$35.53^a \pm 1.61$

a, b, c, d: Mean in the same column having different small letters are significantly different ($P \leq 0.05$). FI: feed intake; FCR: feed conversion ratio; FE: feed efficiency; PER: protein efficiency ratio; PPV: protein productive value; EU: energy utilization.

Chemical composition parameters of Nile tilapia:

The highest significant (P ≤ 0.05) fat (%) and energy content (KJ/100g DM) were detected in *O. niloticus* reared in polyculture system with *M. cephalus,* and *M. capito* at stocking ratio 75%, 13%, and 12%, respectively (T_3) compared to other treatments (Table 4). Where, the highest significant (P ≤ 0.05) crude protein (%) was noticed in *O. niloticus* reared in polyculture system with *M. cephalus* at stocking ratio (75%: 25%, respectively, T_2) compared to other treatments. However, the dry matter content (%) was significantly (P ≤ 0.05) higher in *O. niloticus* reared in polyculture system with *M. cephalus* at stocking ratio (50%: 50%, respectively, T_4) compared to other treatments. Meanwhile, ash content was significantly (P ≤ 0.05) increased in *O. niloticus* reared in monoculture system at stocking ratio (100%) among all treatments.

Growth performance parameters of striped mullet and thin-lipped mullet:

The obtained findings revealed that *M. cephalus* (25%) reared in polyculture system with 75% *O. niloticus* (T_2) achieved the highest significant (P ≤ 0.05) of all tested growth performance parameters followed by *M. cephalus* reared in polyculture system with *O. niloticus*, and *M. capito* (T_3) at stocking ratio (13%: 75%: 12%, respectively) compared to other polyculture (T_4) and monoculture (T_5) systems (Table 5). For thin-lipped mullet reared in polyculture system (T_3) give average of FW = 144.5 g, TWG = 74.5 g, ADG = 0.69 g/fish/day, RGR = 106.1% and SGR = 0.67%/day compared with the average of initial weight (70 ± 2.49 g).

Table 4. Effect of mono- and polyculture systems on chemical composition parameters of Nile tilapia

Treatments	DM (%)	On dry matter basis			
		Ash (%)	Fat (%)	Protein (%)	EC (KJ/100g)
T_1	25.33^d ±0.25	17.89^a ±0.33	24.63^d ±0.01	57.48^b ±0.33	2330^d ±1.93
T_2	28.59^c ±0.21	12.78^b ±0.26	27.63^c ±0.01	59.59^a ±0.26	2498^c ±1.42
T_3	31.75^b ±0.05	12.25^b ±0.61	34.37^a ±0.18	53.38^b ±0.79	2618^a ±2.71
T_4	32.59^a ±0.14	12.12^b ±0.07	31.69^b ±0.14	56.19^c ±0.12	2578^b ±0.80

a, b, c, d: Mean in the same column having different small letters are significantly different (P ≤ 0.05). DM: Dry matter, and EC: Energy content.

Table 5. Effect of mono- and polyculture systems on growth performance parameters of striped mullet

Treatments	FW (g)	TWG (g)	ADG (g/fish/day)	RGR (%)	SGR (%/day)
T_2	338.7^a ±93.68	272.8^a ±33.68	2.55^a ±0.88	413.3^a ±41.97	1.41^a ±0.28
T_3	234.6^b ±32.97	168.6^b ±32.97	1.58^b ±0.31	255.4^b ±49.94	1.16^b ±0.14
T_4	180.8^c ±11.11	114.8^c ±11.11	1.07^c ±0.10	173.9^c ±16.80	0.94^c ±0.06
T_5	163.5^c ±13.83	97.53^c ±13.84	0.91^c ±0.13	147.7^c ±20.99	0.84^c ±0.08

a, b, c: Mean in the same column having different small letters are significantly different (P ≤ 0.05). FW: Final body weight; TWG: Total weight gain; ADG: Average weight gain; RGR: Relative growth rate; SGR: Specific growth rate.

Chemical composition parameters of striped mullet and thin-lipped mullet:

M. cephalus reared in monoculture system (T_5) achieved significantly (P ≤ 0.05) the highest content of dry matter (%), crude protein (%), and energy content (KJ / 100g DM) among all experimental polyculture systems (T_2, T_3, and T_4, Table 6). However, fat and ash contents significantly (P ≤ 0.05) increased in T_2 and T_4, respectively compared to other treatments. With regard, the chemical composition of the whole thin-lipped mullet body reared in polyculture system (T_3) results appeared 33.11% DM, 12.44% ash, 35.69% fat, 51.87% crude protein, and 2634 KJ/100g EC at the end of the experiment.

