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INTEGRATED CAGE-CUM-POND CULTURE SYSTEMS WITH HIGH-VALUED SAHAR (*TOR PUTITORA*) IN CAGES SUSPENDED IN CARP POLYCULTURE PONDS

Eleventh Work Plan, Production System Design and Integration Research 3B (11PSDR3B)
Final Report

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ABSTRACT

This experiment was conducted for 150 days in 15 earthen ponds, 100 m^2 in surface area and 1.2 m in depth, at the Institute of Agriculture and Animal science (IAAS), Rampur, Chitwan, Nepal. One cage (1.5 x 1.5 x 1 m and water volume of 2-m^3) covered with 1-cm mesh net was suspended in each of the treatment ponds. There were one control and four treatments with three replicates each: carps at 1 fish m^{-2} in open ponds without cages (control); Sahar at 5 fish m^{-3} in cages and carps at 1 fish m^{-2} in open ponds (5 fish m^{-3}); (3) Sahar at 25 fish m^{-3} in cages and carps at 1 fish m^{-2} in open ponds (25 fish m^{-3}); Sahar at 50 fish m^{-3} in cages and carps at 1 fish m^{-2} in open ponds (50 fish m^{-3}); Sahar at 100 fish m^{-3} in cages and carps at 1 fish m^{-2} in open ponds (100 fish m^{-3}), giving ratios of caged to open-pond fish of 0:1, 0.1:1, 0.5:1, 1:1, and 2:1. Caged Sahar were fed with a locally made pelleted feed (28% crude protein), while no feed or fertilizer was added into open water of treatment ponds. The control ponds were fertilized weekly using DAP and urea at rates of 4 kg N and 2 kg P ha^{-1} d^{-1}.

Survival of Sahar was high without significant differences among treatments. Daily weight gains of Sahar, ranging from 0.11 to 0.25 g $fish^{-1}$, were significantly higher at low stocking densities of Sahar. Feed conversion ratio (FCR) of Sahar ranged from 2.2 to 2.8, and was not significantly different among treatments. The total net and gross yields of all carps were significantly higher in the control than in treatments. The total net and gross yields of carps in the control were significantly higher than the combined net and gross yields of Sahar and carps in all treatments. The overall FCRs in the treatments were 0.15–0.95, and were significantly better in the lower Sahar density treatments. The control and all treatments produced positive net returns, and the highest net returns were produced by the control, followed by treatments with high to low stocking density of Sahar.

This study demonstrated that high-valued Sahar has potential to be cultured in an integrated cage-cum-pond system, but it is necessary to fine-tune stocking ratios of Sahar to carps. This can be accomplished by adjusting stocking density of Sahar in cages, cage size, or cage number. Growth could also be improved by providing higher quality feed.

INTRODUCTION

Integrated cage-cum-pond culture is a system in which high-valued fish species in cages suspended in ponds are fed with artificial diets, and filter-feeding fish species are stocked in ponds to utilize natural foods derived from cage wastes. This integrated system has been developed and practiced using combinations of catfish-tilapia (Lin, 1990; Lin and Diana, 1995), tilapia-tilapia (Yi et al., 1996; Yi, 1997; Yi and Lin, 2000, 2001), and mixed-sex tilapia-

tilapia (Shrestha, 2002). Although cages were set up in Nile tilapia monoculture ponds in work mentioned above, this integration can also be applied in polyculture systems. In polyculture, ponds are stocked with several species of different feeding habits. It is impossible to target feeding to only high-valued species at large in ponds, because low-valued species consume the feed. Compared to the nutrient utilization efficiency of about 30% in most intensive culture systems (Beveridge and Phillips, 1993; Acosta-Nassar et al., 1994), the nutrient utilization efficiency could reach more than 50% in integrated cage-cum-pond systems, resulting in the release of less nutrients to receiving waters (Yi, 1997).

Rural pond aquaculture in Vietnam is mainly comprised of semi-intensive polyculture of both Indian major and Chinese carps with low average production. Pond production systems in many countries are increasingly reliant on external resources (feed and/or fertilizer) to supplement or stimulate autochthonous food production for fish. Such a system often discourages small-scale farmers because of low return on investment. On the other hand, poor farmers have limited financial resources to focus their whole ponds on the culture of high-valued species using expensive artificial feed. The integrated cage-cum-pond system provides an opportunity for small-scale farmers to use their limited resources to include some high-valued species in their ponds, to generate more income and improve their livelihood. This can be done while improving nutrient utilization efficiency, marketing high-valued species, and reducing fertilizer cost, because the open water can efficiently be supplied with cage wastes as fertilizer. This integrated system is environmentally friendly because fewer waste nutrients are released to the environment.

Sahar (*Tor putitora*) is native to trans-Himalayan zone (Ogale, 2002) and is one of the high-value indigenous fishes of Nepal. It is known to be declining from natural habitats due to ecological alterations (Shrestha, 1994). Being indigenous, it seems a good candidate for aquaculture (Bazaz and Keshavanatha, 1993). Sahar culture in ponds is not very successful, and Islam (2002) concluded that this species is not suitable for pond monoculture due to extremely high FCR (5–7). Sahar may be a suitable species to stock in cages suspended in ponds, with carps for using wastes from Sahar in order to develop an integrated cage-cum-pond culture system in Nepal.

The specific objectives of this study were to:

1) Adapt the integrated cage-cum-pond systems developed by Aquaculture CRSP to local conditions in Nepal;
2) Evaluate appropriate stocking densities for Sahar in cages;
3) Assess growth and production of Sahar in cages and carps in open ponds; and
4) Assess the economic and environmental values of this integrated cage-cum-pond system.

METHODS AND MATERIALS

This experiment was conducted 15 earthen ponds, 100 m^2 in surface area and 1.2 m in depth, at the Institute of Agriculture and Animal Science (IAAS), Rampur, Chitwan, Nepal. In the integrated cage-cum-pond system, one cage covered with 1-cm mesh net, 2.25 m^3 in volume (1.5 x 1.5 x 1 m), was suspended in each treatment pond. There were one control and four treatments with three replicates each: carps at 1 fish m^{-2} in open ponds without cages (control); Sahar at 5 fish m^{-3} in the cage and carps at 1 fish m^{-2} in open ponds (5 fish m^{-3}); (3) Sahar at 25 fish m^{-3} in the cage and carps at 1 fish m^{-2} in open ponds (25 fish m^{-3}); Sahar at 50 fish m^{-3} in the cage and carps at 1 fish m^{-2} in open ponds (50 fish m^{-3}); Sahar at 100 fish m^{-3} in the cage and carps at 1 fish m^{-2} in open ponds (100 fish m^{-3}), giving ratios of caged to open-pond fish of 0:1, 0.1:1, 0.5:1, 1:1, and 2:1. The control and treatments were allocated randomly in the ponds.

Newly excavated ponds were drained and filled with canal water two weeks before fish stocking. They were fertilized at 4 kg N and 2 kg P ha^{-1} d^{-1} for 7 days with diammonium phosphate (DAP) and urea. Prior to filling ponds, cages were placed at the center of the pond 15 cm above the bottom and supported by bamboo poles. A feeding tray was placed in each cage. A wooden platform was constructed to connect cages to the bank for feeding, cage monitoring, and water sampling. Water depth was maintained 1.05 m in all ponds by weekly topping with canal water to replace water loss to evaporation and seepage, while water depth in cages was 0.9 m, giving water volume of 2 m^3 in cages. A wooden depth gauge was fixed in the middle of each pond to measure water depth.

Sahar fingerlings (approximately 5 ± 0.0 g) were stocked in cages, while fingerling silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio* var. *communis*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*), and catla (*Catla catla*) (average weights 6.7 ± 0.2 g, 2.9 ± 0.0 g, 7.4 ± 0.2 g, 10.9 ± 0.3 g, 4.4 ± 0.1 g, 1.9 ± 0.0 g and 3.4 ± 0.0 g, respectively) were stocked in open ponds. The stocking ratio of silver carp, bighead carp, grass carp, common carp, rohu, mrigal, and catla was 4:1:1:1:1:1:1 in all ponds. Fish were stocked on 31 December 2003 and harvested on 29 May 2004. About 20% of Sahar and carps were sampled, counted and bulk weighed monthly during the experimental period.

Caged fish were fed twice daily at 0900–1000 h and 1500–1600 h, with a locally made pelleted feed (28% crude protein) at rates of 3% body weight per day, while no feed or fertilizer was added into open water of the treatment ponds. Feed rations were adjusted based on sampling weights and observed mortality of Sahar. Control ponds were fertilized weekly using DAP and urea at rates of 4 kg N and 2 kg P ha^{-1} d^{-1}. The cages and feeding trays were cleaned biweekly.

Weekly and biweekly measurements of water quality parameters were conducted at 0600–0800 h starting from 31 December 2003. Water temperature, dissolved oxygen (DO), pH, and Secchi disk depth were measured in situ weekly using a DO meter (YSI meter model 50B), pH meter (WTW pH 91) and Secchi disk, respectively. Water samples were collected biweekly from each pond using a plastic column sampler and analyzed for total alkalinity, total ammonium nitrogen (TAN), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen (TKN), soluble reactive phosphorous (SRP), total phosphorous (TP), and chlorophyll *a* (APHA et al., 1985). Gross primary productivity (GPP) and net primary productivity (NPP) were estimated biweekly using the three-point DO curve method (Hall and Moll, 1975). Monthly diel fluctuations of temperature and DO were measured using a DO meter (YSI meter model 50B) at four depths (15, 45, 75, and 100 cm depth above bottom) at 0600, 1000, 1400, 1800, 2200, 0200 and 0600 h of the following day in each pond.

