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EFFECTS OF STOCKING DENSITY ON GROWTH PERFORMANCE OF NILE TILAPIA (*OREOCHROMIS NILOTICUS*) REARED IN THREE DIFFERENT CULTURE SYSTEMS.

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SUMMARY

Three experiments were conducted simultaneously to examine the effects of various stocking densities on growth performance, yield, and economic potential of *Oreochromis niloticus* when reared in three different culture systems: cages, tanks, concrete ponds. Each experiment was represented by two replicates and the treatments included six experimental fish groups stocked at densities of 50, 75, 100, 125, 150, and 200 fish /m^3. Fish in all experimental groups were fed on a formulated diet, containing 30% protein, twice a day at rate of 3% of live body weight throughout the 120 day experimental period. Fish in the individual experiments were weighed at 2-week intervals, and the parameters of weight gain, absolute growth rate, specific growth rate (SGR), feed conversion ratio (FCR), protein efficiency ratio (PER), and survival rate were recorded. Preliminary economic analyses of the various stocking densities in the different rearing units were performed.

The results demonstrated the relationship between stocking density versus growth performance, crop yield and estimated revenue. Maximum weight gain, survival rate, and economic efficiency were obtained at stocking densities of 50 and 75 fish /m^3 in the three culture systems examined. It has been concluded that the latter densities may represent the optimum stocking range for juvenile *O. niloticus* in terms of growth performance and economic efficiency. Although, greater biomass yields were achieved at higher densities, mean fish size and unit value of the yield decreased as density increased. Furthermore, efficiency of feed and protein utilization (FCR and PER) deteriorated significantly ($P<0.05$) at higher densities in all rearing systems. Therefore, density-linked effects seem to be more important than for the differences in rearing systems, which may suggest that changing rearing conditions do not necessarily compensate for such effects on growth depression in *O. niloticus*.

Keywords: Nile tilapia (*Oreochromis niloticus*), growth pereformance, stocking density, culture system

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INTRODUCTION

Stocking density is one of the most important factors affecting growth performance, yield, and revenue in fish culture practices. This has been described for almost all cultured fish species, and also for all types of rearing systems (Carr and Aldrich, 1982 and McGinty, 1991).

A survey of the available literature on stocking density of *O. niloticus*, indicated that optimum densities in different rearing systems need to be established. While Carro-Anzalotta and McGinty (1986) found that growth of *O. niloticus* in cages held in freshwater over 169 days on a 32% protein diet was negatively correlated with stocking density (250, 500, 750, and 1000 $/m^3$), Watanabe *et al.* (1990) reported that growth and feed conversion of red tilapia fed at two protein levels (28 and 32%) did not differ at densities ranging from 100 to 300 $/m^3$, therefore these authors suggested that higher densities could be possible. Several other workers have suggested much more moderate densities. For example, Moustafa (1993) examined growth and feed conversion *O. niloticus* (30 g average body weight) reared in cages at densities of 80, 100, 120, and 140 fish $/m^3$. He recommended a stocking density in the range 80 to 100 $/m^3$ for maximum growth performance and feed efficiency.

Comparisons of these results, however, are complicated by variations in experimental conditions (e.g., culture system, species, duration and feed quality) and differences in biomass densities attained. While a number of studies have examined the effects of stocking density on growth performance of tilapias under individual rearing systems, little information is available on such effects under different rearing conditions. Balarin and Hatton (1979) emphasized that in tilapia culture, there is an optimum stocking rate for maximum production in different rearing systems.

In the present study, the effect of stocking density on growth and feed conversion of *O. niloticus* reared under three culture conditions is assessed to investigate the validity of results under different rearing systems.

