TOPIC AREA:
PRODUCTION SYSTEM DESIGN & BEST MANAGEMENT ALTERNATIVES

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EXPERIMENTAL POND UNIT ASSESSMENT IN BANGLADESH

Production System Design & Best Management Alternatives/Activity/09BMA09NC

FINAL INVESTIGATION REPORT

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ABSTRACT

The purpose of this study was to assess production and water quality parameters in: 1) two freshwater prawn-farming systems in Southwest Bangladesh, 2) prawn-farming ponds in Eastern North Carolina, 3) and tilapia-carp polyculture ponds in Mymensingh region of Bangladesh. In the first study an exploratory survey was conducted to characterize two major prawn farming systems, a modified pond system where rice fields are permanently converted to year-round prawn production and gher (pond) systems where prawn is integrated with rice culture. Studies were conducted for 120 days in the Dumuria, Upazila Province of Khulna District, in Southwest Bangladesh. Freshwater prawn (*Macrobrachium rosenbergii*) was cultured in 8 separated modified ponds allocated to two treatments: prawn culture in modified ponds systems and prawn culture in gher systems. Factorial analysis was run to identify the main ecological processes affecting water quality in the ponds. The Factor1, Factor2, and Factor3 accounted for 37%, 16%, and 13%, respectively, of the overall variability of the data. Factor1 showed the combined effects of rain and liming on the water quality of the ponds/ghers, both of which were elevated at the start of the experiment and then gradually declined at the end. The second factor (Factor2) showed the opposite effects of decomposition and photosynthesis on oxygen and ammonia content of the water. The third factor (Factor3) showed positive correlations among chlorophyll, pH, and dissolved oxygen, which reflected another aspect of photosynthesis related to phytoplankton biomass and oxygen released. The

ANOVA model applied accounted for only 23% of the variability of Factor3, half of it caused by treatment. Phytoplankton biomass and oxygen production were higher in only prawn ponds than in ghers where rice was previously cultured. Mean value (± SD) of soil pH, organic carbon (%), total phosphorus (ppm), and total nitrogen (%) were 7.1 (± 0.30), 1.6 (± 0.3), 15.80 (± 4.8), and 0.15 (± 0.02), respectively, in modified pond systems, and 6.5 (± 0.64), 2.5 (± 1.25), 11.94 (± 3.9), and 0.23 (± 0.11) in gher systems. The mean production of prawn in modified pond and gher culture systems was 407.5 (± 15.55) and 335 (± 19.15) $kg.ha^{-1}$, respectively. Although the prawn production in gher systems was significantly lower ($p < 0.05$), the overall agricultural production, socio-economic, and sustainability benefits may be greater for the gher system since it integrates both rice and prawn production. Potential replenishment of nutrients in bottom mud with prawn culture may also allow for enhanced utilization by rice crops.

The second study experiment evaluated water quality and production parameters using pelleted and powdered fertilizers on prawn growout in experimental ponds in Eastern North Carolina. Prawn farming has become popular in NC and Southeastern United States, particularly for small farmers. An assessment of responses in pond dynamics to different forms of fertilizers could be used for future work aimed at improving management practices both in Bangladesh and the U.S. Four, 0.10-ha earthen ponds were stocked with juvenile *Macrobracium rosenbergii* obtained from a commercial hatchery. A total of 3,000 animals (avg. wt. 0.14 g) were stocked into each pond (30,000/ha) in June at the Tidewater Research Station in Plymouth, NC. One treatment (Pelleted Fertilizer) consisted of a large (4 cm diameter) dense, compact, water stable pellet made from a mixture of grain byproducts. The second treatment (Powdered Fertilizer) used the same ingredient mixture but the pellets were ground to a fine powder form that would pass a #1 brass screen (5 mm x 5 mm). Two of the ponds suffered catastrophic dissolved oxygen (DO) depletion during the production period. One episode was caused by the sudden die-off of submerged plants. The second episode was associated with a severe weather event that caused a rapid mixing of the ponds and resulted in a phytoplankton die-off and dissolved oxygen depletion. Supplemental emergency aeration was provided to both ponds but the DO concentrations remained low for several days. As a result of these die-offs, only one pond in each treatment was harvested. Mean water quality parameters fluctuated during the season but remained within ranges reported for previous studies in production ponds fertilized with organic matter. Prior to the DO depletion events, the water quality between the two treatments was similar and relatively stable. Given the lack of final replication, we will not be able to obtain statistical significance for any of the production variables measured. On a per hectare basis, production equaled 342 and 439 kg/ha and food conversion (wt. feed applied/wt. prawns produced) was 1.7 and 1.4, for the powdered and pelleted fertilizers, respectively.

The aim of the third study was to evaluate water quality and the growth and production of Nile tilapia (*Oreochromis niloticus*) polycultured with Silver carp (*Hypophthalmichthys molitrix*) in ponds under treatments (4 replicate ponds/treatment) of fertilization alone (T_1), feeding alone at 100% ration level (T_3), and fertilization combined with feeding at 50% ration (T_2). The experiment was carried out for 120 days, at the Fisheries Field Laboratory, Bangladesh Agricultural University, Mymensingh, Bangladesh. The recorded range of air temperature was 28-32 ^oC, water temperature 30-34.8 ^oC, transparency 19-65 cm, pH 6.79-10.86, dissolved oxygen 1.75-8.48 mg l^{-1}, total alkalinity 8-152 mg l^{-1}, phosphate-phosphorus 0.08-3.0 mg l^{-1}, nitrate-nitrogen 0.00-0.51 mg l^{-1}, nitrite-nitrogen 0.00-0.26 mg l^{-1}, ammonia-nitrogen 0.14-1.57 mg l^{-1}, TDS 25.6-109 mg l^{-1}, conductivity 55-203 µSc m^{-1} and chlorophyll-*a* 2-250 µg l^{-1}. Temperature, dissolved oxygen, alkalinity, nitrite-nitrogen, phosphate-phosphorus and chlorophyll-a did not vary significantly among the treatments. However, transparency, TDS, and conductivity increased in those treatments where supplementary feed was applied. No significant differences were found in stocking weight and survival (%) for both species. The mean harvesting weight of tilapia was significantly lower in T_1 (fertilization alone) than those of T_2 (fertilization plus 50% supplementary feeds) and T_3 (only feeds) groups, while, for silver carp, the mean harvesting weights did not show significant differences among treatments. Specific growth rate (SGR) for tilapia was lower in T_1 compared with the T_2 and T_3 groups. Tilapia in the T_2 group had a significantly higher SGR than fish in the T_3 group. The feed efficiency (or FCR) was 30% better for tilapia in the T_2 compared to the T_3 treatment. Silver carp SGR was slightly higher in the T_1 (2.3) versus T_2 (2.2) and T_3 (2.15) groups. The combined FCR for both tilapia and silver carps showed a similar pattern as that calculated for the tilapia FCRs. The gross and net production performances of tilapia were considerably higher in T_2 and T_3 as compared with T_1, whereas treatment did not alter these variables for Silver carp. The combined net production of the two species was significantly higher in T_2 (4227 $kgha^{-1}$) and T_3 (3845 $kgha^{-1}$) compared with T_1 (1567 $kgha^{-1}$). The T_2 group also had the highest benefit-cost ratio suggesting the polyculture of tilapia and Silver carp on combined fertilizer and 50% ration inputs is more economical than that of fishes raised either on fertilizer or feeds alone. Collectively these results suggest that farmers can grow tilapia with silver carp to both diversify their crops and improve their incomes with no loss in harvested biomass when utilizing combined fertilization and supplemental feeding of commercial diets at the 50% ration level.

STUDY 1. CHARACTERIZATION OF FRESHWATER PRAWN FARMING SYSTEMS AND ASSESSMENT OF WATER QUALITY PARAMETERS IN SOUTHWEST BANGLADESH

INTRODUCTION

Freshwater river prawn (*Macrobrachium rosenbergii*, locally known as ‘golda’) has been predominantly farmed in Southwest Bangladesh and its potential for expansion is favorable due to the wide availability of abundant freshwater ponds, wetlands, and rice-fields. Prawn, as an indigenous species, is widely distributed in the river systems of the Southwest and Southeast regions and estuaries in the Sundarbans mangrove forests (Hoq 2008; Paul 2008).

Around 1978, some local farmers in the Fakirhat area of Bagerhat district began stocking prawn PL in fish ponds on experimental basis (Kendrick 1994). Some innovative farmers developed prawn-farming technology in the low-lying rice fields during mid 1970s–1980s (Rutherford 1994). In the late 1980s, prawn farming practice was widely adopted in the Fakirhat area of Bagerhat district, where prawns were grown along with major carps (rohu, catla, and mrigal) and exotic carps (silver carp, common carp) in rice fields, incorporating a space for refuge of both prawn and fish in the corners of the rice fields (Kamp and Brand 1994). This modified prawn culture system developed in the rice-fields with raised embankment was locally known as ‘ghers’. Over the last 30 years different modifications have evolved based on trial and error by the farmers themselves and there has been diversification in both the systems and crops utilized. While ghers constitute 70% of farming systems utilized, some farmers have permanently converted their rice-fields into ponds for year-round growout of prawns with a short interval after harvest to allow pond preparation for the next crop.

Owing to the disease outbreak in marine shrimp farms, prawn culture expanded in the mid 1990s and continued over the decade. Freshwater prawn farming has further developed and progressed in both ghers and pond systems in the Southwest and Southeastern districts of Bangladesh by 15% (Wahab et al. 2012). There are 94,350 prawn producers with an average size farm of 0.58 ha. Small and medium scale farmers play a large role in pond culture of prawns with an average size farm of 0.20 ha in major producing areas in the Southwest region (Nuruzzaman 2010).

The annual yield of prawns in Bangladesh ranged from 375 to 500 kg ha^{-1} in integrated prawn-rice culture systems, and 450–500 kg ha^{-1} in converted pond culture systems developed from fallow rice fields (Khondoker 2008). In 2008–2009, Bangladesh produced 26,138 MT of prawns from different production systems, while 90% of this production (23,597 MT) was from aquaculture in the Southwestern region (DoF 2010; Rahman 2010), the rest coming from river, floodplain, and wetland capture fisheries.

It is recognized that prawn farming is an important aquaculture activity in Bangladesh and plays a significant role in poverty alleviation, employment generation, foreign exchange earnings, and in improving socioeconomic conditions of farmers and rural poor (Ahmed et al. 2008). Despite the growth of prawn farming in Bangladesh, a number of challenges, including production technologies and post-harvest processing and marketing, have caste doubts on its sustainability. One of the major causes of frustration among the farmers is the unpredictable and variable production levels that may result, in some cases leading to farm losses. Farmers traditionally manage their prawn farms through liming, fertilization and occasional feeding; these may have implications on the water quality and environmental factors, which may be responsible for the varying degrees of production in different farming systems. Water quality of aquaculture systems, including physical and chemical parameters, bottom soil, and sludge may cause the slower growth of prawn, which needs to be evaluated through research. There has been no basic information on the water quality vis-à-vis environmental parameters of the prawn farming ghers or ponds located in Southwest Bangladesh. The aim of this study is to characterize two major prawn farming systems in the Southwest region developed over the years and to compare and contrast the water quality and environmental parameters so as to understand the reasons for variable production performance among the culture units and between the production systems.