Simple economic analysis was conducted to determine economic returns of each treatment (Shang, 1990). The analysis was based on market prices in Nepal for harvested fish and all other items, which were expressed in local currency NRs (US$ 1 = 75 NRs). Market prices of harvested Sahar and carps were 150 and 75 NRs kg^{-1}, respectively. Market prices of Sahar and carp fingerlings were 0.5 NRs $piece^{-1}$, feed was 15 NRs kg^{-1}, DAP was 22 NRs kg^{-1}, urea was 15 NRs kg^{-1}, cage depreciation was 200 NRs $cage^{-1}$ $year^{-1}$, and cost of working capital was 8% $year^{-1}$.

Data were analyzed statistically by analysis of variance (ANOVA), and regression (Steele and Torrie, 1980) using SPSS (version 11.0) statistical software (SPSS Inc., Chicago). Arcsine transformations were performed on percent data. Differences were considered significant at the 95% confidence level ($P < 0.05$). All means were given with ±1 standard error (S.E.).

RESULTS

Survival of Sahar was high, ranging from 92.7% to 100%, without significant differences among treatments ($P > 0.05$; Table 1). Sahar grew steadily but slowly with daily weight gains of 0.11–0.25 g $fish^{-1}$, and growth rates were significantly higher at lower stocking densities ($P < 0.05$; Figure 1; Table 1). Mean weight of Sahar at harvest, ranging from 21.2 to 43.0 g, decreased linearly with increasing stocking density ($r = -0.86$; Figure 2).

Net and gross fish yields were significantly higher at higher stocking densities of Sahar in cages ($P < 0.05$; Table 1). Net and gross yields of Sahar increased linearly with increased stocking density ($r = 0.96$ and 0.98, respectively; Figure 2). Feed conversion ratio (FCR) of Sahar ranged from 2.2 to 2.8, and was not significantly different among treatments (Table 1).

Survival of common carp, grass carp, mrigal and catla was not significantly different among controls and treatments ($P > 0.05$; Table 2). However, survival of silver carp and rohu was significantly lower in the control than in treatments ($P < 0.05$), and there were no significant differences among treatments ($P > 0.05$). Survival of bighead carp was lowest in the control, intermediate in the 5 and 50 fish m^{-3} treatments, and highest in the 25 and 100 fish m^{-3} treatments ($P < 0.05$; Table 2). Growth of carps was steady but slow in the first two months and more rapid in the rest of the culture period (Figures 3 and 4). Growth and production parameters of common carp, silver carp, bighead carp, and catla were significantly better in the control than in the treatments ($P < 0.05$), which were not significantly different from each other ($P > 0.05$). There were no significant differences in the growth and production of rohu among the control and treatments ($P > 0.05$; Table 2). The growth and production parameters of mrigal were highest in the control, intermediate in the two high density treatments, and lowest in the two low density treatments ($P < 0.05$). The net and gross yields of all carps were significantly higher in the control than in the treatments, which did not differ from each other ($P < 0.05$; Table 2).

The net and gross yields of all carps in the control were significantly higher than combined net and gross yields of Sahar and carps in all treatments ($P < 0.05$; Table 3). Among the treatments, net and gross yields increased linearly with increasing stocking density of Sahar in cages ($r = 0.79$ and 0.85, respectively; Figure 5). In the treatments, combined gross yields increased linearly with increasing feed input to cages ($r = 0.84$; Figure 6), while combined net yields had no significant linear relationship with feed input ($P > 0.05$). The overall FCRs in the treatments were 0.15 to 0.95 in each treatment, and differed significantly by treatment ($P < 0.05$; Table 3).

Water temperature was low (15–18°C) during the initial period of the experiment, increased gradually, and reached about 32°C at the end of the experiment. Water temperature and pH in the control and treatments ranged from 15.3 to 32.4°C, and 7.5 to 8.8, respectively, without significant differences among treatments, while overall mean DO concentrations were significantly lower in the control than in treatments ($P < 0.05$), among which there were no significant differences ($P < 0.05$; Table 4; Figure 7). Total alkalinity increased from the beginning of the experiment, reached its peak at 60 days, then decreased dramatically to the initial level (Figure 7).

Overall mean values of total alkalinity were lowest in the control, intermediate in the 5, 25, and 100 fish m^{-3} treatments, and highest in the 50 fish m^{-3} treatment ($P < 0.05$; Table 4). Overall mean values of all nitrogen and phosphorus parameters, chlorophyll *a*, and gross and net primary production were significantly higher in the control than intreatments ($P < 0.05$; Table 4; Figures 8, 9, 10, and 11). There were no significant differences in overall mean concentrations of nitrate-N and nitrite-N among treatments ($P > 0.05$), while overall mean concentrations of TAN, TKN, SRP, and TP tended to be higher in treatments with higher stocking densities ($P < 0.05$; Table 4). Overall mean concentrations of chlorophyll *a* were also significantly higher in treatments with higher stocking densities ($P < 0.05$), while there were no significant differences in overall mean values of gross and net primary production among treatments ($P > 0.05$). Furthermore, there were no significant differences in Secchi Disk Depth among the control and treatments ($P > 0.05$; Table 4).

Analyses showed that gross revenues were significantly higher in the control than in treatments ($P < 0.05$). Gross revenue also increased significantly with increased stocking density of Sahar ($P < 0.05$; Table 5). The total operation cost was highest in the control and 100 fish m^{-3} treatment, intermediate in the 50 fish m^{-3} treatment, and lowest in the 5 and 25 fish m^{-3} treatments ($P < 0.05$; Table 5). The control and all treatments produced positive net returns, and the highest net returns were produced by the control, followed by treatments from high to low stocking density of Sahar ($P < 0.05$; Table 5).

DISCUSSION

The cage-cum-pond integrated system was developed to integrate intensive feeding in cages and semi-intensive fetilization in open ponds, with fertilizer derived from cage wastes. Very slow growth rate of the fish was recorded in both cages and open ponds throughout the experimental period compared to the fertilized pond without cages.

Sahar in cages showed density-dependent growth with average daily weight gains of 0.11–0.25 g $fish^{-1}$. This is lower than weight gains (0.55-0.75 g $fish^{-1}$) reported by Islam (2002). Growth of Sahar was slow during the first two months of this experiment, when water temperature was below 20°C, and slow growth might be due to low temperature. The poor quality of feed may have also contributed to slow growth of Sahar. Sundar et al. (1998) reported better growth, survival and FCR of Sahar were achieved from feed with 45.4% crude protein among six formulated diets from 21.4% to 50.2% crude protein. In a similar study, Joshi et al. (1989) reported that 35% crude protein was best for growth and feed efficiency of Sahar. Feed with lower crude protein levels (28%) was used in the present experiment, and may have limited Sahar growth.

Average harvest sizes and production of carps in control ponds were significantly greater than in treatment ponds ($P < 0.05$), and this probably is the result of higher fertilization rates. The phosphorus fertilization rates used in the control ponds were somewhat higher than those developed for Nile tilapia ponds with 2 fish m^{-2} (Knud-Hansen et al., 1991). Combined yields of Sahar and carps increased linearly with stocking density of Sahar in cages, which was similar to those results by Yi et al. (1996). However, combined yields in the present experiment ranged from 3.7 to 6.0 kg ha^{-1} day^{-1}, and were lower than those achieved in other experiments with integrated cage-cum-pond systems and other species combinations (Lin et al., 1990; Lin and Diana, 1995; Yi et al., 1996; Yi, 1997; Rai and Lin, 1999; Shrestha, 2002; Yi and Lin, 2000, 2001). This reduced yield was due mainly to less feed input into cages (because of low Sahar biomass) and therefore less cage wastes into open ponds. Carp yields in this cage-cum-pond system were also lower than yields achieved in the fertilized pond, as well as average productivity in carp polyculture ponds in Nepal (2.5 t ha^{-1} yr^{-1}; Yadav, 2003). Low survival of carps in the control may be due to presence of carnivorous fish including snakehead (*Channa striatus*), singhi (*Heteropneustus fossilis*) and eel (*Monopterus cuchia*), which were found during harvest. FCRs of Sahar, ranging from 2.2 to 2.8, were also lower than those reported by Islam (2002).

Most water quality parameters in all ponds were within acceptable ranges for fish culture as reported by Boyd (1982). Fluctuation in DO concentrations might be attributed to photosynthetic rate varying in cloudy and sunny weather, and also to variation in the rate of oxygen production for different treatments. Water quality was not dramatically affected by stocking density of Sahar in cages. However, there were higher total Kjeldahl nitrogen, total ammonia nitrogen (TAN), soluble reactive phosphorus and total phosphorus levels in ponds where Sahar were stocked at higher density. This was most likely due to increased nutrient input from feed wastes into open ponds. The chlorophyll *a* concentrations were very low in treatments with cages, due mainly to low feed inputs into cages and resultant low cage wastes into open ponds.