MATERIALS AND METHODS

Three experiments were simultaneously carried out at the Fish Research Centre, Suez Canal University. Six various densities were simultaneously examined in three different rearing systems. In experiment 1, cages (1x1x2.5 m; length x width x depth) provided with a 10 mm polyethylene mesh were utilized. The cages were placed in a cement pole with a continuous flow of freshwater. A total of 12 cages were stocked with mixed-sex tilapia fingerlings (*O. niloticus*) averaging 30.1 g body weight each. Fish were stocked at six densities of 50, 75, 100, 125, 150, and 200 $/m^3$, and each treatment was represented by two replicates. Dead fish were replaced to maintain stocking rates as planned. Experiment 2 was conducted in a total of twelve 12-m^3 concrete ponds (4x3x1 m; length x width x depth). Juvenile *O. niloticus* averaging 30 g mean body weight were stocked at 6 different stocking rates similar to that of experiment 1 (50, 75, 100, 125, 150, and 200 $/m^3$). Freshwater was continuously pumped to each pond and drain pipes were located opposite the influent water source on the pond bottoms. Due to the unavailability of enough numbers of juvenile fish similar in size to those of experiment 1 and 2, a smaller fish size averaging 15.5 g mean weight was utilized in experiment 3. These fish were randomly distributed at similar rate to that described in experiment 1&2 among twelve 200-l rectangle fiberglass tanks.

One source of water supply was utilized in the above experiments, and flow rates were carefully adjusted in the individual rearing units to provide approximately 1.6 litre /kg /m^3. Oxygen levels and temperature were monitored daily for all individual rearing units (oxygen-temperature meter, 56-NR 87 BB 203). Ammonia, nitrate, and pH were measured weekly (Hach-kit, and pH meter). Average water quality criteria were as follows: temperature, 27 °C; dissolved oxygen, 5.5, 5.6, and 5.7 in cages, concrete ponds, and tanks, respectively; pH, 7.3; total ammonia, 0.01 mg/l; and nitrite, 0.10 mg/l. Fish in all treatments were fed dry pellets containing 30.8% crude protein two times a day (08:00 and 16.00 h) at a rate of 3% of their body weight. Table 1 illustrates the composition and results of proximate analyses of the experimental diet. Fish in the individual experiments were weighed at 2-week intervals, and the amount of feed offered was adjusted accordingly. All the experiments were continued for 120 days.

Table 1. Composition and proximate analyses of the experimental diet.

Ingredients	%
Fish meal	20
Soybean meal	37
Ground yellow corn	29
Corn oil	05
Vitamin mixture(1)	01
Mineral mixture (1)	02
Cellulose	05
Carboxymethyl cellulose	01
Proximate analyses (%)	
Moisture	08.10
Crude Protein	30.80
Ether extract	09.90
Ash	07.80
Crude fiber	06.10
Nitrogen free extract	37.30
Gross energy (kcal/g)(2)	04.20
Cost /kg (L.E.)	01.30

(1) Vitamin and mineral mixture (NRC, 1977).

(2) Gross energy content were calculated based on 5.65 kcal /g, 9.45 kcal /g, and 4.1 kcal /g, for protein, lipid, and carbohydrate, respectively.

Absolute growth rate (g) was calculated from Total body gain/ Number of days; Specific growth rate SGR (%/day)= 100(ln Initial weight- ln Final weight)/ number of days; Feed conversion ratio (FCR)= Dry feed fed (g)/ Live weight gain (g); Protein efficiency ratio (PER)= Weight gain (g)/ Protein intake (g); Survival (%)= 100 (Final number of fish/ Initial number); Yield (kg /m^3 rearing water)= Average weight gain X Number of fish at the end of the experiment /1000.

Preliminary economic feasibility analyses were conducted on the results obtained from the various stocking densities. However, the purpose of these analyses was merely to indicate those densities which appeared to have better economic efficiency rather than to provide detailed economic budget information, therefore, a general revenue pattern was estimated for the various stocking rates. This broad-scale analysis was employed to identify those densities which appeared to offer potential economic return. The assumptions which were used to estimate the gross value of the final yield produced under various stocking rates include, average price of kg /fish for each size (L.E.), cost of kg gain (cost of kg food x feed conversion ratio), total cost (cost of kgain x yield), total revenue (price /kg x yield), and percentage of economic efficiency (total revenue / total cost x 100). The proposed estimates exclude the costs of construction for various rearing systems.

Statistical analysis was performed using statistical package (SAS, 1987). For each experiment, one way analysis of variance was carried out on the final body weights, average weight gain, absolute growth rate, specific growth rate (SGR), feed conversion ratio (FCR), and protein efficiency ratio (PER). Data transformation was made according to Sokal and Rohlf (1981). Duncan's multiple range test was used to compare means when significant F values of group treatments were observed. Difference in survival rates were analyzed for significance by a Chi-square test.