MATERIALS AND METHODS

Site of the Experiment

The present study was carried out on prawn farms located in the Dumuria Upazila of Khulna District, Southwest Bangladesh. The area is situated at N22º51´31.1´´ to N22º52´18.4´´ latitude and E89º26´14.9´´ to E89º29´04.7´´ longitude. The experiment was conducted during 120 days from July to October 2012. Eight culture ponds 4 without connection with rice fields and 4 ponds connected with rice fields (ghers), were used for this study. The ponds were located at Salua Union and ghers were located at Ramkrisnapur Union, both in Dumuria Upazila, Khulna District. Pretested questionnaires were used for collection of baseline data on the culture practices and pond characteristics. Collection of stocking data and harvest data were also made through repeated visits to the farm sites at stocking and harvesting times.

Analyses of water quality parameters

Water samples were collected fortnightly from each pond using a plastic pipe inserted vertically from surface to near bottom. The integrated water samples were transferred to plastic containers (2L), allowed to stand still in the container for about 5 minutes, and brought to the laboratory. Water quality parameters such as temperature (ºC), alkalinity (mg/l), salinity (ppt), pH, ammonia nitrogen (mg N/l), nitrite nitrogen (mg N/l), total nitrogen (mg N/l), total phosphorus (mg P/l), total suspended solid (mg/l), dissolved oxygen (mg/l), secchi disc depth (cm), and Chlorophyll-A (µg/l) were analyzed using standard methods. Water temperature (thermometer) and pH (colometric test, Hach Kit, Model-FF-3) were recorded directly from ponds. For dissolved oxygen estimation, water samples were carefully collected in labeled BOD bottles (125 ml) without entrapment of water bubbles. Dissolved Oxygen (DO) and alkalinity were measured by titration using a Hach kit (model FF-3). Ammonia nitrogen and nitrite nitrogen were also determined through colorimetric tests. The measurements of total dissolved solids (TDS), total nitrogen, and total phosphorus were carried out with a Hach kit (DR/2000, direct reading spectrophotometer). Salinity was measured by salinity refractometer (ATAGO S/Mill-E), and water transparency was determined using a Secchi disc. Chlorophyll-A was analyzed following GF/C glass fiber filtration and acetone extraction (Clesceri and Franson, 1998) using the spectrophotometry method. The evaporation rate was simply measured with an evaporation pan and pond depth was measured at the deepest point of the pond.

Collection and analyses of bottom soil samples

Soil was collected twice (prior to stocking and at the time of the last water sampling) from all ponds. Soil samples kept in separate labeled polyethylene bags, brought to the laboratory and stored prior to analysis.

Parameters analyzed in the laboratory condition were pH, texture, organic carbon (%), total phosphorus (ppm), and total nitrogen (%).

Statistical Analysis

Water quality data was recorded, summarized, and analyzed using Microsoft Excel 2007 and PASW Statistics 18 (Predictive Analytics Software, formerly named SPSS) (Field 2009). One-way analysis of variance (ANOVA) and Duncan's Multiple Range Test were used to determine differences between treatment means at a significance level of $P < 0.05$. Ecological processes that account for the main variability of the measured variables were identified through factorial analysis (Kim and Mueller 1978; Milstein 1993). Factorial analysis is a multivariate exploratory technique that allows an assessment of relationships among a set of variables in terms of a limited number of new variables, which are assumed to be responsible for the covariation among the observed variables. From the several available techniques to extract factors, principal components (Seal 1964; Jeffers 1978) calculated from the correlation matrix among variables were used here. The first factor extracted from that matrix is the linear combination of the original variables that accounts for as much of the variation contained in the samples as possible. The second factor is the second linear function of the original variables that accounts for most of the remaining variability, and so on. The factors are independent of one another, have no units, and are standardized variables (normal distribution, mean=0, variance=1). The coefficients of the linear functions defining the factors are used to interpret their meaning, incorporating the sign and relative size of the coefficients as an indication of the weight to be placed upon each variable. One-way ANOVA and Duncan tests were applied to test the effect of treatment (with or without rice culture in the prawn ponds) on each factor extracted. These analyses were carried out using the Statistical Analysis System program (SAS 2000).

RESULTS

Prawn culture in pond systems

The pond systems were rectangular shaped, had an average depth of 1.5 m, and a surface area ranging from 0.4 ha to 1 ha. In this culture system, the main water sources were rainfall and ground water. Prior to starting culture, all ponds were dried completely for two weeks, tilled by tractor, limed at 250 kg ha^{-1}, treated with rotenone (2.5 kg ha^{-1}) for controlling undesirable species, and filled with rain water during mid June. Hatchery-produced post larvae prawns (5 mm length) were stocked at a low density (20,000 ha^{-1}) typical of that in the Khulna Area. No fertilizer was provided for pond culture systems. Both processed and farm-made supplementary prawn feed was used in this culture system. Small-size processed feed (CP feed, Thailand; and Mega starter, Bangladesh; feed containing 40% crude protein) was used during the first month, and medium-size feed (CP feed, Mega grower containing 30% crude protein) was used during the rest of the culture period. Some homemade (prepared from snail, rice bran, wheat bran, daal) supplementary feed was also used. Prawns were fed twice daily, via a feeding tray placed at the corner of each pond, during early morning and evening. Major harvest of prawns started after 5-6 months of stocking in November to December. Partial harvesting was continued up to April-May of the following year. The average prawn size at harvest was 60-150 g, with larger sizes found during the major harvest.

Prawn culture in "ghers" systems

In the Khulna region, freshwater ponds are mostly cultured in modified rice fields, referred to as the "gher" system. Gher is developed through building higher dikes around the rice fields and excavating a canal inside the periphery to retain water during the dry season. In this culture system, the selected four ghers ranged from 0.4 ha to 6.8 ha with depths ranging from 1.5 to 2.0 m. Prior to culture, modified rice ponds were completely dried, tilled by tractor, and limed at 250 kg ha^{-1}. Farmers used phostoxin tablets, geolite, and bleaching powder as preparatory measures for controlling undesirable fish species. The principal water sources of the ghers are rainfall, ground water pumped as needed, and canals connected with nearby water-bodies. During the rainy season (July-October) the entire gher was inundated and used for cultivation of prawns. However, in the dry season (January – May), farmers cultivate boro rice in the central plateau of the gher, with the trenches holding prawn as refuge. In these gher systems, farmers stocked PL prawn at 25,000 ha^{-1} (8 mm length) during mid June to early July. Ghers were fertilized with urea (25 kg ha^{-1}), triple super phosphate (13 kg ha^{-1}), and mustard oil cake at the standard rate usually applied in the region. Prawns were fed farm made feeds consisting of a mixture of fishmeal, rice bran, mustard oil cake, mollusks, and wheat flour. They also used commercial feed (Mega starter, Mega grower, Quality feed, Bangladesh feed, containing 30-35% crude protein). Adult prawns were harvested primarily from November to January, after a culture period of around 6 months. The average size of prawn at harvest was from 50-120 g.

Assessment of Water Quality using Multivariate analysis

Factorial analyses were run to identify the main ecological processes affecting water quality in the ponds. Total nitrogen, total phosphorus, and total dissolved solids were not included in the factor analysis because each of these variables has several components with different ecological behavior, which makes it difficult to or can compromise interpretation. Table 3 presents the results of the factorial analysis and ANOVA on the extracted factors performed. Three factors were identified, which together accounted for 63% of the overall variability of the data. The ANOVA models of the three extracted factors showed no significant treatment by date interaction, so an ANOVA testing only for main effects was run and is herein presented.

The first factor (Factor1) accounted for 37% of the overall variability of the data. It is a bipolar factor, with water depth and transparency positively correlated between them; salinity, alkalinity, and nitrite positively correlated among them; and both variable groups negatively correlated between them. It shows the combined effects of rain and liming on the water quality of the ponds/ghers, both starting together at the beginning of the experiment and with decreased effects by the end of the experiment. Rain accounts for the negative correlation between water depth and salinity and the positive correlation between water depth and transparency. Rain increases water level in the ponds/ghers, diluting salts and resuspending particles that decrease water transparency. Liming accounts for the positive correlation between alkalinity and nitrite. Liming increases the alkalinity of the water and promotes decomposition of organic matter accumulated on the bottom, which liberates ammonium into the water. Nitrifying bacteria transform ammonium first into nitrite (*Nitrosomonas*) and then into nitrate (*Nitrobacter*), decreasing ammonium and increasing oxygenated nitrogen forms in the water. However, *Nitrosomonas* develop faster than *Nitrobacter* so that prior to the establishment of both nitrification steps, nitrite may accumulate in the water (e.g. Avnimelech et al., 1986; Azov & Tregubova 1995; Prinsloo et al., 1999). *Nitrobacter* is more inhibited by water mixing (Azov & Tregubova 1995) than *Nitrosomonas*, which increases the nitrite accumulation effect during the rainy period when rain mixed water and resuspended particles decreased water transparency. The ANOVA model applied accounted for 90% of the variability of Factor1, almost all due to date. Factor 1 started with high values after the pond preparation with liming and PL stocking. It decreased during the rainy period (Jul-Aug) as rain increased water level and turbidity and decreased salinity, and only when the second step of nitrification was established did nitrite levels decrease. From mid September onward there was no rain, so water depth and transparency stayed at their highest levels and salinity, alkalinity, and nitrite at their lowest levels. The treatment main effect indicates that Factor1 was higher in the ponds where rice was previously cultured.

The second factor (Factor2) accounted for a further 16% of the overall variability of the data. It is a bipolar factor, with ammonium negatively correlated with dissolved oxygen. It shows the opposite effects of decomposition and photosynthesis on oxygen and ammonium content of the water. Through decomposition, oxygen is consumed and ammonium is released into the water, while through photosynthesis, ammonium is absorbed and oxygen is released into the water. High Factor2 values indicate dominance of decomposition and/or low photosynthesis, while low Factor2 values indicate dominance of photosynthesis and/or low decomposition. The ANOVA model applied accounted for 61% of the variability of Factor2, most of all due to date and only 5% due to treatment. After pond preparation and before PL stocking decomposition was low and photosynthesis was high. Intensity of decomposition increased during July, was maximum in August when the highest water temperatures were recorded (31-32°C *vs.* 29-30°C in the other months), and stabilized in an intermediate level until the end of the sampling period. By contrast, photosynthesis decreased during the rainy period when light was limited by cloudiness and mixed water, and stabilized at a higher level when rain stopped and sunshine and calm waters were enhanced and ammonium absorption increased. Photosynthesis was higher in the ponds in which rice was previously cultured since they received fertilizers during pond preparation, and decomposition was higher in only-prawn ponds. The mild differences between treatments were most evident in July and August relative to September and October.

The third factor (Factor3) accounted for a further 13% of the overall variability of the data. It shows positive correlations among chlorophyll, pH, and dissolved oxygen, which reflects another aspect of photosynthesis, this time related to phytoplankton biomass and oxygen release. The ANOVA model applied accounted for only 23% of the variability of Factor3, half of it due to treatment and the other half being insignificant. Phytoplankton biomass and oxygen production were higher in only prawn ponds than in ponds where rice was previously cultured.