High-valued Sahar has potential to be cultured in an integrated cage-cum-pond culture system, but it is necessary to fine-tune stocking ratios of Sahar to carps. This can be done by adjusting stocking density of Sahar in cages, as well as cage size or cage number. Also, growth of Sahar may improve by providing higher quality feed.

ANTICIPATED BENEFITS

This technology will be further improved and adopted to local conditions in Nepal and will provide small-scale rural farmers an opportunity to generate more income and improve their livelihoods using their scare resources. As such, it will benefit small-scale rural farmers in Asia and other countries where integrated systems are practiced.

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Table 1. Performance of Sahar in each treatment.

Parameter	Stocking Density (fish m^{-3})			
	5	25	50	100
STOCKING				
Total Weight (kg $cage^{-1}$)	0.05±0.00^{a}	0.26±0.00^{b}	0.51±0.01^{c}	1.00±0.01^{d}
Mean Weight (g/$fish^{-1}$)	5.2±0.1	5.1±0.1	5.1±0.1	5.0±0.1
HARVEST				
Total Weight (kg $cage^{-1}$)	0.43±0.02^{a}	1.42±0.18^{b}	2.55±0.17^{c}	4.23±0.30^{d}
Mean Weight (g $fish^{-1}$)	43.0±1.8^{a}	30.4±1.7^{b}	25.5±1.7^{bc}	21.2±1.4^{c}
Daily Weight Gain (g $fish^{-1}$ day^{-1})	0.25±0.01^{a}	0.17±0.01^{b}	0.14±0.01^{bc}	0.11±0.01^{c}
Gross Yield (kg $cage^{-1}$ $crop^{-1}$)	0.43±0.02^{a}	1.42±0.18^{b}	2.55±0.17^{c}	4.23±0.30^{d}
Net Yield (kg $cage^{-1}$ $crop^{-1}$)	0.38±0.02^{a}	1.17±0.18^{b}	2.04±0.17^{c}	3.23±0.31^{d}
Survival (%)	100.00±0.00	92.67±7.33	100.00±0.00	99.50±0.29
FCR	1.65±0.13^{a}	2.05±0.21^{ab}	2.02±0.14^{ab}	2.20±0.06^{b}

* Mean values with different superscripts in the same row were significantly different ($P < 0.05$).

Table 2. Performance of carps stocked in each treatment.

Parameter	Stocking Density (fish m^{-3})				
	0	5	25	50	100
COMMON CARP					
STOCKING					
Total Weight (kg $pond^{-1}$)	0.11±0.01	0.11±0.00	0.10±0.00	0.10±0.01	0.12±0.01
Mean Weight (g $fish^{-1}$)	11.0±0.7	10.8±0.4	10.4±0.4	10.4±0.5	11.90±1.00
HARVEST					
Total Weight (kg $pond^{-1}$)	4.02±0.11^{a}	1.81±0.28^{b}	1.59±0.10^{b}	1.51±0.15^{b}	1.61±0.16^{b}
Mean Weight (g $fish^{-1}$)	505.9±83.4^{a}	213.8±43.4^{b}	164.7±10.5^{b}	171.0±22.1^{b}	194.6±24.6^{b}
Daily Weight Gain (g $fish^{-1}$ day^{-1})	3.30±0.55^{a}	1.35±0.29^{b}	1.03±0.07^{b}	1.07±0.15^{b}	1.22±0.16^{b}
Gross Yield (t ha^{-1} $crop^{-1}$)	0.40±0.01^{a}	0.18±0.03^{b}	0.16±0.01^{b}	0.15±0.01^{b}	0.16±0.02^{b}
Net Yield (t ha^{-1} $crop^{-1}$)	0.39±0.01^{a}	0.17±0.03^{b}	0.15±0.01^{b}	0.14±0.01^{b}	0.15±0.02^{b}
Survival (%)	83.33±12.02	86.67±6.67	96.67±3.33	90.00±10.00	83.33±3.33
GRASS CARP					
STOCKING					
Total Weight (kg $pond^{-1}$)	0.07±0.00	0.08±0.00	0.07±0.00	0.07±0.00	0.08±0.01
Mean Weight (g/$fish^{-1}$)	7.2±0.2	8.1±0.3	7.1±0.2	7.1±0.0	7.5±0.5
HARVEST					
Total Weight (kg $pond^{-1}$)	0.95±0.15^{a}	0.22±0.04^{b}	0.23±0.06^{b}	0.27±0.12^{b}	0.28±0.12^{b}
Mean Weight (g $fish^{-1}$)	168.4±22.8^{a}	32.4±7.4^{b}	33.6±8.2^{b}	38.2±13.5^{b}	37.5±9.9^{b}
Daily Weight Gain (g $fish^{-1}$ day^{-1})	1.07±0.15^{a}	0.16±0.05^{b}	0.18±0.05^{b}	0.21±0.09^{b}	0.20±0.07^{b}
Gross Yield (t ha^{-1} $crop^{-1}$)	0.10±0.01^{a}	0.02±0.00^{b}	0.02±0.01^{b}	0.03±0.01^{b}	0.03±0.01^{b}
Net Yield (t ha^{-1} $crop^{-1}$)	0.09±0.01^{a}	0.01±0.00^{b}	0.02±0.01^{b}	0.02±0.01^{b}	0.02±0.01^{b}
Survival (%)	56.67±3.33	70.00±5.77	70.00±10.00	66.67±8.82	70.00±10.00
SILVER CARP					
STOCKING					
Total Weight (kg $pond^{-1}$)	0.25±0.01	0.26±0.01	0.28±0.01	0.28±0.03	0.26±0.01
Mean Weight (g/$fish^{-1}$)	6.3±0.3	6.4±0.2	7.1±0.2	7.0±0.7	6.5±0.2
HARVEST					
Total Weight (kg $pond^{-1}$)	8.68±0.63^{a}	1.82±0.13^{b}	1.75±0.31^{b}	2.38±0.12^{b}	2.17±0.28^{b}
Mean Weight (g $fish^{-1}$)	326.0±27.6^{a}	49.8±4.2^{b}	45.7±9.2^{b}	63.4±2.8^{b}	61.4±9.0^{b}
Daily Weight Gain (g $fish^{-1}$ day^{-1})	2.13±0.18^{a}	0.29±0.03^{b}	0.26±0.06^{b}	0.38±0.01^{b}	0.37±0.06^{b}
Gross Yield (t ha^{-1} $crop^{-1}$)	0.87±0.06^{a}	0.18±0.01^{b}	0.18±0.03^{b}	0.24±0.01^{b}	0.22±0.03^{b}
Net Yield (t ha^{-1} $crop^{-1}$)	0.84±0.06^{a}	0.16±0.01^{b}	0.15±0.03^{b}	0.21±0.01^{b}	0.19±0.03^{b}
Survival (%)	66.67±0.83^{a}	91.67±1.67^{b}	96.67±2.20^{b}	94.17±3.63^{b}	89.17±3.00^{b}
BIGHEAD CARP					
STOCKING					
Total Weight (kg $pond^{-1}$)	0.03±0.00	0.03±0.00	0.03±0.00	0.03±0.00	0.03±0.00
Mean Weight (g/$fish^{-1}$)	3.0±0.0	2.8±0.1	2.9±0.1	2.9±0.0	2.9±0.1
HARVEST					
Total Weight (kg $pond^{-1}$)	1.80±0.13^{a}	0.27±0.06^{b}	0.26±0.04^{b}	0.27±0.05^{b}	0.43±0.11^{b}
Mean Weight (g $fish^{-1}$)	342.9±41.3^{a}	39.9±7.3^{b}	34.0±5.0^{b}	41.3±8.4^{b}	48.1±8.9^{b}
Daily Weight Gain (g $fish^{-1}$ day^{-1})	2.27±0.27^{a}	0.25±0.05^{b}	0.21±0.03^{b}	0.26±0.06^{b}	0.30±0.06^{b}
Gross Yield (t ha^{-1} $crop^{-1}$)	0.18±0.01^{a}	0.03±0.01^{b}	0.03±0.00^{b}	0.03±0.01^{b}	0.04±0.01^{b}
Net Yield (t ha^{-1} $crop^{-1}$)	0.18±0.01^{a}	0.02±0.01^{b}	0.02±0.00^{b}	0.02±0.01^{b}	0.04±0.01^{b}
Survival (%)	53.33±3.33^{a}	66.67±3.33^{ab}	76.67±8.82^{b}	66.67±6.67^{ab}	86.67±8.82^{b}

* Mean values with different superscripts in the same row were significantly different ($P < 0.05$).

Table 2. Continued.