RESULTS AND DISCUSSION

Initial and final fish weights, average weight gain, absolute growth rate, SGR and yield of experiment 1 are summarized in Table 2. The figures represent the average of the two replicates considered together which were not significantly different from each other ($P>0.05$). Average initial fish weights varies in a narrow range (30.0 to 30.2 g) indicating that distribution of the experimental groups was completely random. Over the range of densities examined, stocking density did significantly ($P<0.05$) affect final fish weights in an inverse proportional relationship. Growth rates, expressed as mean individual growth rates, average weight gain, absolute growth rate (g/day), and average specific growth rates (SGR) during the experimental period (120 days), showed a similar trend to that of the final mean weights. Fish stocked at 50 fish /m^3 had significantly ($P<0.05$) higher SGR estimates when compared with other stocking densities (75, 100, 125, 150, and 200 fish /m^3). Nevertheless, SGR's of fish grown in the latter experimental groups were not significantly different ($P>0.05$).

Final fish biomass (kg /m^3) increased with increasing stocking density. Doubling the density from 50 to 100 fish /m^3 resulted in increased final yield from 6.34 kg /m^3 to 9.34 kg /m^3, the equivalent of 147% increase in production level. Additional increase in stocking density, however, did not show similar trends, and no significant differences ($P>0.05$) were detected among density rates of 100, 125, 150, and 200 fish /m^3 (Table 2). Correspondingly, Moustafa (1993) obtained a positive correlation between stocking density and final biomass in caged *O. niloticus*, however, fish held at high stocking densities were not able to reach marketable sizes in a six-month period.

Table 3 illustrates growth performance, efficiency of feed conversion, and results of preliminary economic evaluation of the different treatments in experiment 2. The figures in this table represent the average of the two replicates considered together which were not significantly different from each other ($P>0.05$). In accordance with the results of the first experiment, the effect of stocking density on growth performance was evident as indicated by the inverse relationship between density and different growth parameters. Stocking of juvenile *O. niloticus* (30 g average weight) in concrete ponds for 120 days at rates of 50, 75, 100, 125, 150, and 200 /m^3 resulted in average final weights of 150.1, 138.0, 126.1, 115.4, 102.1, and 91.4 g, respectively. Both fish final weights and averages of weight gain among the different treatments were significantly different (P<0.0.5).

Table 2. Growth performance of *O. niloticus* reared in cages at different dtocking densities.

Parameters	Stocking Densities (fish/m^3)					
	50	75	100	125	150	200
Av. Initial Weight (g)	030.1	030.0	030.0	030.1	030.1	30.10
Av. Final Weight (g)	162.1^{a}	150.0^{b}	128.6^{c}	122.5^{d}	102.1^{e}	87.7^{f}
Av. Weight Gain (g)	132.1^{a}	120.0^{b}	098.4^{c}	092.4^{d}	072.0^{e}	57.6^{f}
Absolute Growth Rate (g/day)	1.10^{a}	1.00^{b}	0.82^{c}	0.77^{d}	0.60^{e}	0.48^{f}
Specific growth rate (%/day)	1.40^{a}	1.34^{b}	1.21^{b}	1.17^{b}	1.02^{b}	0.89^{d}
Feed conversion ratio (FCR)	1.90^{a}	1.90^{a}	2.50^{b}	2.90^{c}	3.10^{d}	3.40^{e}
Protein efficiency ratio (PER)	1.70^{a}	1.71^{a}	1.29^{b}	1.11^{c}	1.04^{d}	0.95^{e}
Survival (%)	96^{a}	96^{a}	96^{a}	94^{a}	90^{b}	90^{b}
Yield (kg/m^3)	6.34^{a}	8.64^{b}	9.34^{c}	10.90^{c}	9.72^{c}	10.36^{c}
Price of kg fish (L.E.)	7	7	7	7	6	5
Cost of kg gain (L.E.)	2.47	2.47	3.25	3.77	4.03	4.42
Total cost (L.E.)	15.65	21.34	30.35	41.09	39.17	45.79
Total revenue (L.E.)	44.38	60.48	65.38	76.30	58.32	51.81
Economic efficiency (%)	283.57	283.41	215.38	185.68	148.88	113.12

* Figures in each row having the same superscript are not significantly different (P>0.05).