Analyses of Soil Samples

Soil was collected twice (prior to stocking and at the time of the last water sampling) from all the ponds as shown in Table 4. The textures of soil were silt loam and silt clay loam in modified pond culture systems, whereas in gher systems, clay, silt loam, silt clay, and silt clay loam were the main soil constituents. Available soil pH was observed from four ponds of each treatment. The mean soil pH was recorded 7.1 ± 0.30 in pond culture. In this system, available pH in sediment was found to be lowest (6.5) in early July and highest (7.5) in the month of October. The mean soil pH was 6.5 ± 0.64 in gher culture systems. In this system, lowest pH was 5.4 and highest was 7.0 in the month of October. The mean soil organic carbon content was 1.6 ± 0.3 % in pond systems with the lowest and highest values at 1.0 and 1.9%, respectively. The mean soil organic carbon content was found 2.5 ± 1.25 % in gher systems. In this system, the lowest organic carbon was observed (1.3%) in early July and the highest (4.5%) at the end of October. The mean soil available phosphorus levels were 15.80 ± 4.8 ppm in pond systems. In gher systems, on the other hand, the mean soil phosphorus level was 11.94 ± 3.9 ppm. The mean total nitrogen in sediment was 0.15 ± 0.02 % and 0.23 ± 0.11 % in pond and gher systems, respectively.

Prawn Production in Gher and Pond Systems

Table 5 showed that the average prawn production from the pond culture systems was 407.5 ± 15.55 kg/ha and that from gher system was 335 ± 19.15 kg/ha. The production of rice and fruits/vegetables has yet to be collected for understanding the overall benefit of the gher system.

DISCUSSION

Characterization of farming system: Farmers innovation and rationale

Two types of farming systems, one in the modified pond and the other in gher systems, have evolved in the Southwest greater Khulna region of Bangladesh. In pond systems, prawns are cultured for longer periods with a short dry season for pond preparation and re-excavation. In gher systems, rice is farmed and after harvest the entire field is inundated with water for prawn growout. Gher prawn culture is only done for one season from June/July to November/December, while ponds are used for the whole year from June to May.

Multivariate analysis of water quality

The observed values of the variables are the result of different processes that occur simultaneously in the ponds. Since the water samples integrate water from the entire water column, the values observed are affected by processes acting at the surface and bottom. For example, the observed oxygen content of the water sample is affected by photosynthesis occurring in the surface layers and by decomposition occurring mainly in the bottom layers. Factor analysis, a multivariate method based on correlations among variables, allowed identification of the main ecological processes affecting water quality in the ponds.

Water quality variability with time

Figure 1 presents the tridimensional plot of the three factors extracted, showing time variability. In July, after liming and with the start of rains, salinity and alkalinity were high and water depth and transparency low (Factor1 high) with high photosynthesis and low decomposition (Factor2 low). Phytoplankton biomass (Factor3) presented a wide range of values among ponds (most July points in the upper right section of the figure, from front to back). With time the effects of liming decreased, those of rain accumulation increased, nitrification and decomposition of organic matter developed, but cloudy weather and still turbid waters did not allow phytoplankton biomass and photosynthesis to increase. Thus, in August, Factor1 values were still high but lower than in July, Factor2 strongly moved towards increased ammonium release due to decomposition, and Factor3 concentrated more into the mid-value range (most August points in the mid-height left mid-depth section of the figure). When rain stopped phytoplankton biomass did not change much (Factor3 continued in mid values) but photosynthesis was more efficient (Factor2 moved right), so that most September-October points are down and in the center of the Factor2*Factor3 surface.

Water quality variability between treatments

Variability between treatments was very small as compared to the variability in time due to rain, and was related to different management procedures, as expected. The differences in Factor1 between treatments seem to be related to water depth, which were deeper in ponds where prawns only are grown. The prawn ponds are relatively deeper than the ghers as the latter are used for rice farming, therefore maintained at a lower depth. The trenches in the ghers, however, are of similar depths of the prawn ponds.

Differences in Factor2 between treatments were related to the previous history of the ponds. Before the experiment, the ponds were used either for rice or for prawn culture. In June, all ponds were tilled and prepared for the new prawn culture season. This action mixed organic matter remaining from the previous cultures with the soil of the pond bottom. Since organic matter accumulated in prawn culture is more readily degradable than rice straw, decomposition was more pronounced in ponds where only prawns are grown (more positive Factor2 values). Together with this, photosynthesis in rice ponds was enhanced by fertilization at pond preparation time (more negative Factor2 values), a procedure that was not applied to prawn ponds.

Differences in Factor 3 between treatments were related to differences in prawn stocking density and not to the previous rice or prawn culture in the ponds. Prawn stocking density was 17% lower in ponds relative to gher systems. The lower prawn density exerted lower grazing pressure on the phytoplankton, leading to higher chlorophyll and oxygen production than in the other ponds.

CONCLUSIONS AND RECOMMENDATIONS

- Most of the water quality variability observed in this study occurred over time, related to the effects of heavy rains at the beginning of the culture period. Only a small part of the variability was due to treatment, linked to management procedures.
- The production of prawns in gher systems was significantly lower than that of the modified pond culture system.
- However, the overall socio-economic benefits and sustainability may be enhanced in the gher culture system that integrates both rice and prawn for ensuring food security for the farming households.

- Increased utilization of nutrient sinks in the bottom mud allows for better replenishment of gher culture systems.
- Bottom mud of pond systems, and of gher systems to a lesser extent, may be utilized for dyke cropping of seasonal vegetables as well as short duration fruit crops.
- Further research on the potential for integrating prawns that are destined for export, with finfishes and with dyke cropping can enhance domestic consumption of protein and micronutrients for improving nutritional security of households.

STUDY 2: EXPERIMENTAL POND ASSESSMENT FOR PRAWN CULTURE IN EASTERN NORTH CAROLINA

This experiment evaluated water quality and production parameters using pelleted and powdered fertilizers on prawn growout in experimental ponds in Eastern North Carolina. Prawn farming has become popular in NC and Southeastern United States, particularly for small farmers. We evaluated water quality and production parameters of prawn grown in ponds with application of pelleted and powdered fertilizers, both to assess responses in pond dynamics that could be used for future work aimed at improving management practices both in Bangladesh and the U.S.

MATERIALS AND METHODS

Four, 0.10-ha earthen ponds were stocked with juvenile *Macrobracium rosenbergii* obtained from a commercial hatchery. A total of 3,000 animals (avg. wt. 0.14 g) were stocked into each pond (30,000/ha) in June at the Tidewater Research Station in Plymouth, NC. The ponds received feed and fertilizer inputs according to protocols established for the management of the ponds. A variety of physical and chemical analyses were performed on all the ponds (Egna et al. 1987; APHA et al. 2012).

Two organic fertilizer treatments were evaluated to determine their effects on water quality dynamics and production variables. One treatment (Pelleted Fertilizer) consisted of a large (4 cm diameter), dense, compact, water stable pellet made from a mixture of grain byproducts. The second treatment (Powdered Fertilizer) used the same ingredient mixture but the pellets were ground to a fine powder form that would pass a #1 brass screen (5 mm x 5 mm). Our hypothesis was that the higher surface area of the ingredients in the Powdered Fertilizer treatment would result in more rapid breakdown of the ingredients and lead to greater daily fluctuations in water quality variables. The ponds were harvested in September after a 104-day culture period. Total prawn production was determined and average weights were calculated to estimate survival. Due to a limited availability of ponds and larvae, only 2 ponds per treatment were stocked.

RESULTS AND DISCUSSION

Two of the ponds (nos. 11 and 14; Table 6) suffered catastrophic dissolved oxygen (DO) depletion during the production period. One episode was caused by the sudden die-off of submerged plants. The second episode was associated with a severe weather event that caused a rapid mixing of the ponds and resulted in a phytoplankton die-off and dissolved oxygen depletion. Supplemental emergency aeration was provided to both ponds but the DO concentrations remained low for several days. As a result of these die-offs, only one pond in each treatment was harvested. Given the lack of final replication, we will not be able to obtain statistical significance for any of the production variables measured. However, several observations about the water quality dynamics and the hydrologic variables can be made based on the collected data.

Mean water quality parameters fluctuated during the season but remained within ranges reported for previous studies (reviewed by Boyd 1990) in production ponds fertilized with organic matter (Table 7). Prior to the DO depletion events, the water quality between the two treatments was similar and relatively stable. Phosphorus values are several times higher than those normally reported in the literature. Based on our 20 years of experience with these ponds and with the water source (Castle Hayne aquifer with high hardness), these phosphorus concentrations are typical and furthermore do not appear to indicate excessive fertilization. Indeed, the phosphorus levels remain high throughout the production period but do not contribute to phytoplankton production. Chlorophyll-α and Secchi disk values remained at relatively moderate and stable levels in all ponds throughout the summer months, despite the presence of high amounts of orthophosphate. We have hypothesized that the phosphorus analysis itself (ascorbic acid method) is detecting different chemical forms of phosphorus that are non-reactive, which leads to artificially high measured levels.

Final production and mean harvest weight of prawns are within values cited in the literature for heavily fertilized earthen ponds (Table 8; D'Abramo et al. 2009). On a per hectare basis, production equals 342 and 439 kg/ha. Food conversion (wt. feed applied/wt. prawns produced) is 1.7 and 1.4, respectively.

The physical characteristics of the ponds, including the evaporation and seepage values, were determined for the four ponds during the production period (Table 9). All four ponds were constructed at the same time and were very similar in dimension (surface area and depth). Evaporation values were determined from published pan evaporation rates provided by National Weather Service automated station located within 1 km of the ponds. Evaporation values are slightly higher than those reported for many other aquaculture ponds. Wind velocity in the area where the ponds are located is relatively high and constant, which contributes to elevated evaporation rates. Mean seepage values were determined in several ponds during the course of the production period. These values are relatively low and within other published values for earthen ponds constructed on coastal plain soils.

Twenty-four hour sampling of the ponds revealed very little stratification of the water column during the first month (June; Figure 2) of the production cycle when the ambient daytime temperatures were lower and the phytoplankton abundance was also relatively low (Table 6). Thermal stratification was very evident in September (Figure 2) when air temperatures were much higher and phytoplankton abundance was greater, which prevents light penetration to the lower levels of the water column.

SUMMARY

Statistical comparisons between treatments were complicated by the catastrophic die-off and subsequent DO depletion in two ponds. However, water quality, production, and hydrologic variables were similar to those reported in the literature for heavily fertilized earthen ponds used for freshwater prawn production. Future studies should incorporate a higher number of replicates to increase the power of statistical comparison according to the variation inherent in water quality and production data.