Parameter	Stocking Density (fish m^{-3})				
	0	5	25	50	100
ROHU					
STOCKING					
Total Weight (kg $pond^{-1}$)	0.05±0.00	0.04±0.00	0.04±0.00	0.04±0.00	0.04±0.00
Mean Weight (g/$fish^{-1}$)	4.6±0.2	4.4±0.1	4.4±0.1	4.3±0.1	4.5±0.2
HARVEST					
Total Weight (kg $pond^{-1}$)	0.73±0.18	0.72±0.17	0.71±0.11	0.77±0.07	0.73±0.07
Mean Weight (g $fish^{-1}$)	133.5±40.5	83.2±23.1	78.9±10.1	88.6±5.3	78.3±3.2
Daily Weight Gain (g $fish^{-1}$ day^{-1})	0.86±0.27	0.53±0.15	0.50±0.07	0.56±0.04	0.49±0.02
Gross Yield (t ha^{-1} $crop^{-1}$)	0.07±0.02	0.07±0.02	0.07±0.01	0.08±0.01	0.07±0.01
Net Yield (t ha^{-1} $crop^{-1}$)	0.07±0.02	0.07±0.02	0.07±0.01	0.07±0.01	0.07±0.01
Survival (%)	56.67±3.33 ^{a}	90.00±5.77 ^{b}	90.00±5.77 ^{b}	86.67±3.33 ^{b}	93.33±6.67 ^{b}
MRIGAL					
STOCKING					
Total Weight (kg $pond^{-1}$)	0.02±0.00	0.02±0.00	0.02±0.00	0.02±0.00	0.02±0.00
Mean Weight (g/$fish^{-1}$)	1.9±0.1	1.9±0.0	2.0±0.1	2.0±0.1	1.8±0.1
HARVEST					
Total Weight (kg $pond^{-1}$)	0.91±0.06	0.51±0.11	0.62±0.05	0.75±0.15	0.73±0.14
Mean Weight (g $fish^{-1}$)	112.5±16.5 ^{a}	52.5±10.4 ^{b}	61.8±4.8 ^{b}	77.5±13.8 ^{ab}	74.4±12.2 ^{ab}
Daily Weight Gain (g $fish^{-1}$ day^{-1})	0.74±0.11 ^{a}	0.34±0.07 ^{b}	0.40±0.03 ^{b}	0.50±0.09 ^{ab}	0.48±0.08 ^{ab}
Gross Yield (t ha^{-1} $crop^{-1}$)	0.09±0.01	0.05±0.01	0.06±0.00	0.08±0.01	0.07±0.01
Net Yield (t ha^{-1} $crop^{-1}$)	0.09±0.01	0.05±0.01	0.06±0.00	0.07±0.01	0.07±0.01
Survival (%)	83.33±8.82	96.67±3.33	100.00±0.00	96.67±3.33	96.67±3.33
CATLA					
STOCKING					
Total Weight (kg $pond^{-1}$)	0.03±0.00	0.03±0.00	0.03±0.00	0.03±0.00	0.03±0.00
Mean Weight (g $fish^{-1}$)	3.5±0.1	3.33±0.09	3.40±0.10	3.47±0.12	3.37±0.03
HARVEST					
Total Weight (kg $pond^{-1}$)	1.53±0.39 ^{a}	0.44±0.08 ^{b}	0.41±0.06 ^{b}	0.35±0.06 ^{b}	0.39±0.08 ^{b}
Mean Weight (g $fish^{-1}$)	265.6±57.4 ^{a}	63.4±11.2 ^{b}	76.9±16.3 ^{b}	59.6±5.8 ^{b}	68.0±18.7 ^{b}
Daily Weight Gain (g $fish^{-1}$ day^{-1})	1.75±0.38 ^{a}	0.40±0.07 ^{b}	0.49±0.11 ^{b}	0.37±0.04 ^{b}	0.43±0.12 ^{b}
Gross Yield (t ha^{-1} $crop^{-1}$)	0.15±0.04 ^{a}	0.04±0.01 ^{b}	0.04±0.01 ^{b}	0.04±0.01 ^{b}	0.04±0.01 ^{b}
Net Yield (t ha^{-1} $crop^{-1}$)	0.15±0.04 ^{a}	0.04±0.01 ^{b}	0.04±0.01 ^{b}	0.03±0.01 ^{b}	0.04±0.01 ^{b}
Survival (%)	56.67±3.33	70.00±0.00	56.67±8.82	60.00±11.55	60.00±5.77
ALL CARPS					
Gross Yield (t ha^{-1} $crop^{-1}$)	1.86±0.06 ^{a}	0.58±0.05 ^{b}	0.56±0.07 ^{b}	0.63±0.05 ^{b}	0.63±0.05 ^{b}
Net Yield (t ha^{-1} $crop^{-1}$)	1.81±0.06 ^{a}	0.52±0.05 ^{b}	0.50±0.07 ^{b}	0.57±0.05 ^{b}	0.58±0.05 ^{b}

* Mean values with different superscripts in the same row were significantly different ($P < 0.05$).

Table 3. Combined performance of both caged Sahar and open-pond carps in each treatment.

Parameter	Stocking Density (fish m^{-3})				
	0	5	25	50	100
Initial Fish Biomass (kg)	0.34±0.01 ^{a}	0.39±0.00 ^{b}	0.59±0.01 ^{c}	0.84±0.00 ^{d}	1.35±0.02 ^{e}
Final Fish Biomass (kg)	11.75±0.65 ^{a}	4.68±0.70 ^{d}	5.50±0.55 ^{cd}	6.75±0.59 ^{c}	8.83±0.56 ^{b}
Fish Biomass Gain (kg $pond^{-1}$)	11.41±0.64 ^{a}	4.28±0.70 ^{c}	4.91±0.54 ^{c}	5.91±0.59 ^{bc}	7.48±0.57 ^{b}
Gross Fish Yield (t ha^{-1} $crop^{-1}$)	1.17±0.07 ^{a}	0.47±0.07 ^{d}	0.55±0.06 ^{cd}	0.67±0.06 ^{c}	0.88±0.06 ^{b}
Net Fish Yield (t ha^{-1} $crop^{-1}$)	1.14±0.06 ^{a}	0.43±0.07 ^{c}	0.49±0.05 ^{c}	0.59±0.06 ^{bc}	0.75±0.06 ^{b}
Overall FCR	0.00±0.00 ^{a}	0.15±0.02 ^{b}	0.48±0.02 ^{c}	0.70±0.07 ^{d}	0.95±0.03 ^{e}

* Mean values with different superscripts in the same row were significantly different ($P < 0.05$).

Table 4. Overall mean values and ranges of water quality parameters in each treatment.

Parameter	Stocking Density (fish m^{-3})				
	0	5	25	50	100
Temperature (^oC)	23.0±0.1[a] (15.3-32.4)	23.2±0.1[b] (15.4-32.4)	23.2±0.1[b] (15.3-32.3)	23.2±0.0[b] (15.3-32.4)	23.2±0.0[b] (15.3-32.4)
DO (mg L^{-1})	4.3±0.1[a] (0.2-15.2)	5.4±0.3[b] (2.0-15.4)	5.6±0.3[b] (1.8-15.8)	5.7±0.4[b] (3.6-14.4)	5.5±0.1[b] (2.3-15.6)
pH	8.1 (7.5-8.8)	8.0 (7.5-8.5)	8.1 (7.5-8.5)	8.1 (7.6-8.4)	8.1 (7.5-8.4)
Total Alkalinity (mg L^{-1} as $CaCO_3$)	123±2[a] (80-152)	132±1[bc] (108-219)	126±4[abc] (98-200)	132±1[c] (104-210)	130±2[ac] (101-209)
TAN (mg L^{-1})	0.31±0.01[a] (0.14-0.55)	0.14±0.01[b] (0.00-0.61)	0.13±0.01[b] (0.01-0.55)	0.16±0.01[bc] (0.02-0.62)	0.17±0.01[c] (0.00-0.70)
NO_2-N (mg L^{-1})	0.01±0.00[a] (0.00-0.02)	0.00±0.00[b] (0.00-0.01)	0.00±0.00[b] (0.00-0.01)	0.00±0.00[b] (0.00-0.01)	0.01±0.00[b] (0.00-0.01)
NO_2-N (mg L^{-1})	0.09±0.02[a] (0.02-0.44)	0.02±0.00[b] (0.00-0.04)	0.02±0.00[b] (0.00-0.03)	0.02±0.00[b] (0.00-0.03)	0.03±0.00[b] (0.00-0.04)
TKN (mg L^{-1})	4.21±0.33[a] (2.46-5.84)	1.39±0.02[b] (0.94-2.21)	1.64±0.09[b] (1.06-3.19)	1.83±0.04[bc] (1.21-3.19)	2.26±0.04[c] (1.39-1.69)
SRP (mg L^{-1})	0.38±0.02[a] (0.03-0.79)	0.04±0.01[b] (0.02-0.07)	0.07±0.01[c] (0.03-0.11)	0.08±0.01[cd] (0.04-0.13)	0.11±0.01[d] (0.03-0.18)
TP (mg L^{-1})	1.06±0.06[a] (0.26-1.63)	0.20±0.02[b] (0.12-0.23)	0.25±0.02[b] (0.18-0.39)	0.28±0.01[bc] (0.20-0.58)	0.38±0.00[c] (0.28-0.52)
Chlorophyll *a* (mg m^{-3})	291±15[a] (66-772)	42 ±5[b] (18-66)	59±10[bc] (25-105)	52±2[bc] (32-68)	70±6[c] (47-108)
Secchi Disk Depth (cm)	29±2 (13-56)	41±2 (28-58)	37±3 (26-49)	38±4 (28-51)	34±2 (28-43)
GPP (g C m^{-2} 12 hr^{-1})	4.0±0.3[a] (1.2-7.6)	1.9±0.0[b] (1.2-2.3)	2.0±0.1[b] (1.3-2.6)	2.0±0.1[b] (1.3-3.0)	2.3±0.1[b] (1.1-3.2)
NPP (g C m^{-2} 12 hr^{-1})	2.0±0.2[a] (0.5-3.7)	1.0±0.0[b] (0.6-1.3)	1.0±0.1[b] (0.6-1.2)	1.0±0.0[b] (0.6-1.5)	1.1±0.1[b] (0.4-1.6)

[abcd] Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

Table 5. Economic analysis (in NRs) for each treatment.