Table 3 .Growth performance of *O. niloticus* reared in concrete ponds at different stocking densities.

Parameters	Stocking Densities (fish/m^3)					
	50	75	100	125	150	200
Av. Initial Weight (g)	30.10	30.00	30.10	30.20	30.10	30.20
Av. Final Weight (g)	150.1^{a}	138.0^{b}	126.6^{c}	115.4^{d}	102.1^{e}	91.4^{f}
Av. Weight Gain (g)	120.0^{a}	108.0^{b}	96.4^{c}	85.2^{d}	72.0^{e}	61.2^{f}
Absolute Growth Rate (g/day)	1.00^{a}	0.90^{b}	0.82^{b}	0.71^{c}	0.60^{d}	0.51^{e}
Specific growth rate (%/day)	1.34^{a}	1.27^{b}	1.19^{bc}	1.12^{c}	1.02^{d}	0.92^{e}
Feed conversion ratio (FCR)	1.90^{a}	1.90^{a}	2.30^{b}	2.70^{c}	3.00^{d}	3.30^{e}
Protein efficiency ratio (PER)	1.70^{a}	1.71^{a}	1.41^{b}	1.20^{c}	1.08^{d}	0.98^{e}
Survival (%)	96^{a}	95^{a}	90^{b}	88^{c}	80^{d}	80^{d}
Yield (kg/m^3)	5.76	7.66	8.64	9.37	8.64	9.79
Price of kg fish (L.E.)	7	7	7	7	6	5
Cost of kg gain (L.E.)	2.47	2.47	3.99	3.51	3.90	4.29
Total cost (L.E.)	14.22	18.67	25.83	34.15	33.69	41.99
Total revenue (L.E.)	40.32	53.62	60.48	65.59	51.84	48.95
Economic efficiency (%)	283.54	287.19	234.14	192.06	153.87	116.57

* Figures in each row having the same superscript are not significantly different (P>0.05)

Averages of specific growth rates and absolute growth rates (g /day) for the same stocking densities cited above were 1.34, 1.27, 1.19, 1.12, 1.02, and 0.92; and 1.0, 0.9, 0.8, 0.71, 0.60, and 0.51, respectively, and differences among treatments were significant ($P<0.05$), favouring lower stocking rates. Furthermore, statistics of both specific growth rates and absolute growth rates reflect the main trends observed for weight gains and final weights.

Results of experiment 3 are summarized in Table 4, which include Initial and final fish weights, average weight gain, absolute growth rate, SGR, FCR, PER, survival rate%, and yield. Varying stocking rates of juvenile *O. niloticus* averaging 15.6 g produced, in general, similar results to those of the above experiments. The inverse relationship between density and different growth parameters which have been previously noted was apparent. However, it is interesting to observe that in contrary to the results of the experiment 1 and experiment 2, average final weights of fish stocked at densities of 50 and 75 /m^3 were not significantly different ($P>0.05$). This is probably due to the difference in the initial weights of this group compared to the above experiments (15.6 v. 30.1g), which may indicate that growth rates did not diverge until late in the study, and biomass densities reached certain levels, suggesting that inhibitory effects of high stocking densities emerged as biomass reached high levels.

Table 4. Growth performance of *O. niloticus* reared in fiberglass tanks at different stocking densities.