Table 6. Effect of mono- and polyculture systems on chemical composition parameters of striped mullet

Treatments	DM (%)	On dry matter basis			
		Ash (%)	Fat (%)	Protein (%)	EC (KJ/100g)
T_2	31.45^b ±0.16	14.57^{ab} ±0.09	33.04^a ±0.00	52.39^d ±0.10	2542^b ±0.52
T_3	31.51^b ±0.03	14.27^b ±0.39	31.07^c ±0.19	54.66^b ±0.20	2518^c ±2.94
T_4	29.49^c ±0.24	15.26^a ±0.11	31.28^c ±0.03	53.46^c ±0.13	2498^c ±0.59
T_5	32.88^a ±0.13	11.66^c ±0.12	32.47^b ±0.09	55.87^a ±0.21	2602^a ±0.35

a, b, c, d: Mean in the same column having different small letters are significantly different (P ≤ 0.05). DM: Dry matter, and EC: Energy content.

Graded size parameters of Nile tilapia:

The graded size No. 1 basis on fish weight (%) of *O. niloticus* reared in polyculture system with *M. cephalus,* at stocking ratio 75%, and 25%, respectively (T_2) increased significantly (P ≤ 0.05) compared to those reared in mono and polyculture systems (Table 7). Meanwhile, *O. niloticus* reared in polyculture system with *M. cephalus,* and *M. capito* at stocking ratio 75%, 13%, and 12%, respectively (T_3) achieved significantly (P ≤ 0.05) the highest size No.2 based on fish weight (%) compared to those reared in polyculture (T_2) and monoculture (T_1) systems, and with insignificant (P ≥ 0.05) difference in case of *O. niloticus* reared in polyculture system (T_4).

Table 7. Effect of mono- and polyculture systems on graded size parameters of Nile tilapia

Parameters	On fish weight basis (%)			
	T_1	T_2	T_3	T_4
Size No.1*	85.29^a ±0.79	85.49^a ±2.14	73.77^b ±3.87	81.93^{ab} ±3.46
Size No. 2**	14.71^b ±0.79	14.51^b ±2.14	26.23^a ±3.87	18.07^{ab} ±3.46

a, b: Mean in the same row having different small letters are significantly different (P ≤ 0.05).
*** Size No.1: fish weight ranged 413.8 – 570 g (average = 460.3 g)**
**** Size No. 2: fish weight ranged 250 – 385 g (average = 302.6 g)**

Economic efficiency parameters:

Fish (*O. niloticus* and *M. cephalus*) reared in polyculture system at stocking ratio 75%, and 25%, respectively (T_2) had significantly ($P \leq 0.05$) increased total outputs, net return, and economic efficiency parameters among all experimental aquaculture systems (Table 8). Meanwhile, *M. cephalus* reared in monoculture system (T_5) significantly ($P \leq 0.05$) achieved the highest total costs and the negatively lowest total outputs, net return, and economic efficiency parameters among all the experimental polyculture (T_2, T_3, T_4) systems or even monoculture (T_1) system of *O. niloticus*.

Table 8. Effect of mono- and polyculture systems of experimental fish on economic efficiency parameters

Treatments	Total costs[1]	Total outputs[2]	Net return[3]	Economic efficiency[4]
T_1	$322.6^d \pm 0.00$	$590.8^b \pm 12.5$	$268.2^b \pm 12.5$	$83.2^b \pm 3.88$
T_2	$356.0^c \pm 0.00$	$665.1^a \pm 20.6$	$309.0^a \pm 20.5$	$86.8^a \pm 5.77$
T_3	$311.9^e \pm 0.00$	$481.8^c \pm 18.4$	$169.9^c \pm 18.4$	$54.5^c \pm 5.91$
T_4	$369.3^b \pm 0.00$	$377.7^d \pm 30.6$	$30.6^d \pm 0.60$	$8.3^d \pm 1.28$
T_5	$380.4^a \pm 0.00$	$309.1^d \pm 0.0$	$-71.3^e \pm 0.04$	$-18.7^e \pm 0.00$

a, b, c, d, e: Mean in the same column having different small letters are significantly different ($P \leq 0.05$).
1- Total costs per treatment (LE) = Total cost of feeds per treatment* + Total cost of fingerlings per treatment**
*** Total cost of feeds per treatment (LE) = feed costs per one kg diet × feed intake (Kg)**
**** Total cost of fingerlings per treatment (LE) = the cost of fingerlings / each species per treatment × number fish species in each treatment**
2- Total outputs per treatments (LE / Kg) = fish price × total fish production
3- Total net return per treatments (LE) = total output – total costs
4- Economic efficiency per treatment (%) = (net return / total costs) × 100