Parameter	Stocking Density (fish m^{-3})				
	0	5	25	50	100
GROSS REVENUE PER POND					
Sahar	-	56.81^{a}	174.99^{b}	306.00^{c}	484.04^{d}
Catla	1354.13^{a}	392.18^{b}	373.88^{b}	429.56^{b}	431.93^{b}
Total	1354.13^{a}	448.98^{d}	548.87^{cd}	735.56^{c}	915.96^{b}
OPERATION COST PER POND					
Sahar Fingerlings	-	5.00^{a}	25.00^{b}	50.00^{c}	100.00^{d}
Carp Fingerlings	50.00	50.00	50.00	50.00	50.00
Urea	105.00^{a}	5.25^{b}	5.25^{b}	5.25^{b}	5.25^{b}
DAP	305.60^{a}	15.28^{b}	15.28^{b}	15.28^{b}	15.28^{b}
Feed	-	9.33^{a}	34.66^{b}	61.04^{c}	105.92^{d}
Cage Depreciation	0.00^{a}	200.00^{b}	200.00^{b}	200.00^{b}	200.00^{b}
Working Capital Cost	15.08^{a}	9.36^{b}	10.85^{b}	12.54^{ab}	15.66^{a}
Total	473.68^{a}	294.12^{b}	340.94^{b}	394.01^{ab}	492.01^{a}
NET RETURN PER POND	880.45^{a}	154.86^{d}	207.93^{d}	341.54^{c}	423.95^{b}

[abcd] Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

Figure 1. Growth of Sahar in each treatment.

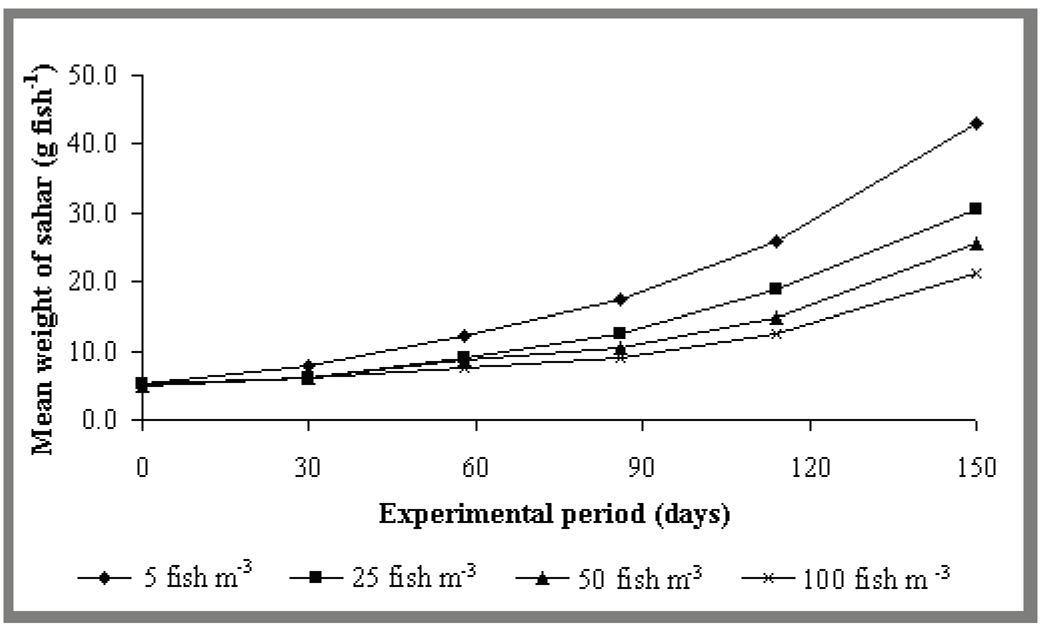


Figure 2. Relationships between mean weight at harvest, net and gross yields of Sahar and stocking density in cages.

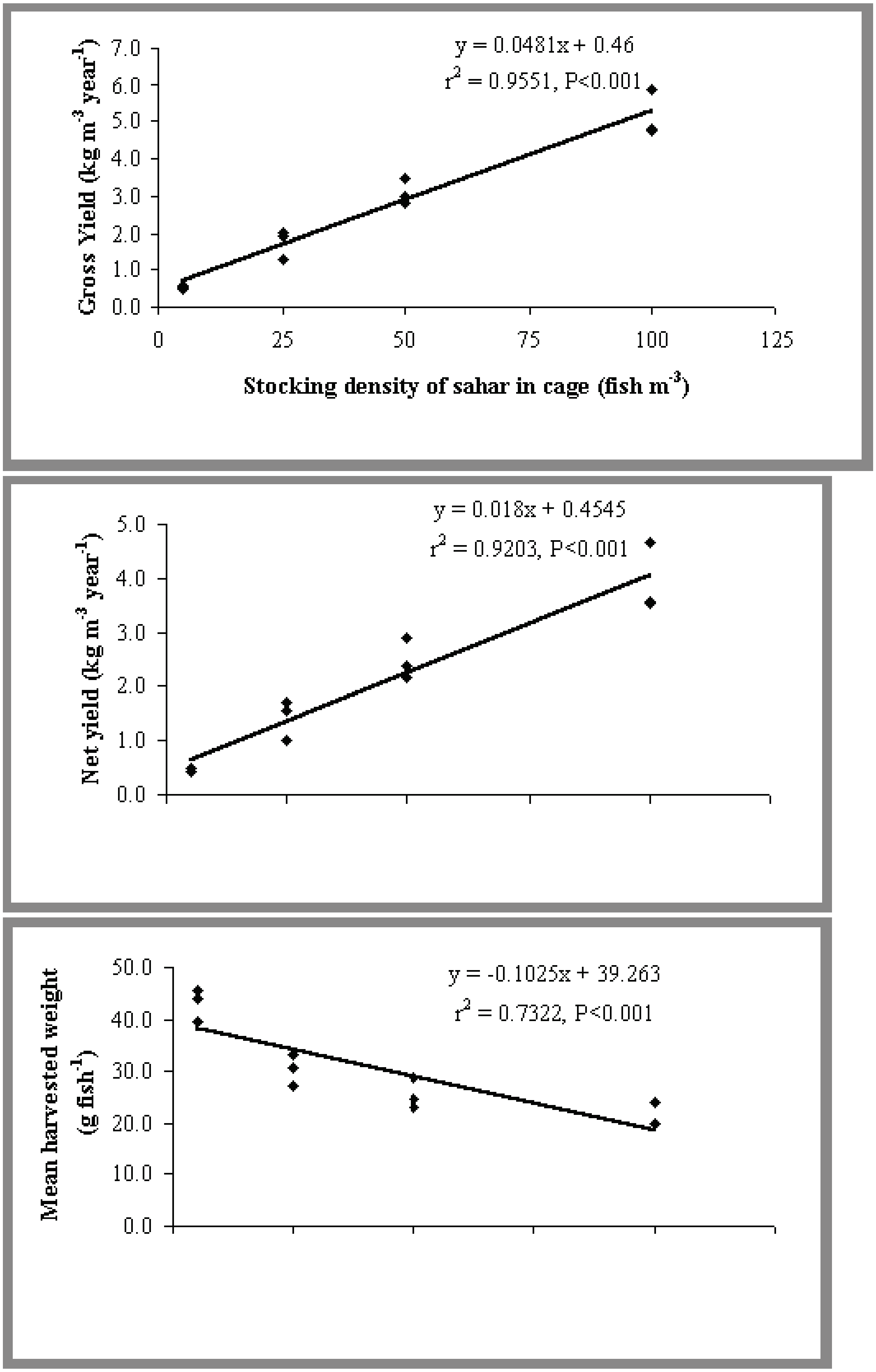
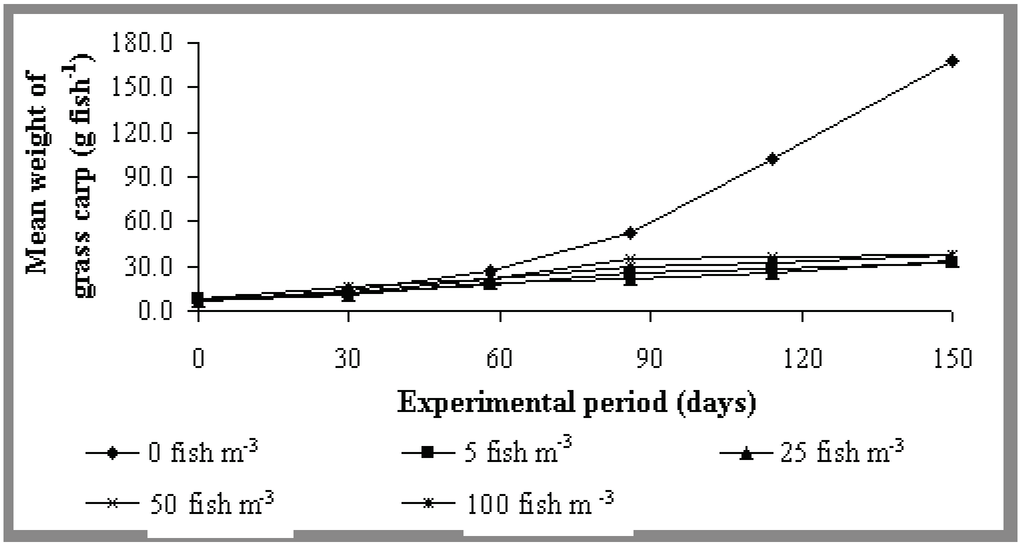


Figure 3. Growth of common carp, silver carp, bighead carp, and grass carp in each treatment.