Parameter	Stocking Densities (fish/m^3)					
	50	75	100	125	150	200
Av. Initial Weight (g)	15.80	15.50	15.40	15.60	15.60	15.70
Av. Final Weight (g)	123.8^a	122.3^a	110.2^b	99.6^c	86.4^d	72.1^e
Av. Weight Gain (g)	108.0^a	106.8^a	94.8^b	84.0^c	70.8^d	56.4^e
Absolute Growth Rate (g/day)	1.10^a	1.0^b	0.82^c	0.77^d	0.60^e	0.48^f
Specific growth rate (%/day)	1.40^a	1.34^b	1.21^b	1.17^b	1.02^b	0.89^d
Feed conversion ratio (FCR)	1.90^a	1.90^a	2.50^b	2.90^c	3.10^d	3.40^e
Protein efficiency ratio (PER)	1.70^a	1.71^a	1.29^b	1.11^c	1.04^d	0.95^e
Survival (%)	96^a	96^a	96^a	94^a	90^b	90^b
Yield (kg/m^3)	6.34^a	8.64^b	9.34^c	10.90^c	9.72^c	10.36^c
Price of kg fish (L.E.)	7	7	7	7	6	5
Cost of kg gain (L.E.)	2.47	2.47	3.25	3.77	4.03	4.42
Total cost (L.E.)	15.65	21.34	30.35	41.09	39.17	45.79
Total revenue (L.E.)	44.38	60.48	65.38	76.30	58.32	51.81
Economic efficiency (%)	283.57	283.41	215.38	185.68	148.88	113.12

* Figures in each row having the same superscript are not significantly different ($P>0.05$).

The above results are in accordance with Coche (1977) who found that growth of *O. niloticus* in cages held in freshwater was negatively correlated with stocking densities ranging from 30 to 50 kg /m^3. Similarly, Moustafa (1993) reported that specific growth rates of *T. nilotica* (30.1 g average weight) fed on diets containing different protein levels (20 to 32%) in freshwater cages decreased linearly as stocking density increased (80, 100, 120, and 140 fish /m^3). Comparable results were obtained in concrete ponds when juvenile *O. niloticus* held at different stocking rates (Eid and Magouz, 1995).

The interrelation of a single fish "cohort" is affected by several factors that include species, size, and space. The relation that such factors bear to growth, and the way and the magnitude to which they interact with each other is primarily shaped by stocking density. Fish have evolved various defense mechanisms to face the severe competition for food and space resulting from increased fish numbers. These imply certain behavioural patterns involving defense and dominance, with their associated patrolling of territories and acts of aggression (Brett, 1979), which are usually density dependent (Fenderson and Carpenter, 1971). While few fish may benefit from such behavioural patterns, many of the low-ranking members must increase their energy expenditure to avoid counteracts with the dominant fish and to secure their feeds. Accordingly, a decreased growth rate with increasing density may attributed to reduced feed consumption (Vijayan and Leatherland, 1988), crowdedness and reduced living space that leads to fish disturbance during feeding and normal activities (Coche, 1977), increased energy-demanding activity levels connected with social interactions (Fenderson and Carpenter, 1971 and Li and Brocksen, 1977), and/ or suppression of growth in sub-ordinates by intimidation (Wirtz, 1974). Fish raised under high stocking densities may exhibit a stress response similar in nature to the General Adaptation Syndrome proposed for mammalian vertebrates (Schreck, 1981).

Brown (1957) emphasized the effect of space on fish growth rate when they were raised in aquaria of different sizes. Maximum growth was occurred in the larger space. Additionally, Yamagishi (1962) detected that growth rate of rainbow trout increased with an increase in the bottom area of the culture unit. Nonetheless, extensive work on the hypothesis of "living space effect" which was introduced as early as 1902 (Hoffbauer, 1902, cited by Meske, 1985) and attracted attention for a number of years (Mann, 1960; Krupauer, 1963; and Sager, 1963) has demolished it and introduced decisive evidence that demonstrate the independence of growth on space or volume (Sengbusch, 1965).

Swingle (1956) advocated that the so called "living space effect" is not necessarily responsible *per se* for limiting growth performance at high stocking densities, but it is possibly due to the presence of a hormone-like secretion or excretion that acted as a repressive growth factor. Several evidence have been accumulated over the recent years supporting the presence of a pheromone-like material in tilapia culture systems (Rappaport and Sarig, 1975 and Balarin and Haller,1979). Such effects, however, are different from these described by Chen and Prowse (1964) for the Malacca all-tilapia hybrid when fish were held either in small divided-off section of a pond where they grew slower than those kept in larger bodies of water, which is thought to be primarily linked with social interactions as mentioned earlier.