STUDY 3. ASSESSMENT OF WATER QUALITY AND PRODUCTION POTENTIALS OF EXPERIMENTAL POND UNITS FOR THE POLYCULTURE OF TILAPIA AND SILVER CARP IN BANGLADESH

INTRODUCTION

Polyculture is a system in which species with distinct feeding niches are used in different proportions within the same pond to improve utilization of natural pond organisms and external feed inputs for better fish production (Jhingran 1995). Inland aquaculture in Bangladesh mainly consists of three Indian major carps and two/three Chinese carps grown in polyculture systems. The culture system is mostly fertilized and supplementary fed with rice bran and oil cake. The exotic Silver carp (*Hypophthalmichthys molitrix*) is an important candidate species in polyculture systems in Bangladesh (Kadir et al. 2007). It is a filter feeding omnivore that prefers natural food organisms enhanced through fertilizers or supplementary feed inputs provided to ponds. The culture of Nile tilapia (*Oreochromis niloticus*) has recently emerged in Bangladesh and is now the 2nd most abundant cultivar outside of carps. This species is largely monocultured in ponds with the use of significant feed inputs alone. Tilapia can be grown in mono and polyculture systems and evidence suggests the latter practice gives higher production than that of monoculture (Khouraiba et al. 1991). However, a full assessment of utilization of carp in tilapia culture has yet to be tested in Bangladesh under semi-intensive conditions whereby fertilizer and supplementary feeds are used in culture. Fertilizers are 10-15% the cost of feeds and their utilization is strongly correlated to enhanced growth of fish due to improved phytoplankton and zooplankton productivity (Abbas and Hafeez-Ur-Rehman, 2005) that can be utilized by both tilapia and carp. The use of fertilizers along with supplementary feed also improves soil fertility as well as increase pond productivity (Batterson 1994; Diana et al. 1996; Feng et al. 2005; Goyal et al. 2005). Tilapia tend to concentrate their feeding activity on supplemental feed, while silver carp utilizes natural productivity enhanced through fertilizer (Almazan and Boyd 1978; Egna and Boyd 1997; Lin 1997). Therefore, higher pond yields may be attained through application of fertilizer and feed in tilapia and silver carp polyculture. Studies show that tilapia monoculture is more efficient under a pond management practice that incorporates fertilization combined with 50% satiation feeding with commercial diet than that with fertilization alone or feeding a commercial diet at 100% satiation alone (Diana et al. 1994). Whether a similar efficiency can be attained when tilapia are polycultured with silver carp is unknown.

The aim of this study was to assess water quality, fish production, and economics of tilapia and silver carp polyculture in ponds under different management strategies that incorporate fertilization alone, full ration feeding alone, and a combination of fertilization and feeding at 50% ration level.

MATERIALS AND METHODS

Experimental site and design

The present study was conducted for 120 days at the Fisheries Field Laboratory, Bangladesh Agricultural University, Mymensingh, Bangladesh. The fish species Nile tilapia (*Oreochromis niloticus*) and Silver carp (*Hypophthalmichthys molitrix*) were stocked in 12 ponds in a completely randomized design allocated to three treatments (see table below): T_1) fertilization alone (Urea 60 kg ha^{-1} and TSP 35 kg ha^{-1} per week), T_2) fertilization and supplementary feeding (Urea 60 kg ha^{-1} and TSP 35 kg ha^{-1} per week plus commercial pelleted tilapia feed daily at half the ration typically applied to commercial production), and T_3) feeding alone daily at the full ration typically applied to commercial production in Bangladesh (20% down to 5% of body weight).

Treatments/Factors	Treatment 1	Treatment 2	Treatment 3
Stocking			
Tilapia	200	200	200
Silver carp	25	25	25
Fertilization/feeding	Fertilization alone	Fertilization + 50% Feed	100% Feed alone

Each earthen pond had an area of 2.5 acres (100 m^2) and depth of 1.0 m. The depth was maintained at 1.0 m during the experiment. Prior to the experiment, all ponds were completely dried for two weeks. Lime was applied at 0.025 kg m^{-2}. Four days after liming, the ponds were filled in with water from an adjacent deep tube-well. All ponds were fertilized initially with urea and triple super phosphate (TSP) at the rates of 60 kg ha^{-1} and TSP 35 kg ha^{-1}, respectively. The fertilization rate is similar to that previously reported whereby the efficiency of tilapia in monoculture is greatest with combined fertilization and 50% satiation feeding than with either fertilization alone or feeding to satiation alone (Diana et al. 1994). After this, urea and TSP were mixed together and applied weekly to ponds for the appropriate treatment groups by spreading. Tilapia (5.39 ± 0.13 cm length and 3.0 ± 0.18 g weight) and silver carp fingerlings (14.03 ± 0.26 cm length and 18.2 ± 1.18 g weight) were stocked 2 weeks later with 200 tilapia (2 tilapia m^{-2}) and 25 silver carp (0.25 carp m^{-2}) respectively. Only commercial pelleted tilapia feed (non floating; 30% crude protein and 5% fat; Mega feed, Bangladesh) was used twice daily (at 07:00 am and 18:00 pm). Following stocking, fish were fed the full ration amount (treatment-3, T_3) at a rate of 20% of body weight (BW) for 30 days, then 15% BW for 30 days (through 60 days post-stocking), 10% BW for 30 days (through 90 days post-stocking), and 5% body weight until harvest. This feeding rate follows that typically being used by tilapia farms in Bangladesh. In treatment-2 (T_2), feed was used at half of the estimated daily feeding rate as that used for T_3, i.e., 10% after stocking for 30 days, reduced to 7.5% from day 30-60 post-stocking, 5% from 60-90 days post-stocking, and 2.5% until harvest. Monthly sampling was made to assess growth (20 fishes of each species of tilapia and silver carp) and to adjust the feeding rate. Weights and lengths of 20 randomly chosen fishes of each species were determined during monthly sampling. At the end of the experiment, fish were harvested by repeated netting using a seine net and then by de-watering the ponds using low-lift pump. Total number and average weight of tilapia and carp was used to assess total biomass of fish at harvest. Mean weight gain (mean final weight - mean initial weight), total weight gain (total harvest weight - total stock weight), specific growth rate (SGR= $[(\ln weight_f - \ln weight_i)/(time_f - time_i)] \times 100$), and feed conversion ratio (feed consumed/body weight gain), and survivorship were calculated for the experiment.

Analyses of water quality parameters

Water samples were collected weekly from all ponds in 250 ml plastic bottles. Integrated samples were collected covering vertical layers of the water column (using vertical haul of the tube sampler covering about 3-4 feet depth). Water temperature was recorded with a Celsius thermometer. Transparency was measured with a Secchi disc of 20 cm diameter. Dissolved oxygen and pH were measured by a portable multi-parameter meter (HACH sension[tm] 156). The total alkalinity, nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonia-nitrogen (NH_3-N), total dissolved solid (TDS), conductivity, and phosphate-phosphorus (PO_4-P) were determined using HACH Kit (DR - 4000, a direct reading spectrophotometer). Chlorophyll-A was analyzed spectrophotometrically following GF/C glass fiber filtration and acetone extraction (Clesceri and Franson 1998).

Cost-benefit analysis

An economic analysis of different treatments was performed on the basis of expenditure incurred and the total estimated return from the selling price of tilapia and silver carp. All input costs were recorded. The net benefit was calculated using the following formula: Net benefit = total sale - total investment. Benefit-cost ratio was calculated as total returns ÷ total investment.

Statistical Analysis

Water quality data were recorded, summarized, and analyzed using Microsoft Excel 2007 and PASW Statistics 18 (Predictive Analytics Software, formerly named SPSS) (Field 2009). One-way analysis of variance (ANOVA) and Tukey's multicomparison test were used to determine differences between treatment means at a significance level of $P < 0.05$.

RESULTS

Environmental parameters

Table 9 and Figures 3-15 presents mean water quality data among treatments over the course of the experiment. Air temperature, water temperature, DO, alkalinity, nitrite-nitrogen, phosphate-phosphorus, and chlorophyll-a did not vary significantly among the treatments. However, transparency, TDS, and conductivity varied significantly among the treatments, with higher values seen with full feeding and intermediate values with combined feeding and fertilization. The pH, nitrate-nitrogen, and ammonia-nitrogen were marginally significant among the groups. TDS increased during the first month with initial development of the ecological system, and then moderate as optimum temperature allowed greater decomposition rates. Conductivity presented a rather similar pattern. The patterns of ammonia, nitrite, and nitrate were affected by liming (performed before fish stocking) with increasing values after each application that subsequently decreased thereafter. The temperature remained relatively constant showing some decrease at the end of July and into early August due to heavy rains. Oxygen was generally high, around 6 mgl^{-1} during stocking and about 4.5 to 5.0 $mg\ l^{-1}$ thereafter.

Growth and production performance of tilapia and Silver carp

Growth, survival, and production performance of tilapia and silver carp are shown in Table 10 and Figures 16 and 17. Initial stocking weight was similar in all groups for both species. The mean harvesting weight of tilapia was significantly lower in T_1 (fertilizer alone) than those of T_2 (fertilizer + 50% supplementary feed) and T_3 (only supplementary feed at 100% ration level). There were no significant differences in mean harvest weight for silver carp among treatments. Survival for silver carp (92-100%) and tilapia (81-89%) was high and did not differ among the treatment groups. Specific growth rate (SGR) for both tilapia and silver carp varied significantly among three treatments, being highest in the T_2 and T_3 groups for tilapia (22-23% increase over T_1 group). Feed conversion ratio (FCR) for tilapia was significantly lower (greater feed efficiency) in the T_2 compared with the T_3 group. Combined FCR (for both tilapia and silver carps) presented rather similar pattern. The gross and net production performances of tilapia were considerably higher in T_2 and T_3 as compared with T_1, whereas, no difference in this parameter was seen for silver carp among the treatments. The combined net production of two species was significantly higher in T_2 (4227 $kgha^{-1}$) and T_3 (3845 $kgha^{-1}$) relative to the T_1 (1567 $kgha^{-1}$) treatment.

Cost-benefit analysis

The results of benefit-cost analysis are shown in Table 11. The major variable input costs were mainly due to supplemental feed. Seed also accounted for considerable portion of input costs. The total investment was slightly higher in T_3 than in T_2, and both these groups had greater input due to feed costs relative to the T_1 group. The highest net benefit was estimated in T_2, followed by T_3 and T_1, respectively. Treatment two (T_2) showed a significantly higher benefit-cost ratio than T_1, but not with T_3.

DISCUSSION

The ponds used in the experiment were similar in size, shape, depth and source of water. Temperature, dissolved oxygen, alkalinity, nitrite-nitrogen, phosphate-phosphorus, and chlorophyll-a did not vary significantly among the treatments. Nitrate-nitrogen, pH, and ammonia-nitrogen were marginally significant, while transparency, TDS, and conductivity were higher in groups that were fed commercial diets with or without fertilization, and lowest where fertilization was used alone. Nevertheless, the water quality parameters recorded in treatments T_1, T_2, and T_3 were found within the suitable range of fish culture.

Water transparency grossly indicates the presence or absence of natural food particles as well as productivity of a water body. Wahab et al. (1995) suggested that the transparency of productive water should be 40 cm or less. During the study period, water transparency ranged from 19 to 65 cm, which was similar with the findings of Kohinoor et al. (2001) in polyculture of small indigenous fishes. In ponds in Thailand that received little fertilization, Secchi disc depth (SDD) averaged 50 cm for most of a fish grow out period (Diana et al. 1987), however, in Panama (Hughes et al. 1991), Indonesia (McNabb et al. 1988), and Rwanda (Hanson et al. 1989), SDD averaged 20 to 30 cm in lightly fertilized ponds. It would appear that productivity was less depleted in ponds where fertilization was used alone than that of ponds where commercial feed was applied.