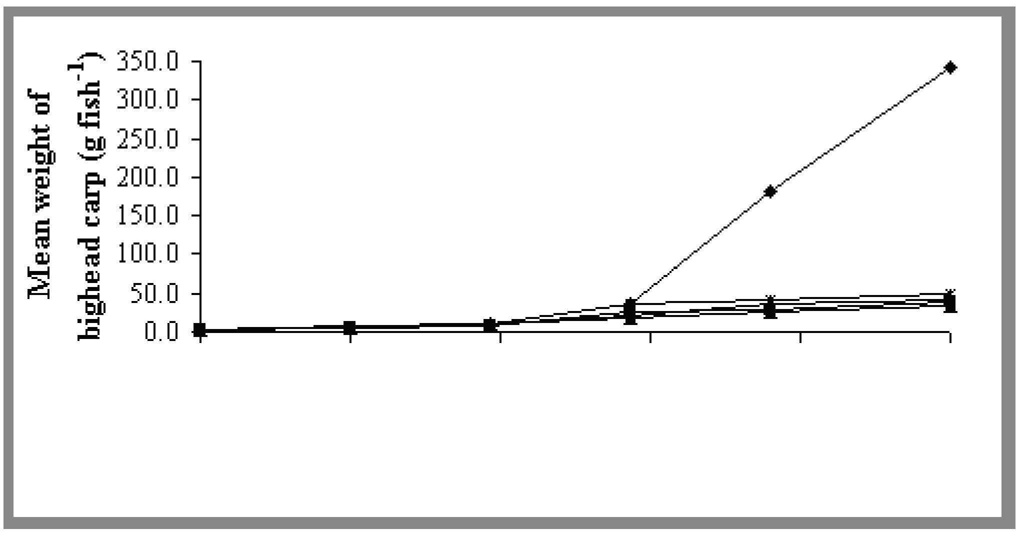


Figure 4. Growth of rohu, catla, and mrigal in each treatment.

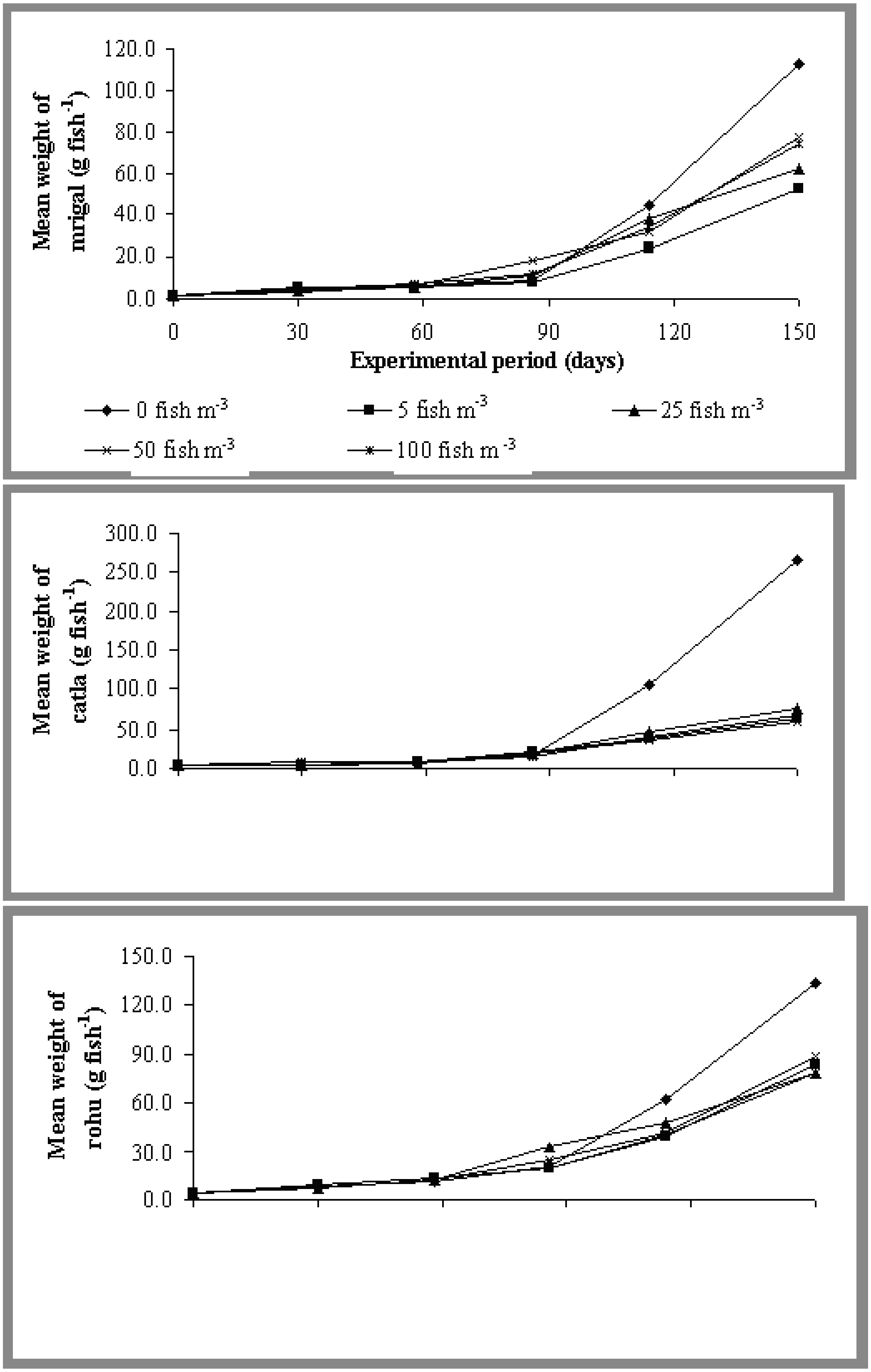


Figure 5. Relationships between combined net and gross yields of Sahar and carps and stocking densities of Sahar in cages.