Rearing systems is of prime importance in determining exogenous conditions as well as other water quality criteria which are essentially related to culture conditions. Allen (1974) examined the growth obtained by stocking five densities, ranging from 90 to 720 fish/ m^3, of channel catfish. He found that the decrease in growth rate of fish raised at the higher density is almost entirely due to decreasing oxygen concentrations, which fell progressively as fish numbers increased. Therefore, considerable attention was made to evaluate water quality in the different rearing systems during the course of the present study. The results indicated that differences in water quality criteria among the different rearing systems and among different treatments in each system were not spacious, illustrating that water quality was not a major factor to blame. Therefore, it appears that it may well be crowding and not water quality that affected growth performance in the present study. It should also be mentioned that the present experimental design based on the assumption that volume of the rearing units *per se* do not affect growth rate, but it is the density that has the prime influence on growth performance of fish as exhaustive experiments in this respect demolished the so-called space factor effect (Meske, 1985).

Results of experiment 1 indicated that averages of feed conversion ratios (FCR) estimated for stocking densities of 50, 75, 100, 125, 150, and 200 fish /m^3 were 1.9, 1.9, 2.5, 2.9, 3.1, and 3.4, respectively. Furthermore, average protein efficiency ratios decreased as fish density increased with treatments means of 1.7, 1.71, 1.29, 1.11, 1.04, 0.95 for 50, 75, 100, 125, 150, and 200 fish/ m^3 densities, respectively (Table 2). Such feed and protein conversions reflect the suitability of the feed management employed in the present study and are similar to those reported by other workers, e.g., Jauncey and Ross (1982). FCR, and PER values obtained with treatments containing moderate densities (50 and 75 fish/m3) were not statistically different ($P>0.05$), but both 50 and 75 fish /m^3 treatments produced significantly ($P<0.05$) better values than those in other treatments. Further increase in stocking density resulted in higher FCR estimates (Table 2). Protein efficiency ratios (PER) showed similar trends to that for FCR's. Similarly, results of experiment 2 manifested that Juvenile *O. niloticus* reared in concrete ponds under low stocking rates (50 and 75/m^3) may utilize feed and dietary protein more efficiently than those reared under higher densities (100, 125, 150, and 200 /m^3), as indicated from both FCR and PER. Fish in the former groups, however, were more efficient, in this respect, when compared with those in the latter ones (Table 3).

Feed conversion and efficiency of protein utilization in experiment 3 were, in general, similar to that observed in the previous experiments (Table 4). Fish reared under low stocking rates (50 and 75 /m^3) utilized feed and dietary protein more efficiently ($P<0.05$) than these reared under moderate densities (100 and 125 fish/m^3) which in turn were better, in this respect, than those reared at the highest densities (150, and 200 /m^3). Table 4 shows that averages of feed conversion ratios (FCR) and protein efficiency ratios (PER) estimated for stocking densities of 50, 75, 100, 125, 150, and 200 fish /m^3 were 1.9, 1.9, 2.4, 2.9, 3.3, and 3.4; and 1.70, 1.71, 1.35, 1.11, 0.98, and 0.95, respectively.

The above results indicated that feed conversion and efficiency of protein utilization were comparable in the different culture systems. Similarly, Brett (1979) reported that highly crowded conditions resulted in reduced feed conversion efficiency. Furthermore, the present findings are in partial agreement with those obtained by Moustafa (1993) who observed that FCR and PER of caged *T. nilotica* increased in a linear manner with increasing stocking rates. The latter author, however, examined stocking densities above 75 fish /m^3. Therefore, it seems that FCR and PER in Nile tilapia could be chiefly affected when stocking rates exceed 75 fish /m^3. On the other hand, Watanabe *et al.* (1990) found that feed conversion efficiency of monosex Florida red tilapia held in cages did not differ at densities ranging from 100 to 300 fish /m^3. Correspondingly, Wannigama and Weerakoon (1983) and Wannigama *et al.* (1985) observed no differences in feed conversion of *O. niloticus* (22-30 g average weight) reared in cages over 120 days at densities of 400, 600, and 800 fish /m^3. While comparisons with such results are complicated by variations in experimental conditions (e.g., species, culture systems, initial fish size, differences in biomass attained, feed quality, water current speed, ..etc..), critical examination of the available literature suggest that conclusions derived from stocking density experiments on tilapia could be varied widely according to the prevailing conditions. Therefore, generalization of such conclusions could be very erroneous.