Water temperature is one of the most important water quality parameters that influences growth, food intake, reproduction, and other biological activities of aquatic organisms. In addition to seasonal effects (Egna and Boyd 1997), water temperature can also exhibit vertical stratification in shallow tropical ponds. Diana et al. (1991a) found 3 to 5 ºC differences in temperature from the top to the bottom of the pond water column in Thailand. In the current experiment, water temperature fell within the suitable range (30 to 34.8ºC) for both tilapia and carp in the three treatments. pH is considered as an important factor in fish culture and is treated as the productivity index of a water body. The mean values of pH in the present experiment were 8.95, 8.70, and 8.50 in T_1, T_2, and T_3 treatments, respectively, which are well within the range found for pond culture practices in Bangladesh.

Dissolved oxygen concentration is one of the vital water quality parameters in aquaculture. Over the course of a day, oxygen levels can change even more dramatically than temperature. Diana et al. (1991b) showed oxygen variations of up to 10 mg l^{-1} from daytime lows to highs for surface waters of ponds in Thailand. The mean values of oxygen concentration in the present experiment were 5.35 (±0.12) mgl^{-1}, 5.32 (±0.19) mgl^{-1} and 5.22 (±0.15) mgl^{-1} in the T_1, T_2, and T_3 treatments, respectively. The concentration of dissolved oxygen in the experimental ponds ranged from 1.75 to 8.48 mgl^{-1}. Boyd (1990) showed that alkalinity below 30 mgl^{-1} as $CaCo_3$ limits primary production in well-fertilized ponds, while in unfertilized ponds alkalinities below 120 mg l^{-1} can reduce primary production. In another experiment, total alkalinity values ranged from 19.0 to 155 mg l^{-1} (Chowdhury et al., 2000). Total alkalinity in the present study ranged from 8 to 152 mg l^{-1} indicating a suitable range for fish culture. There were no differences in alkalinity among the three treatments, which averaged between 91.95 and 95.57 in the present investigation.

The availability of nitrogen is important to primary productivity in fish ponds. Inorganic nitrogen in ponds exists mainly as nitrate, nitrite, ammonia, and ammonium. The presence of different forms of nitrogen is affected by pH, oxygen concentration, and organisms that may produce or consume certain forms of nitrogen (Boyd 1990). Considering nitrogen as a nutrient, algal cells generally take in nitrogen as nitrate, although ammonia may also be utilized by phytoplankton (Knud-Hansen et al. 1991). In order to maintain high levels of primary production, nutrients must be provided in relationship to the needs of plankton and to supplies available from allochthonous sources. CRSP fertilization experiments have documented nitrogen limitation when ponds were fertilized with chicken manure at high inputs (Diana et al, 1991b; Knud-Hansen et al. 1993, Teichert-Coddington et al. 1992). CRSP fertilization experiments to date demonstrate that high rates of primary production occur when N and P are both provided as inputs, usually at rate of 4N:1P (by mass) and a total application of 28kg N and 7 kg P per hectare per week (Knud-Hansen and Batterson 1994). The availability of phosphate-phosphorus is essential for phytoplankton, the primary producer of waters. In the present experiment, the phosphate-phosphorous (PO_4-P) concentration ranged from 0.08 to 3.0 mgl^{-1}. In Bangladesh aquaculture ponds, Uddin (2002) and Rahman (2005) recorded phosphate-phosphorus values of 0.03 to 4.46 mg l^{-1} and 0.21 to 4.0 mg l^{-1}, which encompasses the range observed here for tilapia and Silver carp polyculture. Chlorophyll-*a* (μgl^{-1}) is the indicator of pond productivity, which shows an inverse relationship with water transparency. In the present experiment, the mean (± SE) values of chlorophyll-*a* were 63.4 (±6.39) μgl^{-1}, 72.11 (±6.95) μgl^{-1}, and 74.31 (±5.68) μgl^{-1} in T_1, T_2, and T_3 treatments.

The growth rate of tilapia was comparatively low in T_1 (fertilization only) than those of T_2 (fertilizer plus 50% supplementary feed) and T_3 (only supplementary feed at 100% ration level). The mean harvesting weights of silver carp were 286.08g (±19.59), 254.25g (±15.82), and 240.25 (±10.34) in T_1, T_2, and T_3, respectively, which falls within the range of previous studies where mean weight ranged from 189.9 to 280.35 g (Ahmed 2005).

In the1980s, fish yields obtained from manure-fertilized ponds were reported to range from 7 to 36 kg ha/d (2,555 to 13,140 kg/ha/yr) (Buck et al. 1979; Wolhfarth et al. 1980; Barash et al. 1982; Wolhforth and Hulata 1987). Almost all the high yield ponds (> 30 kg/ha/d) in those reports were polycultured with tilapia and Chinese carps, where both common and silver carps accounted for a large portion of the total yields. In the 1990s, semi-intensive culture of tilapia has gradually gained popularity in developing tropical countries. The yields of tilapia monoculture from manured ponds ranged from 8.6 to 19.2 kg/ha/d (Diana et al. 1991; Green et al. 1994). These yields were comparatively lower than those of Israeli polyculture (20 kg/ha/d) systems (Milstein et al., 1991). In the 2000s, in Bangladesh, Fatema (2004), Uddin (2007), and Rahman (2005) obtained tilapia production in periphyton-based, prawn polyculture systems that ranged from 2711.6 kg ha^{-1} to 3,523.3 kg ha^{-1}; 2,155.1 kg ha^{-1} to 3,445.2 kg ha^{-1}, and 3,562.4 kg ha^{-1} to 4,309.6 kg ha^{-1}, respectively. In this current experiment, the net production of tilapia over a period of 120 days was 947.5 (± 100.9) kg ha^{-1}, 3592.5 (± 174.6) kg ha^{-1}, and 3332.5 (± 259.5) $kgha^{-1}$ in T_1, T_2, and T_3, respectively. The best feed efficiency or lowest feed conversion ratio was for tilapia raised on fertilizer and supplementary feed at 50% ration level. The net production performances of silver carp were 620 (± 132.2) kg ha^{-1}, 635 (± 110.9) $kgha^{-1}$, and 512.5 (± 88.35) $kgha^{-1}$ in T_1, T_2, and T_3, respectively. The highest net production of silver carp was obtained in T_2 and the lowest in T_3. Paul (1998) and Nahid (2006) obtained Silver carp production of 390.1 kg ha^{-1} to 471.3 kg ha^{-1} and 457.30 to 794.32 kg ha^{-1}, which was comparable to the present study.

The total production of tilapia and Silver carp was highest with fish raised on combined fertilizer and supplementary feed at the 50% ration level relative to those raised on fertilizers or 100% feed ration alone, which is similar to previous results seen with tilapia grown in monoculture (Diana et al. 1994). The T_2 group also had the best feed efficiency and the highest benefit-cost ratio, suggesting the polyculture of tilapia and Silver carp on combined fertilizer and 50% ration inputs is more economical than that of fishes raised either on fertilizer or feeds alone. Collectively, these results suggest that farmers can grow tilapia with silver carp to diversify their crops with no loss in biomass harvested and improve their incomes with combined fertilization and supplemental feeding of commercial diets. Further studies are needed to establish if higher stocking densities or even lower feed rations might provide additional cost savings to farmers who adopt carp and tilapia polyculture in Bangladesh.

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Table 1. *Characterizations of prawn pond farming systems in Southwest Bangladesh.*

Pond ID	Shape, Size & Water Depth	Water Source & availability	Stocking Density & PL Size	Pre-stocking Management	Post-stocking Management	Feed Type	Farming Period
01	Rectangular, 0.4ha, 1.5m	Rainfall & ground water, 12 months	25,000ha^{-1}, 5mm	Tilling: By Tractor Liming: 250 kgha^{-1} Fertilizer: N/A	G.C: 15 days Interval F.T.C: Daily	Mega Starter, grower, farmed made	June-April/May
02	Rectangular, 1.0 ha, 1.5m	Rainfall & ground water, 12 months	20,000ha^{-1}, 5mm	Tilling: By Tractor Liming: 250 kgha^{-1} Fertilizer: N/A	G.C: 15 days Interval F.T.C: Daily	Mega Starter, grower, farmed made	June-April/May
03	Rectangular, 0.8 ha, 2 m	Rainfall & ground water, 12 months	22,500ha^{-1}, 5mm	Tilling: By Tractor Liming: 250kgha^{-1} Fertilizer: N/A	G.C: 15 days Interval F.T.C: Daily	CP Feed, Mus. Oil cake, farmed made	June-April/May
04	Rectangular, 0.6 ha, 2 m	Rainfall & ground water, 12 months	17,500ha^{-1}, 5mm	Tilling: By Tractor Liming: 250 kgha^{-1} Fertilizer: N/A	G.C: 15 days Interval F.T.C: Daily	CP Feed, Mus. Oil cake, farmed made	June-April/May

*G.C: Growth Checking, *F.T.C: Feeding Tray Checking

Table 2. Characterizations of prawn gher culture systems in Southwest Bangladesh.

Gher ID	Shape, Size & Water Depth	Water Source & availability	Stocking Density & PL Size	Pre-stocking Management	Post-stocking Management	Feed Type	Farming Period
05	Rectangular, 6.8 ha, 1.5m	Rainfall, ground water & canal, 6 months	30,000ha^{-1}, 7mm	Tilling: By Tractor Liming: 150kgha^{-1} Fertilizer (kgha^{-1}): Urea-25, TSP-15	G.C: 7 days Interval F.T.C: Daily	Mega Starter, grower, Quality, farmed made	June/July - Dec/Jan
06	Rectangular, 0.8 ha, 1.5m	Rainfall, ground water & canal, 6 months	22,500ha^{-1}, 8mm	Tilling: By Tractor Liming: 250 kgha^{-1} Fertilizer (kgha^{-1}): Urea-15, TSP-10	G.C: 7 days Interval F.T.C: Daily	Mega Starter, grower, farmed made	June/July - Dec/Jan
07	Rectangular, 0.4 ha, 2 m	Rainfall, ground water & canal, 6 months	25,000ha^{-1}, 8mm	Tilling: By Tractor Liming: 150 kgha^{-1} Fertilizer (kgha^{-1}): Urea-15, TSP-8	G.C: 7 days Interval F.T.C: Daily	Mega Starter, grower, Quality, farmed made	June/July - Dec/Jan
08	Rectangular, 0.6 ha, 1.5m	Rainfall, ground water & canal, 6 months	25,000ha^{-1}, 8mm	Tilling: By Tractor Liming: 150kgha^{-1} Fertilizer (kgha^{-1}): Urea-15, TSP-8	G.C: 7 days Interval F.T.C: Daily	Mega Starter, grower, farmed made	June/July - Dec/Jan

*G.C: Growth Checking, *F.T.C: Feeding Tray Checking

Table 3. *Factorial analysis results of environmental parameters and the prawn pond and prawn gher culture system in Southwest Bangladesh.*