DISCUSSION

Growth is the process of accumulation of flesh as a result of protein synthesis. Knowledge of fish growth is of energetic importance for obtaining the high yield of fish. The rate of growth differs from species to species and sometimes it differs even within the species also, as well as affected by many factors such as seasonality, fish species, availability of food and oxygen, stocking density, aquaculture system, and age (Dutta, 1994 and Viadero, 2005). In the present study, *O. niloticus* reared in polyculture system with *M. cephalus* at stocking rate 75%: 25%, respectively (T_2) achieved the highest significant of all growth performance parameters compared to other mono and poly culture systems. Improving growth performance may be related to mixed cultures between fish species which can show symbiotic effects and food supply for others. Natural feeds of all layers of a water body are properly utilized in polyculture system. Inversely, in monoculture system those feeds are not utilized (Ali *et al*., 2017). Tahoun *et al*. (2013) indicated that tilapia–mullet polyculture lead to improving water quality and increasing growth performance, which reflected enhancing the efficiency of natural food resources and system sustainability. The present obtained results are in accordance with the findings of Afifi *et al*. (1996); Abdel Hakim *et al*. (2000, 2001 and 2012); El-Dahhar *et al*. (2006) and El-Sagheer *et al.* (2008).

One possibility to explain the increased growth of fish in polyculture is based on the nutritional values contained in the food. Typical tilapia assimilation efficiency is 70% for protein and 51% for total energy (Bowen, 1982). Therefore, 30% of the protein and 49% of the energy would be available to mullet from tilapia feces. Additionally, the higher tilapia density or the higher feeding rate provides more protein and energy available for tilapia and mullet in the polyculture system. The uneaten feed and fecal matter from the tilapia result in better growth of mullet. With uneaten feed, some feed particles always reach the bottom where it becomes available to mullet. More importantly, the fecal matter from the tilapia contributes to the detrital rain that supports the mullet (Yi *et al.,* 2002). Consequently, the species farmed together in one pond as in polyculture technique, tolerate each other's presence, and each species also improves the growth and feed efficiency of the other species (Papoutsoglou *et al*., 1992).

Among the three tested species, Nile tilapia attained the highest ADG and SGR in comparison with striped mullet and thin-lipped grey mullet; there were no significant differences in growth of thin-lipped grey mullet or striped mullet stocked at different densities. This may be attributable to the fact that Nile tilapia grows faster than mullet. In a 150-d Nile tilapia–striped mullet polyculture trial, Nile tilapia exhibited SGRs of 1.76–1.98% per day, whereas the SGRs for striped mullet were 1.03–1.31% per day (Abou Zeid *et al*., 2005). Moreover, Milstein (1995) found that Nile tilapia demonstrated superior production and higher ADG in a polyculture system when Nile tilapia constituted the majority of cultured organisms in the pond and were farmed with shrimp and mullet. Moreover, Khalil *et al*. (2011) confirmed the superiority of Nile tilapia (*O. niloticus*) compared with other tilapia species (*Sarotherodon galilaeus* and *Tilapia zillii*) reared in polyculture system, regarding to growth performance parameters in all experimental cage's sites.