Reduced feed intake, feed conversion ratio (FCR), and protein utilization (PER) associated with high stocking rates are frequently reported in fish; e.g., in *Sarotherodon niloticus* (Moustafa, 1993), in Atlantic salmon (Halvorsen, 1987), in *Salvelinus fontinalis* (Vijayan and Leatherland, 1988), and in rainbow trout (Holm *et al.*, 1990). The latter authors concluded that stress and interaction effects in extremely dense rainbow trout cultures tend to reduce feeding and feed conversion efficiency. It seems that efficiency of feed conversion may decline as fish are forced to swim more actively under crowded conditions (Shepherd and Bromage, 1992). Symons (1970, 1971) reported increased energy-demanding activity levels connected with social interactions associated with behavioural adjustment of population density in Atlantic salmon. Metcalfe (1988) obtained a positive correlation between metabolic expenditure and feed intake influenced by social behaviour in fish, and this may explain the differences found in growth between different densities.

In experiment 1, stocking density did not affect survival rate until exceeds 150 fish/m^3, and no significant differences ($P>0.05$) were detected among densities ranged from 50 to 125 /m^3 (Table 2). Lowest survival was 90% in treatments stocked at 150 and 200 fish /m^3, which may be expected due to increased aggression and intraspecific competition. The results may suggest that the seriously harmful effects of high stocking densities in tilapia emerged as biomass reached high levels. Comparable results were reported for juvenile *O. niloticus* grown in freshwater cages (Carro-Anzalotta and McGinty, 1986). Working with Atlantic salmon and rainbow trout, Fenderson and Carpenter (1971) and Li and Brocksen (1977) reached similar conclusions, respectively. Comparable results were obtained in experiment 2, where a significant decrease ($P<0.05$) in survival rates were recorded among fish held under high stocking densities (150 and 200 /m^3) when compared to those kept under moderate stocking rates (100 and 125 /m^3), with best results were observed for fish reared under lower stocking rates of 50 and 75 fish /m^3 (Table 3).

Results of experiment 3 indicated that survival rate decreases with increasing density above 125 fish /m^3 (Table 4), lower and moderate densities, however, were not significantly affected ($P>0.05$). This result is not in consistency with that obtained from the former experiments (experiment 1&2), and may be related to the smaller initial sizes of fish in this experiment, therefore, total biomass in the individual rearing units was considerably less than that of the other experiments, resulting in improved rearing conditions. Furthermore, it is widely accepted that small fish could thigh degree of crowdedness compared with larger ones (Brett, 1979)), thus fish in this experiment showed a better tolerance to higher stocking densities.

Results of experiment 1 showed that maximum yield occurred at the highest stocking densities (125, 150, and 200 /m^3) but at the expense of individual mean weight. While total production can be increased by increasing stocking densities, the mean size of the harvested fish decreases. Consequentially, unit crop value is decreased while production costs for feed and seed are increased (Table 2). Thus, the highest total revenue was obtained with cages stocked at a moderate density of 125 /m^3. Maximum economic efficiency, however, was achieved with much lower densities (50 and 75 /m^3). Therefore, the present results suggest that stocking of juvenile *O. niloticus* at moderate densities (50 & 75 /m^3) may have an economic advantage over higher densities. Similarly, results of experiment 2 and experiment 3 showed a clear relationship between stocking density and crop yields and estimated revenues (Tables 4 & 5). Over the range of densities examined in experiment 2 **(Table 4) stocking density did positively $P<0.05$) affect production levels,** but consequentially the mean size of the harvested fish decreased, although not in a strictly proportional relationship. Increasing density 50% from 50 to 75 /m^3 resulted in a 33% increase in production level, while an additional 33% increase in density from 75 to 100/ m^3 produced only a 13% increase in total yield. As observed before, harvest size of fish was significantly influenced by stocking density with the more marketable fish sizes being produced at the lower densities of 50 and 75 fish /m^3. Thus, the unit crop value of the latter densities is increased and their economic efficiencies are improved.