Factor:	**Factor1**	**Factor2**	**Factor3**
Water depth	-0.89	-0.03	0.02
Salinity	0.81	-0.19	-0.00
Alkalinity	0.72	0.35	0.20
Secchi	-0.81	0.19	0.23
Chlorophyll	-0.12	-0.05	0.75
pH	0.29	0.44	0.56
DO	0.23	-0.65	0.45
Ammonium	0.34	0.71	-0.10
Nitrite	0.66	-0.29	-0.13
Explained variance (%)	37%	16%	13%
Factor Interpretation	rain effects, liming effect, and delay of 2nd nitrification step	decomposition vs. photosynthesis	photosynthesis
ANOVA			
Significance	***	***	*
r^2	0.90	0.61	0.23
Sources of variance	**Sig., %SS**	**Sig., %SS**	**Sig., %SS**
treatment	*, 1	*, 5	**, 50
date	***, 99	***, 95	NS, 50
Mean multicomparisons by treatment			
Pond, only prawn culture	b	a	a
Gher, prawn culture with previous rice culture	a	b	b
Mean multicomparisons by date			
2-Jul (before PL stocking)	a	c	a
17-Jul	b	b	a
5-Aug	c	a	a
23-Aug	c	a	a
9-Sep	de	b	a
27-Sep	e	bc	a
8-Oct	d	b	a
30-Oct	de	b	a

Underlined factor coefficients were used for interpretation. r^2 = coefficient of determination). Sig = significance. Significance levels: *P < 0.05, **P < 0.01, ***P < 0.001, NS = not significant. %SS = percentage of total sums of squares. Mean multicomparisons: same letters in each column indicate no significant differences at the 0.05 level. n=64 observations**.**

Table 4. *Analyses of sediment parameters in prawn pond and gher culture systems in Southwest Bangladesh.*

Date	ID	pH	Organic Carbon (%)	Total-N (%)	P (ppm)	Sand (%)	Silt (%)	Clay (%)	Texture type
2/7/12 **(In Pond System)**									
	1	6.48	1.805	0.158	21.26	11	72	17	Silt loam
	2	7.1	1.628	0.142	19.05	7	62	27	silt clay loam
	3	7.2	1.605	0.14	7.62	11	62	27	silt clay loam
	4	7.28	1.166	0.102	12.33	13	80	7	Silt loam
30/10/12									
	1	6.96	1.896	0.168	13.23	6	56	38	silt clay loam
	2	7.26	1.024	0.178	15.64	6	66	28	silt clay loam
	3	7.47	1.787	0.159	18.85	6	56	38	silt clay loam
	4	7.36	1.886	0.17	18.35	6	74	20	Silt loam
Mean ± SD		7.1 ± 0.3	1.60 ± 0.33	0.15 ± 0.02	15.8 ± 4.8	8.3 ± 2.9	66 ± 8.7	25.3± 10.5	
2/7/12 **(In Gher System)**									
	5	6.65	4.448	0.386	17.55	17	16	67	clay
	6	6.88	2.206	0.193	16.95	11	66	23	Silt loam
	7	6.9	1.987	0.174	12.13	13	42	45	silt clay
	8	6.76	1.277	0.114	8.12	29	44	27	clay loam
30/10/12									
	5	6.7	4.485	0.387	14.04	20	42	38	clay loam
	6	7.06	1.932	0.346	9.72	18	64	18	Silt loam
	7	5.56	1.805	0.156	7.22	12	56	32	silt clay loam
	8	5.38	1.805	0.158	9.82	14	66	20	silt clay loam
Mean ± SD		6.5 ± 0.64	2.49 ± 1.24	0.23 ± 0.11	11.9 ± 3.9	16.7 ±5.8	50± 17.1	33.7± 16.2	

Table 5. *Production of freshwater prawn in pond and gher culture systems.*

Treatment	Pond ID	Pond Area (ha)	Total Production (kg)	Total Production (kg ha^{-1})	Mean Production (kg ha^{-1}) (±SD)
Pond System	1	0.4	170	425	407.5 ± 15.55
	2	1	390	390	
	3	0.8	320	400	
	4	0.6	250	415	
Gher System	5	6.8	2400	350	335 ± 19.15
	6	0.8	250	310	
	7	0.4	140	350	
	8	0.6	200	330	

Table 6. *Mean monthly water quality and production variables for 0.10-ha. earthen ponds stocked with freshwater prawns (Marcobrachium rosenbergii) and fertilized weekly with either a pelleted organic fertilizer or the same fertilizer in powder form. Ponds were harvested after 104 days.*

	Pelleted Treatment							
	Pond 14				Pond 15			
Variable	June	July	August	September	June	July	August	September
Dissolved Oxygen (mg/L)	9.01 ± 1.06	13.23 ± 0.40	10.54 ± 1.09	8.31 ± 2.13	9.24 ± 0.65	5.75 ± 0.90	10.48 ± 1.44	12.89 ± 2.08
Temperature (°C)	26.8 ± 3.3	30.7 ± 0.7	29.5 ± 0.5	27.7 ± 2.6	27.9 ± 1.2	29.5 ± 0.8	29.6 ± 0.6	27.2 ± 3.1
pH	8.3 ± 0.1	9.1 ± 0.4	9.4 ± 0.2	7.9 ± 0.2	8.4 ± 0.2	8.2 ± 0.3	8.7 ± 0.1	8.9 ± 0.1
Alkalinity (mg/L)	380	243 ± 11	216 ± 2	238 ± 0	380	291 ± 5	279 ± 2	259 ± 5
Ammonia (mg/L NH_3-N)	0.55 ± 0.03	0.34 ± 0.02	0.35 ± 0.02	0.50 ± 0.01	0.81 ± 0.06	0.71 ± 0.12	0.68 ± 0.04	0.44 ± 0.05
Nitrite (mg/L NO_2^-)	0.52 ± 0.10	0.31 ± 0.18	0.62 ± 0.00	0.16 ± 0.16	0.31 ± 0.18	0.72 ± 0.10	0.31 ± 0.17	0.62 ± 0.31
Nitrate (mg/L NO_3-N)	0.2	0.4 ± 0.1	0.5 ± 0.0	0.4 ± 0.3	0.2	0.2 ± 0.2	0.6 ± 0.1	0.3 ± 0.0
Phosphorus (mg/L PO_4^{3-})	0.12	0.57 ± 0.16	1.97 ± 0.54	2.81 ± 0.46	0.75	1.86 ± 0.09	3.19 ± 0.49	3.59 ± 0.12
Chlorophyll A (µg/L)	10.19 ± 5.62	4.76 ± 1.69	7.77 ± 3.13	25.13	31.76 ± 3.43	30.58 ± 4.99	84.80 ± 14.11	72.38
Secchi Depth (inches)	25 ± 4	27 ± 3	30 ± 0	16 ± 3	16 ± 7	10 ± 0	13 ± 1	13 ± 1
Evaporation (inches)	0.123 ± 0.014	0.124 ± 0.009	0.136 ± 0.007	0.106 ± 0.004	0.123 ± 0.014	0.124 ± 0.009	0.136 ± 0.007	0.106 ± 0.004
Total Fed (kg)	-	67.86	114.25	88.45	-	67.86	114.25	88.45
Initial Stocking Weight (kg)	0.408				0.408			
Average Weight (g)	0.136				0.136			
Final Weight (kg)	-				48.74			
Average Weight (g)	-				28.69			
% Survival	-				57%			

	Powder Treatment							
	Pond 11				Pond 18			
Variable	June	July	August	September	June	July	August	September
Dissolved Oxygen (mg/L)	2.11 ± 0.39	7.93 ± 2.09	7.20 ± 0.41	8.34 ± 0.91	7.92 ± 1.78	6.78 ± 0.24	7.63 ± 1.50	9.26 ± 1.65
Temperature (°C)	27.3 ± 1.1	29.6 ± 0.3	28.3 ± 0.4	26.1 ± 2.6	28.1 ± 1.7	30.5 ± 1.0	29.2 ± 0.7	27.5 ± 2.4
pH	7.9 ± 0.2	7.3 ± 0.4	8.2 ± 0.1	8.1 ± 0.2	8.4 ± 0.2	8.0 ± 0.2	8.3 ± 0.1	8.2 ± 0.0
Alkalinity (mg/L)	434	323 ± 4	311 ± 4	291 ± 0	366	287 ± 1	280 ± 6	271 ± 0
Ammonia (mg/L NH_3-N)	0.71 ± 11	0.68 ± 0.09	0.81 ± 0.10	0.62 ± 0.14	0.76 ± 0.05	0.71 ± 0.17	0.71 ± 0.07	0.39 ± 0.03
Nitrite (mg/L NO_2^-)	0.47 ± 0.13	1.24 ± 0.31	1.12 ± 0.29	0.62 ± 0.00	0.21 ± 0.21	0.62 ± 0.18	0.74 ± 0.16	1.09 ± 0.47
Nitrate (mg/L NO_3-N)	0.6	0.5 ± 0.2	0.2 ± 0.1	0.1 ± 0.1	0.0	0.8 ± 0.1	0.5 ± 0.2	0.6 ± 0.4
Phosphorus (mg/L PO_4^{3-})	0.21	1.46 ± 0.35	4.51 ± 0.47	3.50 ± 0.00	0.09	1.01 ± 0.17	2.28 ± 0.33	2.50 ± 0.19
Chlorophyll A (µg/L)	10.01 ± 0.88	51.15 ±10.48	46.01 ± 11.54	49.90	19.48 ± 7.00	29.54 ± 2.92	56.00 ± 16.19	56.03
Secchi Depth (inches)	23 ± 6	20 ± 2	16 ± 1	19 ± 1	12 ± 1	13 ± 2	14 ± 1	18 ± 1
Evaporation (inches)	0.123 ± 0.014	0.124 ± 0.009	0.136 ± 0.007	0.106 ± 0.004	0.123 ± 0.014	0.124 ± 0.009	0.136 ± 0.007	0.106 ± 0.004
Total Fed (kg)	-	67.86	114.25	88.45	-	67.86	114.25	88.45
Initial Stocking Weight (kg)	0.408				0.408			
Average Weight (g)	0.136				0.136			
Final Weight (kg)	-				38.06			
Average Weight (g)	-				31.30			
% Survival	-				41%			

Table 7. *Summary of mean (± SEM) water quality and production variables according to treatment (Pelleted versus Powdered fertilizers) after a 104-day growout trial in ponds stocked with freshwater prawns (Macrobrachium rosenbergii).*

	Pelleted Treatment	**Powder Treatment**
Dissolved Oxygen (mg/L)	9.97 ± 0.57	7.06 ± 0.55
Temperature (°C)	28.8 ± 0.5	28.5 ± 0.4
pH	8.68 ± 0.12	8.08 ± 0.09
Alkalinity (mg/L)	265 ± 11	305 ± 9
Ammonia (mg/L NH_3-N)	0.55 ± 0.04	0.70 ± 0.04
Nitrite (mg/L NO_2)	0.45 ± 0.06	0.79 ± 0.10
Nitrate (mg/L NO_3-N)	0.4 ± 0.0	0.4 ± 0.1
Phosphorus (mg/L PO_4^{3-})	2.13 ± 0.28	2.44 ± 0.33
Chlorophyll-A (ug/L)	34.11 ± 7.52	41.68 ± 5.48
Secchi Depth (inches)	19 ± 2	16 ± 1
Evaporation (inches)	0.123 ± 0.004	0.123 ± 0.004
Total Feed (kg)	596.48	596.48
Initial Stocking Biomass (kg)	0.408	0.408
Average Initial Weight (g)	0.136	0.136
Final Harvest Biomass (kg)	48.74	38.06
Average Final Weight (g)	28.69	31.30
Survival	57%	41%