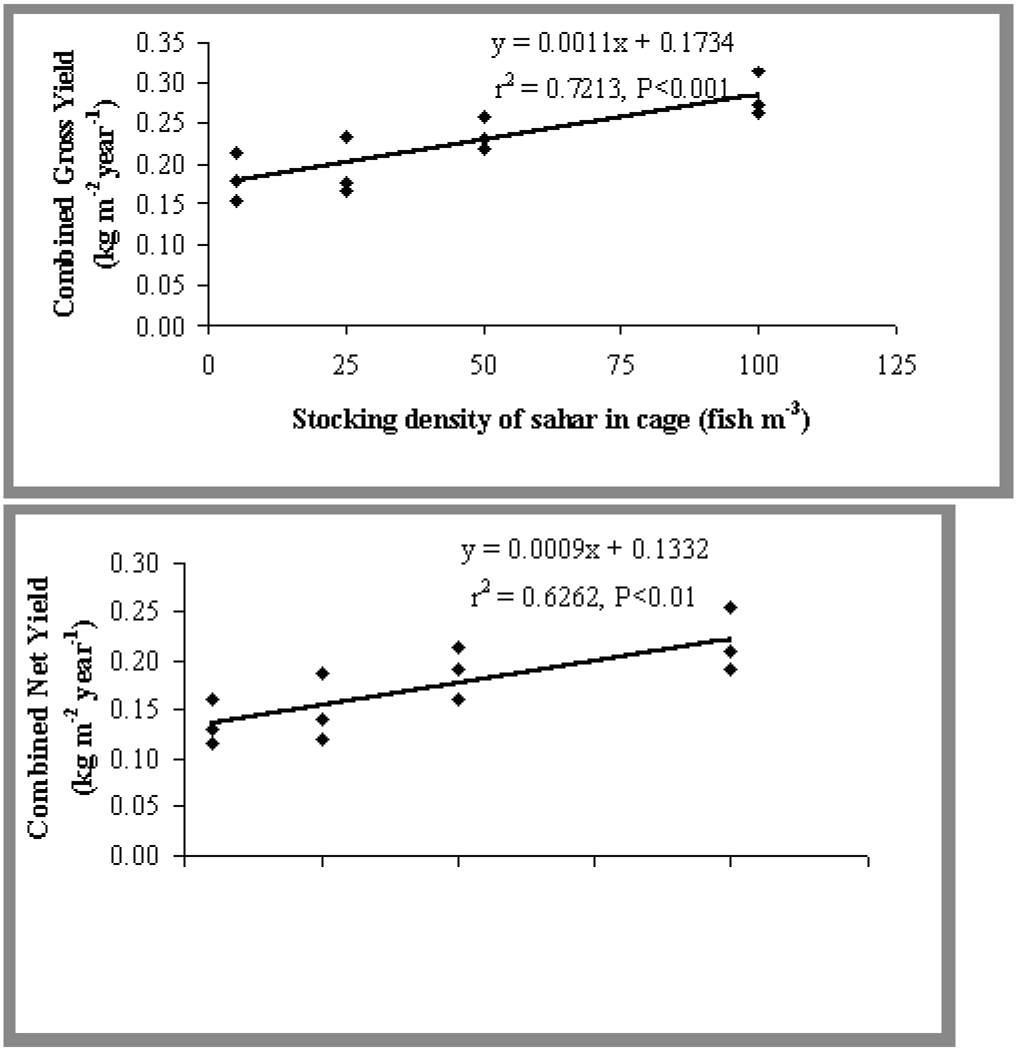


Figure 6. Relationships between combined gross yields of Sahar and carps and total feed inputs to the cages.

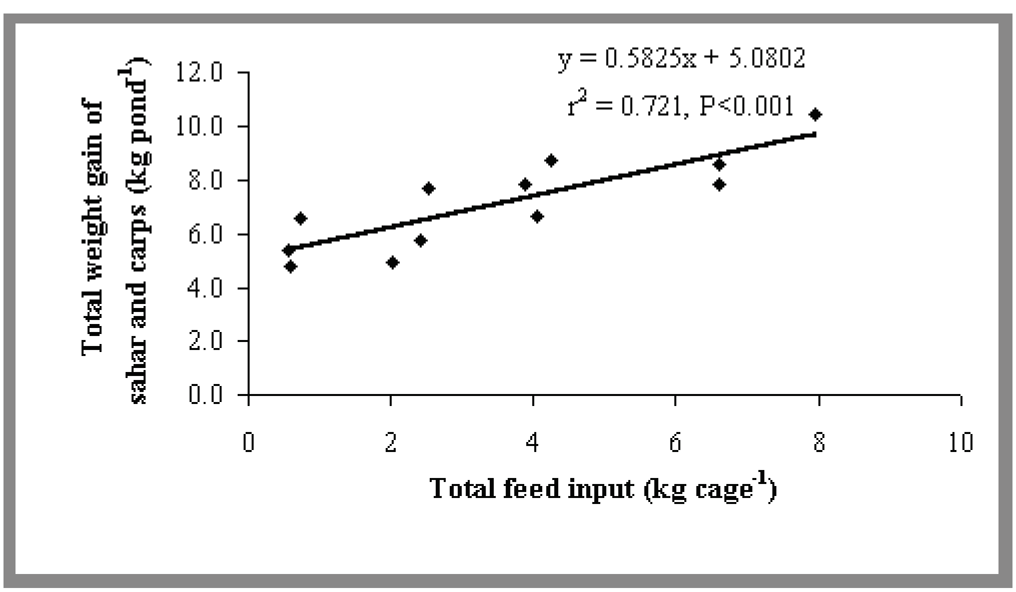


Figure 7. Changes in DO, pH, and total alkalinity at 0800 h in each treatment over the experiment.

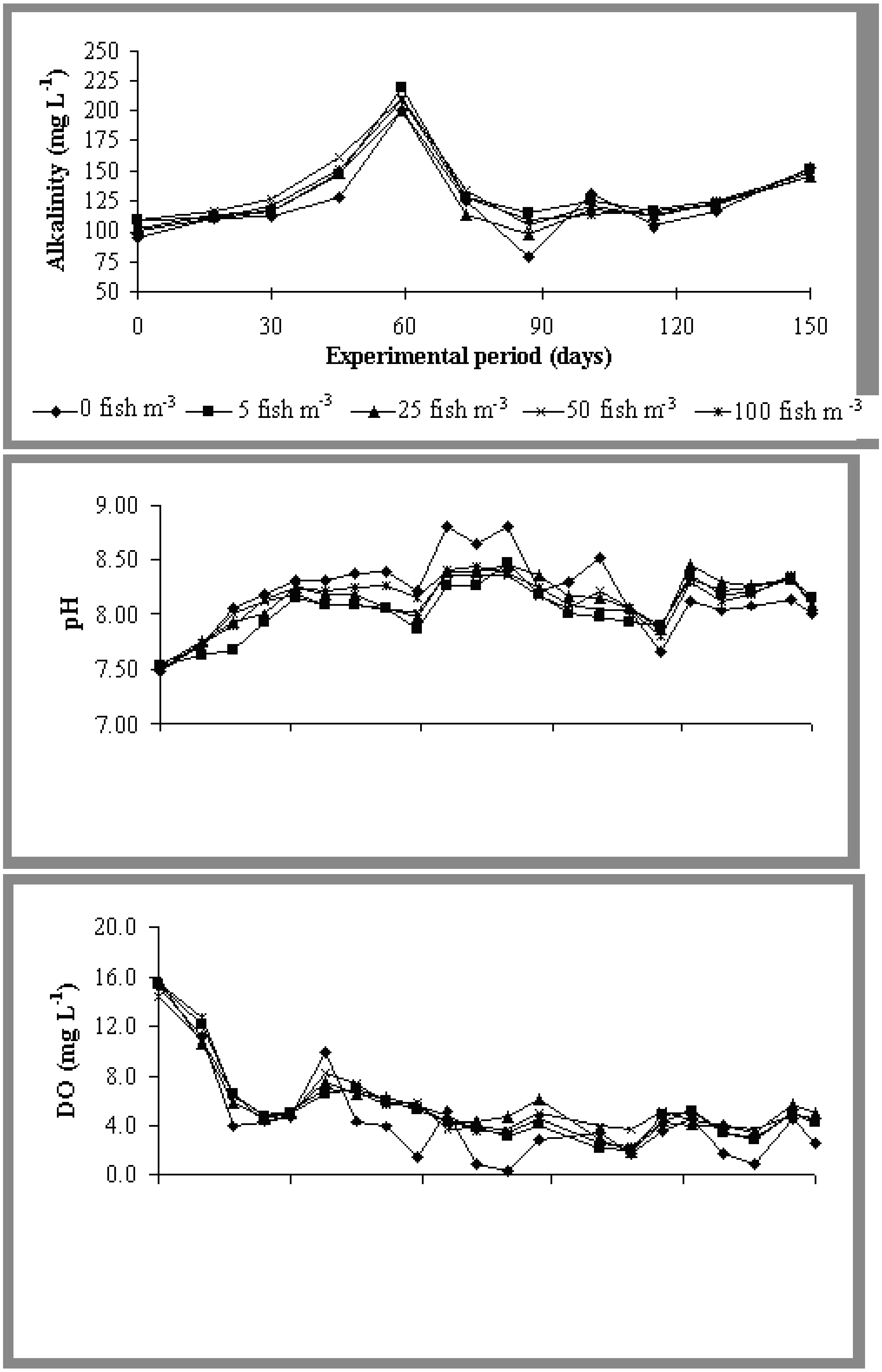


Figure 8. Changes in total ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, and total Kjeldahl nitrogen at 0800 h in each treatment.