In the present study, *O. niloticus* reared in polyculture system with *M. cephalus* (at stocking ratio 75%: 25%, respectively, T_2) caused significantly increases of feed utilization parameters, and it had the better feed conversion ratio followed by the same fish species reared in polyculture system (T_4) at stocking ratio (50%: 50%) compared to other mono- (T_1) and polyculture (T_3) systems. This superiority of *O. niloticus* in feed utilization parameters due to the polyculture system with *M. cephalus* at different stocking ratio (75%: 25%, respectively, T_2; or 50%: 50% T_4), as well as it's potentially related with the highest growth performance parameters among other experimental aquaculture systems. In addition, this performance may be associated with positive trophic feeding interactions between the two fish species (Orina *et al*., 2018). As in the current findings regarding the positive effects of polyculture system of *O. niloticus* with *M. cephalus* on feed utilization parameters were also reported by Abou Zeid *et al*. (2005); Eid (2006) and Tahoun *et al*. (2013). In this respect, Abdel-Tawwab *et al*. (2005) attributed the positive effect of polyculture to the trophic divergence between species, where the favorite foods of mullet are diatoms, while Nile tilapia consumes mostly green algae and cyanobacteria. Furthermore, mullet excrete a significant amount of nutrients that promote the growth of phytoplankton, which as stated above is a primary food source for filter-feeding Nile tilapia (Brusle, 1981; Abdel-Tawwab *et al*., 2005 and Kang and Xian, 2008). This synergy in the tilapia–mullet polyculture system leads to an optimized use of the aquatic food web, a reduction in interspecific and intraspecific competition for food, and improvements in feed efficiency.

Generally, the present findings of *O. niloticus* chemical composition were took unclear trends between all treatments, which may be due to different fish rearing systems, feeding habits, and stocking ratio, which affected the biochemical contents in the body. Where, the polyculture of *O. niloticus*- *M. cephalus* at different stocking rate had significantly increased dry matter, crude protein, fat, and energy contents of *O. niloticus* compared to those reared in monoculture system. These positive effects may possibly relate with the highest growth performance and feed utilization of *O. niloticus* reared in the polyculture system with *M. cephalus* than monoculture system of *O. niloticus*. In agreement with the obtained findings herein, Khalil *et al*. (2008) concluded that the polyculture system of red tilapia and striped mullet reflected that higher mean of all growth performance parameters and body composition than fish reared under monoculture condition. In addition, the best stocking ratio between two species was 3 red tilapia: 1 striped mullet as gross production. Where, the polyculture is the only possible way of simultaneously producing more than one fish species from the same rearing space (Papoutsoglou *et al*., 2001). The principle of polyculture is based on the fact that cultured fish species feed different levels of food chain and environment (Milstein *et al*., 2002). The productivity of the aquatic system is thus increased by more efficiently utilizing ecological resources within the environment. 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 (Hassan, 2011).

These conflicting results may be related with different factors such as fish feeding habits, fish stocking ratio, and aquaculture systems. Where, the fish polyculture system as practiced in aquaculture *via* stocking of fish species of different food habits proved to be an important management tool in utilizing efficiently the natural food resources in fish pond. Synergistic interactions among fish species are manifested by higher growth and yield in polyculture than in monoculture (Karplus *et al*., 1996). The bases for these interactions are the increase of available food resources and the improvement of environmental conditions (Milstein, 1992). In this regard, Hepher (1988) stated that natural food organisms contain low energy, while protein is in excess; therefore, fish consuming only natural food have minimal fat and maximum protein accumulation in their body. These results are also in agreement with findings reported by Weatherley and Gill (1987); Jobling (1994) and Shearer (1994). In addition, Hassan (2011) stated that the chemical composition showed that tilapia and mullet fed zooplankton and reared in polyculture system had significantly higher contents of protein than other fish species fed with artificial feed. These results may be due to the high protein content in zooplankton than artificial feed diets.

Aquaculture plays an important role in the economy (Soliman and Yacout, 2015); where, the polyculture fish farms are well established systems that proved both productive and economic efficiency (Ibrahem *et al*., 2011). In the present study, fish (*O. niloticus* and *M. cephalus*) reared in polyculture systems at different stocking ratio, especially 75% and 25%, respectively (T_2) achieved the highest total outputs, net return, and economic efficiency parameters than those reared in monoculture system from each species (T_1 and T_5, respectively). These positive findings in economic efficiency parameters may be strongly relevant with the highest growth performance of both fish species, as well as the highest feed utilization, and graded size of *O. niloticus* reared in polyculture systems than those reared in monoculture system. In this regard, the high biomass production is attributable mainly to high-quality rearing conditions throughout the trial, such as feed and water quality provided by the daily water exchange and the weekly application of fertilizers. Furthermore, owing to the positive influence of striped mullet and thin-lipped grey mullet on water quality, the yield of Nile tilapia and the overall conversion rate of input nutrients were high in the polyculture ponds, consistent with other studies that have reported improvements in Nile tilapia and striped mullet production with economically value in polyculture systems (Milstein, 1995; Eid and El-Gamal, 1996; El-Sagheer, 2001 and Abdel-Tawwab *et al*., 2005). Similarly, Scorvo-Filho *et al*. (1995) found that the total biomass yield of striped mullet grown in a polyculture system with common carp was greater than that of striped mullet reared in a monoculture system. Also, Dankwa *et al*. (2004) reported that the economic efficiency and net return showed that the total income from polyculture was higher than those from the monoculture system. Furthermore, the economic and budget analyses revealed that tilapia–mullet polyculture is a feasible technique and can be ecological-friendly as well as economically attractive for tilapia farmers (Tahoun *et al*., 2013).