Table 8. *Summary (mean) of physical characteristics and water budget measurements of four, earthen ponds used for culture of freshwater prawns (Macrobrachium rosenbergii) in Eastern North Carolina.*

Variable	**Value**
Pond area (m^2)	1110.7
Pond volume (m^3)	42,559
Pond Depth in meters (max/min)	1.67 (1.73/1.61)
Evaporation (cm/day)	0.312
Seepage (cm/day)	0.322

Table 9. *Water quality parameters in tilapia-carp polyculture in ponds with fertilization alone, fertilization + 50% feed ration, or feed alone at 100% ration. Mean (± SEM) and range of values.*

Parameters	**Treatments**			**Significance Level & Coefficient of Determination**
	T_1	**T_2**	**T_3**	
Air Temperature (°C)	30.21±0.12 (28.0-32.0)	30.21±0.12 (28.0-32.0)	30.21±0.12 (28.0-32.0)	1.000 r^2=0.000
Water Temperature (°C)	31.34±0.14 (30.0-34.5)	31.32±0.13 (30-34.50)	31.45±0.13 (30-34.80)	0.700 r^2=0.002
Transparency (cm)	33.67±0.74^a (21.0-50.0)	42.67±0.16^b (19.0-65.0)	39.0±0.13^c (21.0-55.0)	0.000*** r^2=0.06
pH	8.95^a (6.99-10.86)	8.70^{ab} (6.79-10)	8.50^b (6.89-10.09)	.0140* r^2=0.05
DO (mg l^{-1})	5.35±0.12 (3.36-7.50)	5.32±0.19 (1.75-8.48)	5.22±0.15 (2.20-8.26)	0.828 r^2=0.002
Alkalinity (mg l^{-1})	94.35±2.75 (8.0-144.0)	95.57±2.28 (67.0-144.0)	91.95±2.34 (64-152)	0.573 r^2=0.003
Nitrate (mg l^{-1})	0.05±0.007^a (0.01-0.21)	0.07±0.007^{ab} (0.00-0.25)	0.09±0.01^b (0.01-0.51)	0.040* r^2=0.03
Nitrite (mg l^{-1})	0.03±0.004 (0.00-0.12)	0.04±0.007 (0.00-0.26)	0.04±0.006 (0.00-0.25)	0.608 r^2=0.001
Ammonia (mg l^{-1})	0.42±0.04^{ab} (0.15-1.27)	0.54±0.05^a (0.19-1.57)	0.34±0.02^b (0.14-1.26)	0.002** r^2=0.01
Phosphate (mg l^{-1})	0.86±0.09 (0.08-3.0)	1.20±0.12 (0.26-3.0)	1.14±0.10 (0.16-3.0)	0.062 r^2=0.02
TDS (mg l^{-1})	56.73±2.19^a (25.60-108)	66.5±2.1^b (37.1-100.5)	69.72±2.20^b (42.0-109.0)	0.000*** r^2=0.09
Conductivity (µS cm^{-1})	112.11±3.53^a (55.0-157.90)	134.32±3.73^b (69.9-187.8)	144.67±3.57^b (90.0-203.0)	0.000*** r^2=0.19
Chlorophyll-*a* (µg l^{-1})	63.4±6.39 (10.0-250.0)	72.11±6.95 (10-250)	74.31±5.68 (2.0-150.0)	0.440 r^2=0.008

Significance level: * = $p < 0.05$, **= $p < 0.01$, *** = $p < 0.001$,
r^2= Coefficient of Determination
Mean values with different superscript letters in each row indicate significant differences between groups, if the main effects of treatment are significant.

Table 10. Comparison of production parameters of tilapia and Silver carp under different treatments (means ± SEM).

Characters	Treatment			Significance Level & Coefficient of Determination
	T_1	T_2	T_3	
Oreochromis niloticus				
Mean stocking weight (g)	2.95 ± 0.16	3.0 ± 0.18	3.08 ± 0.18	NS r^2=0.98
Mean harvesting weight (g)	88.08 ± 14.87^b	250.2 ± 10.03^a	246.75 ± 7.53^a	*** r^2=0.39
Mean weight gain (g)	85.13 ± 14.87^b	247.2 ± 10.03^a	243.67 ± 7.53^a	*** r^2=0.39
Specific Growth Rate (SGR)	2.83 ± 0.004^a	3.69 ± 0.006^b	3.66 ± 0.005^c	*** r^2=0.72
Feed Conversion Ratio (FCR)	-	0.86 ± 0.03^b	1.88 ± 0.04^a	*** r^2=0.98
Survival (%)	81.25 ±3.19	86.75 ± 3.95	88.5 ± 3.23	NS r^2=0.19
Gross Production (kg ha^{-1})	1007.5 ± 100.9^b	3652.5 ± 174.6^a	3392.5 ± 259.5^a	*** r^2=0.62
Net Production (kg ha^{-1})	947.5 ± 100.9^b	3592.5 ± 174.6^a	3332.5 ± 259.5^a	*** r^2=0.62
Hypophthalmichthys molitrix				
Mean stocking weight (g)	18.1 ± 1.17	18.2 ± 1.16	18.2 ± 1.18	NS r^2=0.75
Mean harvesting weight(g)	286.08 ± 19.59	254.25 ± 15.82	240.25 ± 10.34	NS r^2=0.03
Mean weight gain (g)	267.98 ± 19.59	236.05 ± 15.82	222.05 ± 10.34	NS r^2=0.03
Specific Growth Rate (SGR)	2.30 ± 0.01^a	2.2 ± 0.01^b	2.15 ± 0.01^c	*** r^2=0.88
Survival (%)	100.00 ± 00	97.00 ± 3.00	92.0 ± 5.66	NS r^2=0.21
Gross Production (kg ha^{-1})	665 ± 132.2	680 ± 110.9	557.5 ± 88.35	NS r^2=0.04
Net Production (kg ha^{-1})	620 ± 132.2	635 ± 110.9	512.5 ± 88.35	NS r^2=0.04
Combined FCR	-	0.72 ± 0.02^b	1.62 ± 0.03^a	*** r^2=0.97
Combined Net Production (kg ha^{-1})	**1567.5 ± 207.5^b**	**4227.5 ± 135.5^a**	**3845 ± 342.47^a**	*** r^2=0.56

Significance level: * = $p \leq 0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.001$, and NS= Not Significant
r^2= Coefficient of Determination
Treatment names: T_1 stands for fertilization alone, T_2 for fertilization + 50% feed, T_3 for 100% feed alone.
Mean values followed by different superscript letters in each row indicate significant differences based on Tukey's test, if the main effects are significant ($p < 0.05$).

Table 11: *Comparisons of economics among different treatments (based on 1 ha farm area & 4 months culture period.*

Items	Treatments		
	T_1	**T_2**	**T_3**
Financial Inputs			
Lime	1000	1000	1000
Urea	3000	3000	-
TSP	4500	4500	-
Feed	-	25000	50000
Tilapia Seeds	20000	20000	20000
Silver carp seeds	6000	6000	6000
Labor & Land rental cost	17000	17000	17000
Total Cost	51500	76500	94000
Bank Interest (12% annually)	6180	9180	11280
Total Investments	57680	85650	105280
Financial Returns			
Tilapia	50290	180000	170600
Silver carp	31000	35500	27200
Total Returns	81290^{b}	215500^{a}	197800^{a}
Net Benefits	23520^{b}	129850^{a}	92520^{a}
Benefit-cost ratio (BCR)	**1.40^{b}**	**2.48^{a}**	**1.88^{a}**

Currencies are given in Bangladeshi Taka, BDT (1 USD= 80 BDT)

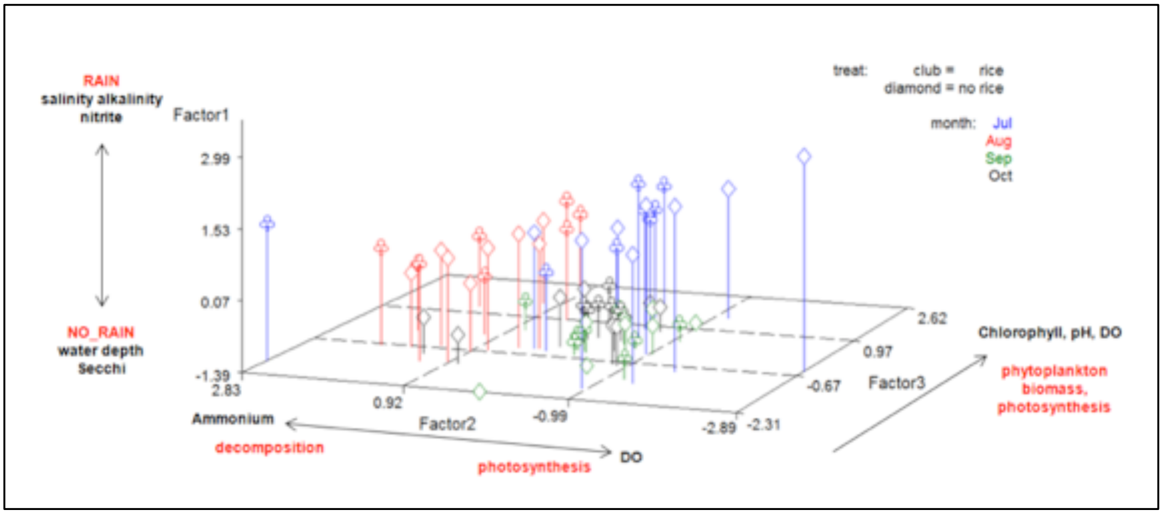


Figure 1. *Tridimensional plot of the 3 factors extracted for the prawn pond (no rice) and gher systems (rice).*