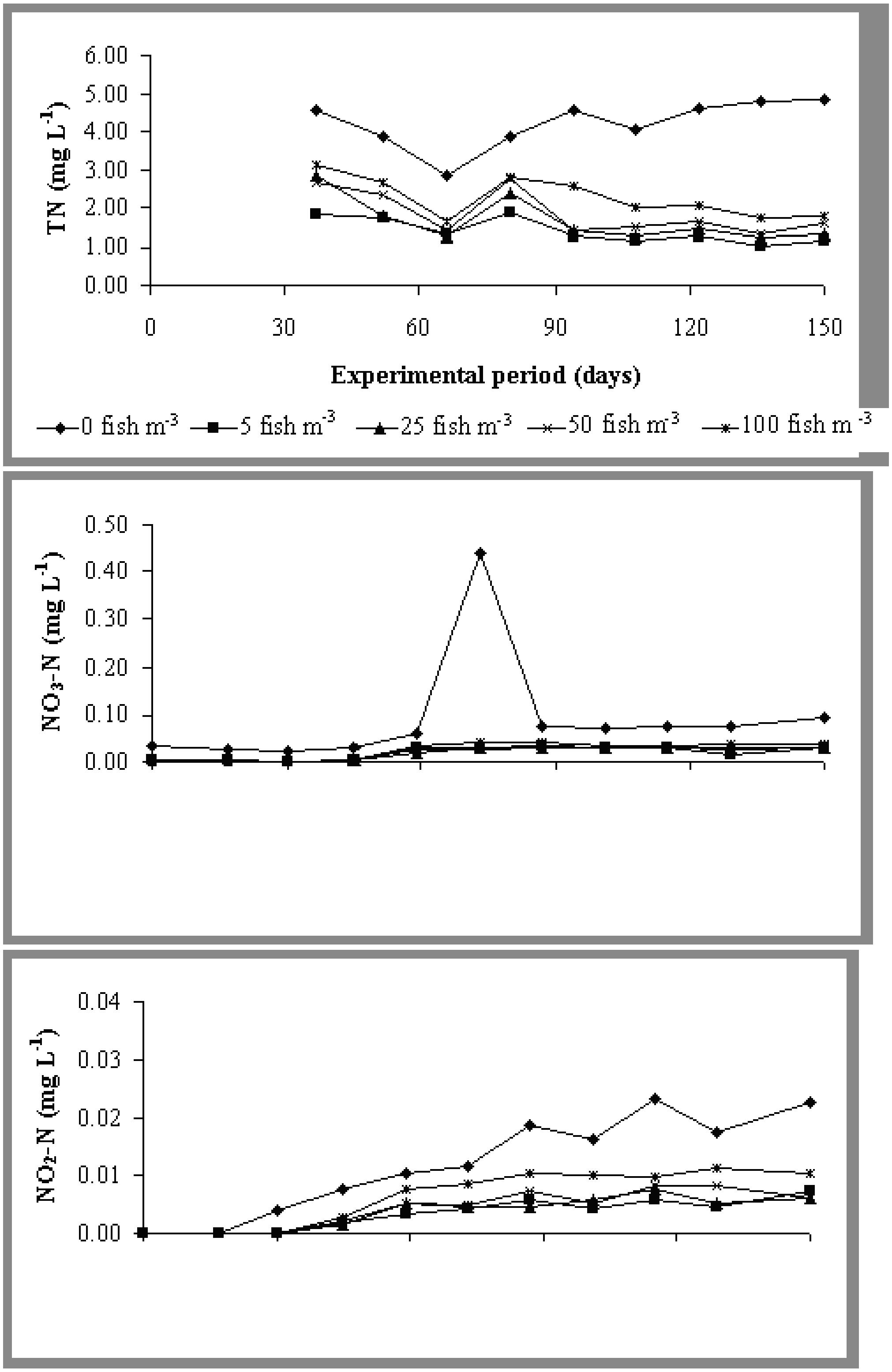


Figure 9. Changes in total phosphorous and soluble reactive phosphorus at 0800 h in each treatment.

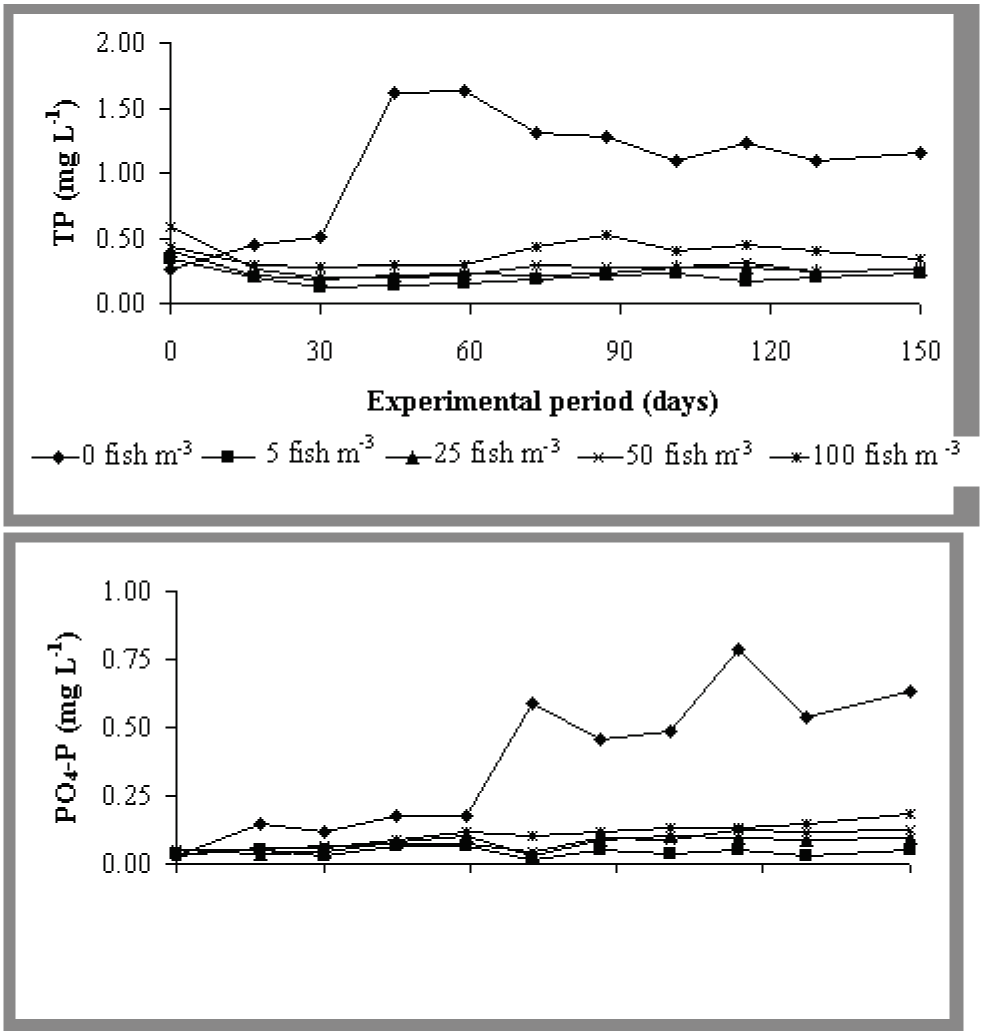


Figure 10. Changes in Secchi disk visibility and chlorophyll a at 0800 h in each treatment.

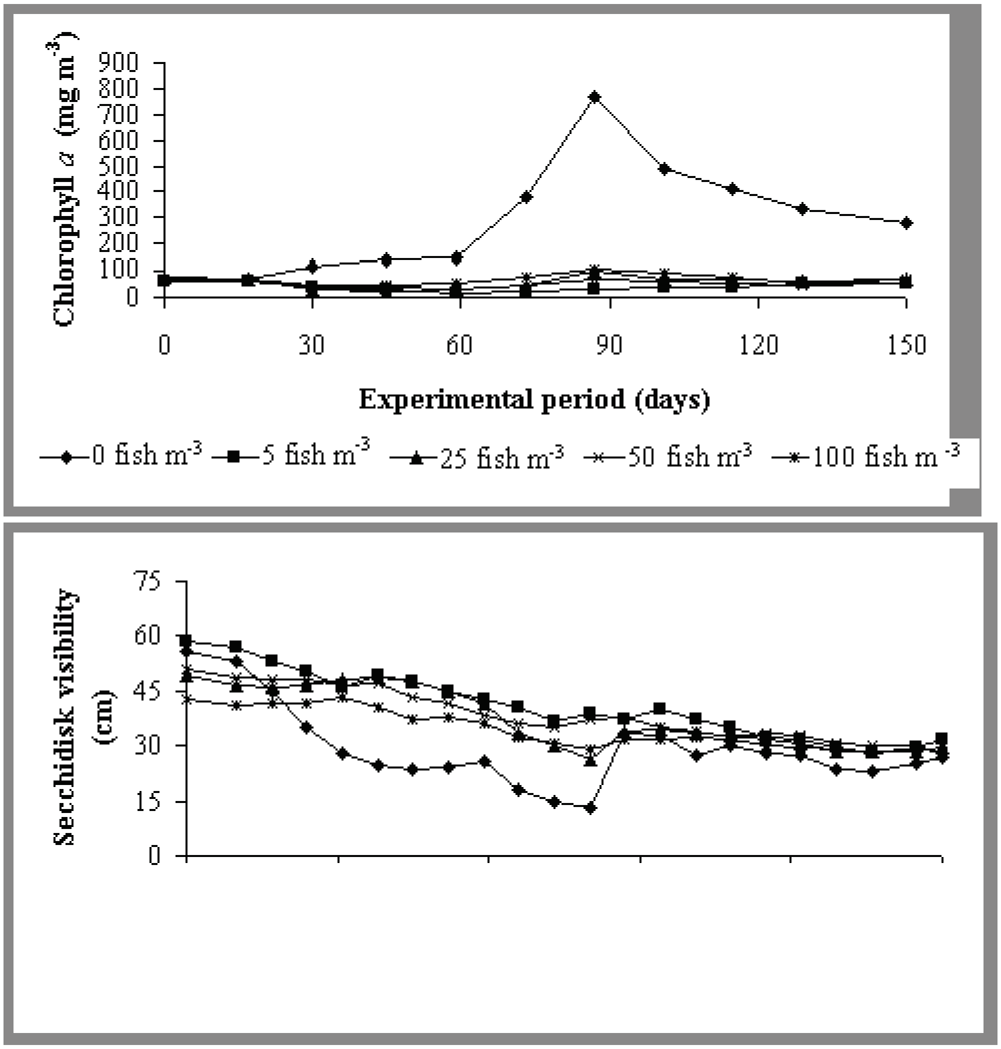


Figure 11. Changes in gross and net primary production at 0800 h in each treatment.