The results of this study demonstrated that maximum production of marketable fish can be attained by stocking juveniles at moderate densities in the order of approximately 50 to 75 /m^3, which may represent the optimum stocking range for juvenile *O. niloticus* in terms of growth performance. The results also demonstrated that efficiency of production, in terms of net revenue, is higher at the above densities. Moustafa (1993) investigated the effects of stocking rates on growth performance of juvenile *O. niloticus* (average 30 g initial body weight) held in cages at densities ranging from 80 to 140 fish /m^3. He concluded that maximum yields would be obtained with densities ranging from 80 to 100 fish /m^3. Nevertheless, this author did not examine the effect of stocking rates below 80 fish /m^3. The current selected stocking densities (50, 75, 100, 125, 150, and 200 /m^3), however, bracketed these suggested densities and indicated that maximum growth performance is obtainable with densities below that recommended by Moustafa (1993). It may be advocated that should the latter author had examined the effect of lower stocking densities, he might have reached different conclusions.

Maximum biomass production is attainable by stocking fish at higher densities, e.g. 200 /m^3, which may favour a culture practice that include a selective harvesting of larger juveniles at an intermediate stage and transfer to other culture units to reduce biomass densities, improving the overall growth rate and maximizing net revenue. Such a culture scheme has been suggested for large operations cage culture of *O. niloticus* by other investigators (Campell, 1985), particularly the results of experiment 3 seem to imply that growth rate do not diminish until the biomass densities reach certain levels.

As discussed above, growth rate decreased significantly with higher densities at all rearing systems. Therefore, density-linked effects seem to be more important than for the differences in rearing systems, and changing rearing conditions did not compensate for such effects on growth depression. Similarly, Holm *et al.* (1990) were not able to compensate for density-linked growth depression in rainbow trout by enhanced feeding regimes (high frequency of feeding). This may be due to other stress and interaction effects discussed earlier, which tend to reduce growth performance, feeding, and feed conversion efficiency.

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تأثيرات الكثافة على النمو وأداء أسماك البلطى النيلى المربى تحت ثلاثة أنظمة مختلفة للإستزراع السمكى.

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أجريت ثلاث تجارب لدراسة تأثيرات الكثافات السمكية المختلفة على النمو وأداء أسماك البلطى النيلى من حيث الإنتاج والكفاءة الإقتصادية عند تربيتها فى ثلاث أنظمة مختلفة هى الأقفاص السمكية والأحواض الأسمنتية و أحواض الفيبر جلاس . إشتملت كل تجربة على مكررين تجريبيين تكون كل منهما من ٦ كثافات سمكية مختلفة هى ٥٠ ، ٧٥ ، ١٠٠ ، ١٢٥ ، ١٥٠ و ٢٠٠ سمكة فى المتر المكعب من المياة . غذيت الأسماك على عليقة موحدة تحتوى على ٣٠٪ من البروتين بواقع ٣٪ من وزن الجسم موزعة على مرتين فى اليوم الواحد وقد إستمرت التجربة ١٢٠ يوما. تم وزن الأسماك مرة كل إسبوعين و كذلك تسجيل البيانات الخاصة بالزيادة المطلقة فى الوزن ومعدل النمو النسبى و معدل التحويل الغذائى والكفاءة التحويلية للبروتين ومعدل النفوق. كذلك إجرى تحليل مبدئى لدراسة الكفاءة الإقتصادية للمعاملات المختلفة.

أوضحت الدراسة العلاقة بين النمو والإنتاج والعائد الإقتصادى للكثافات المختلفة للنظم المستخدمة فى هذة الدراسة ، وكان أفضلها من ناحية النمو والكفاءة التحويلية ومعدل النفوق والكفاءة الإقتصادية هى الكثافات التى تتراوح بين ٥٠ و ٧٥ سمكة فى المتر المكعب من الماء وذلك فىأنظمة الإنتاج المختلفة. ومع أن الإنتاج من حيث الكتلة الحية كان أعلى فى الكثافات الأكبر من ذلك إلا أن متوسط وزن الأسماك كان أقل من مثيلة فى الكثافات الأقل. كما لوحظ أن نظم التربية المختلفة لم تؤدى إلى إختلاف النتائج مما قد يعنى أن بعض التغييرات فى ظروف التربية لايمكنها أن تعوض التأثيرات المثبطة للنمو فى حالة الكثافات السمكية المرتفعة.