Polyculture of fishes plays a vital role for nutritional and economical aspects in the fish production (Ali *et al*., 2017). Where, the present findings regarding the economic efficiency parameters are in full agreement with those reported by Green and El Nagdy (1995) and Abdel-Hakim *et al.* (2000) who studied the polyculture system of tilapia, eel, and mullet. Also, Abdel-Hakim *et al*. (2006) indicated that feeding of the Nile tilapia in polyculture with mullet and common carp in earthen ponds at feeding level of 2.5% resulted the best economic efficiency. In contrary, Bakeer (2006) reported that *M. cephalus* reared in monoculture system with supplementary feeding recorded the highest profitability for the lowest stocking density rate of 1 fish/m^3. Where, the differences between their results and that obtained findings in the present study may be due to the differences of culture system, experimental management, fish feeding habits, feeding regime, fish species, age, stocking density, and initial bodyweight of cultured fish.

CONCLUSION

Based on the obtained results herein, it could be concluded that rearing *O. niloticus* in polyculture system with *M. cephalus* at stocking ratio 75%: 25%, respectively (T_2) is more effective than other aquaculture systems under the experimental conditions of the present study. Additionally, further studies are required for increased stocking density in polyculture technique with other fish species in pond culture.

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تأثير نظامي الاستزراع الأحادي والمتعدد على آداء النمو، الاستفادة الغذائية والكفاءة الإقتصادية لأسماك البلطي النيلي ، البوري الحر والطوباره

أحمد إسماعيل محرم ، محمد معاذ رفاعي ، فتحي فتوح خليل و زهور عيد محمد شعبان
قسم إنتاج الحيوان ، كلية الزراعة ، جامعة المنصورة ، المنصورة ، مصر

أجريت دراسة حقلية لتقييم تأثير نظامى الاستزراع الآحادى والمتعدد فى تحويطات شبكية (هابات) لأسماك البلطي النيلي، البوري الحر والطوباره بنسب تخزينية مختلفة على قياسات أداء النمو، الاستفادة الغذائية، التحليل الكيماوي للجسم والكفاءة الإقتصادية للأسماك التجريبية لمدة 107 يوما. مُثلت المعاملات التجريبية فى خمس معاملات كالآتى 100% بلطي نيلى (المعاملة الأولي، استزراع آحادى)، 75% بلطي نيلي : 25% بوري حر (المعاملة الثانية، استزراع متعدد)، 75% بلطي نيلي : 13% بوري حر : 12% طوباره (المعاملة الثالثة، استزراع متعدد)، 50% بلطي نيلي : 50% بوري حر (المعاملة الرابعة، استزراع متعدد) و 100% بوري حر (المعاملة الخامسة، أستزراع آحادي). أظهرت أسماك البلطي النيلي والبوري الحر التى تم زراعتها فى نظام متعدد بنسبة تخزينية 75% بلطي نيلي : 25% بوري حر (المعاملة الثانية، استزراع متعدد) أعلى معنوية فى كل قياسات أداء النمو، الاستفادة الغذائية والكفاءة الإقتصادية تليها نفس الأنواع السمكية التى تم زراعتها فى نظام متعدد (المعاملة الرابعة) بنسب تخزينية 50% : 50% مقارنة بنظم الاستزراع السمكي التجريبية الأخري. وبصفة عامة يمكن التوصية بأن زراعة أسماك البلطي النيلي وحيد الجنس فى نظام استزراع متعدد مع أسماك البوري الحر بنسبة تخزينية 75% : 25% على التوالي (المعاملة الثانية) هى الأكثر تأثيراً عن نُظم الاستزراع الأخري تحت الظروف التجريبية للدراسة الحالية.