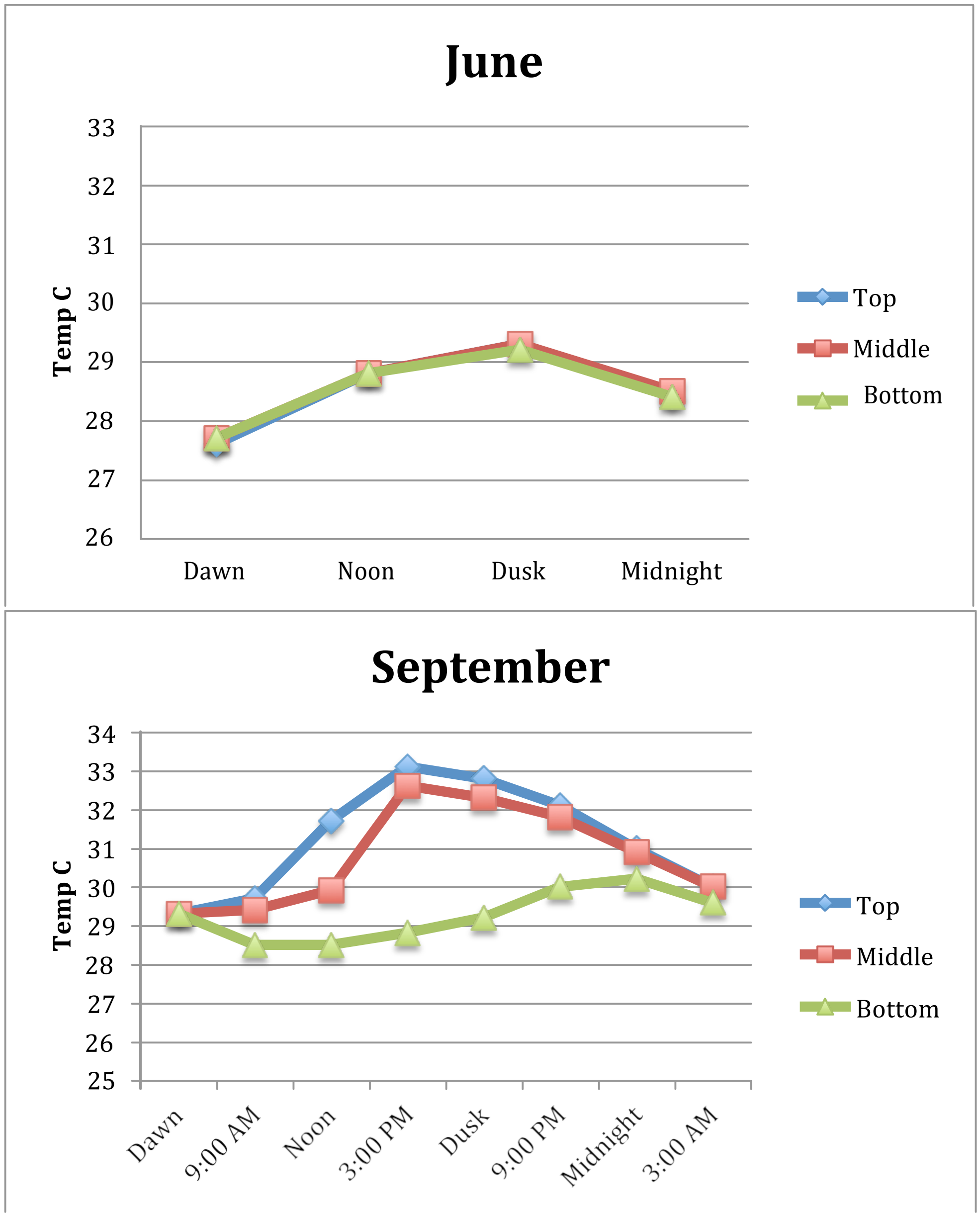


Figure 2. *Water temperature taken at different depths in a 0.10-ha earthen pond over a 24-h period during the month of June (top) and September (bottom) 2012.*

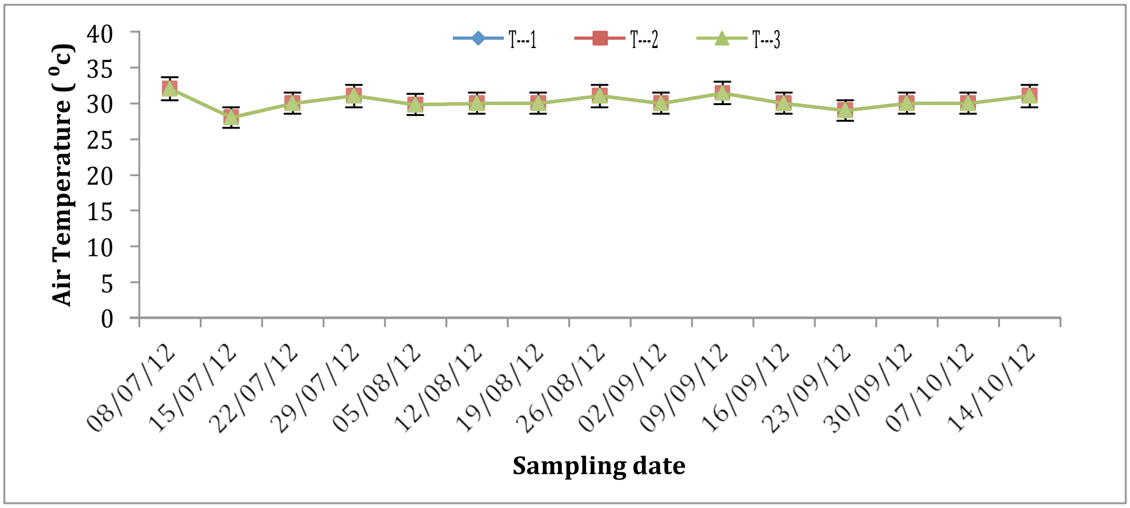


Figure 3. *Weekly variation of air temperature among three treatments.*

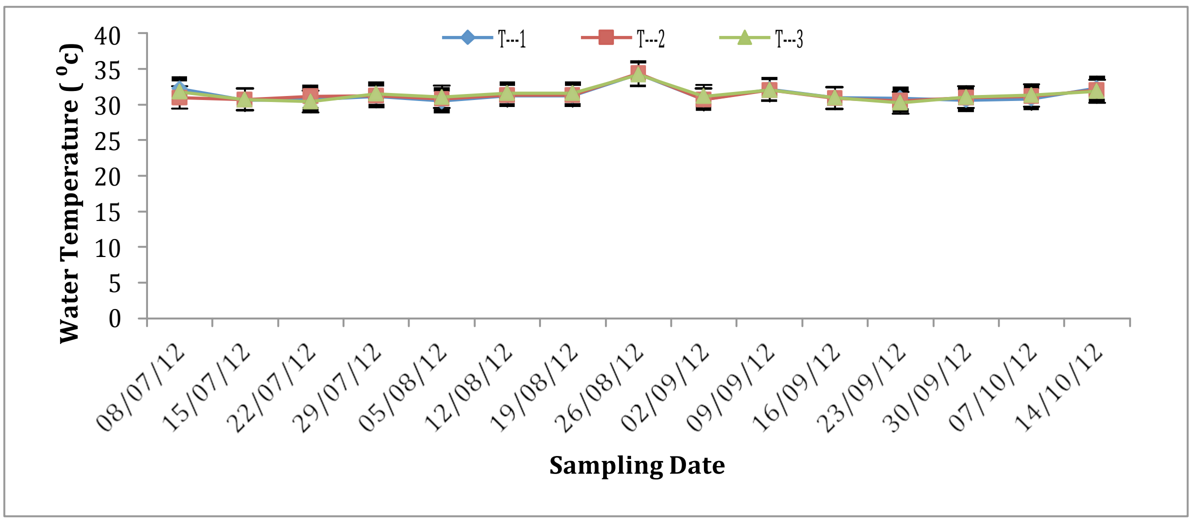


Figure 4. *Weekly variation of water temperature among three treatments.*

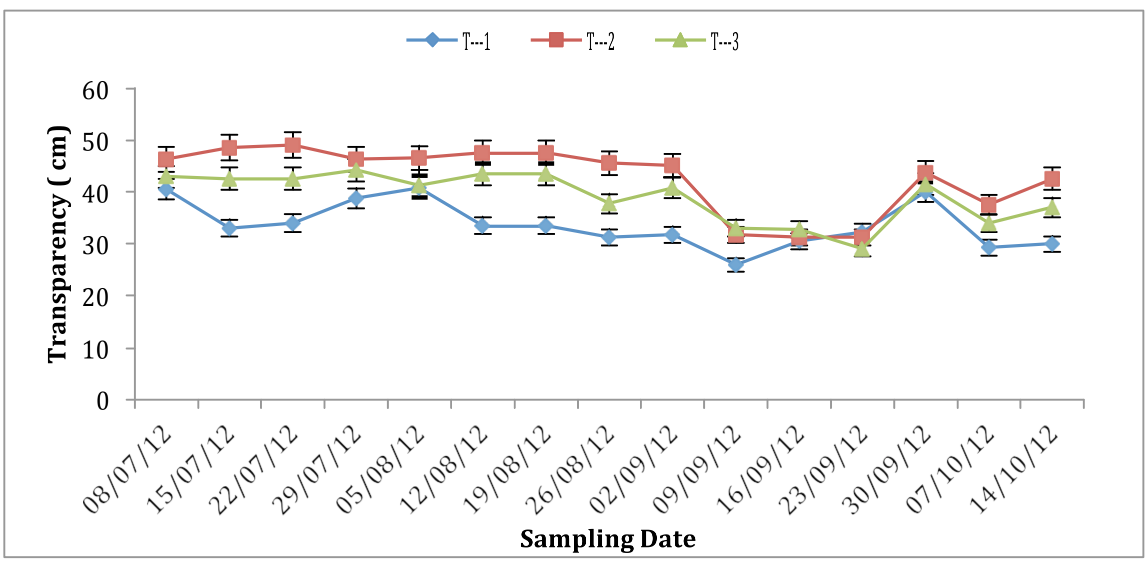


Figure 5. *Weekly variation of Transparency among three treatments.*

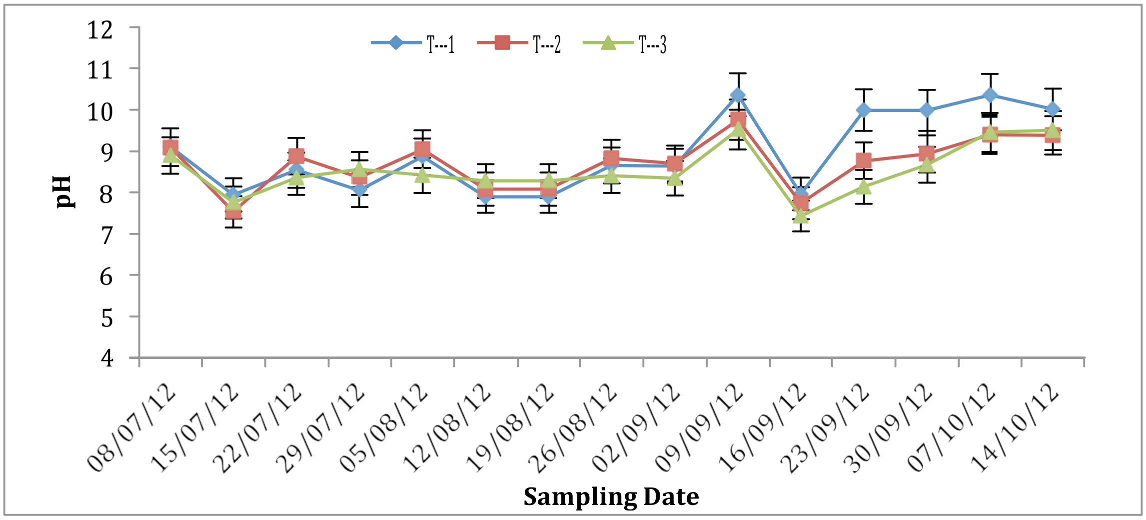


Figure 6. *Weekly variation of pH among three treatments.*

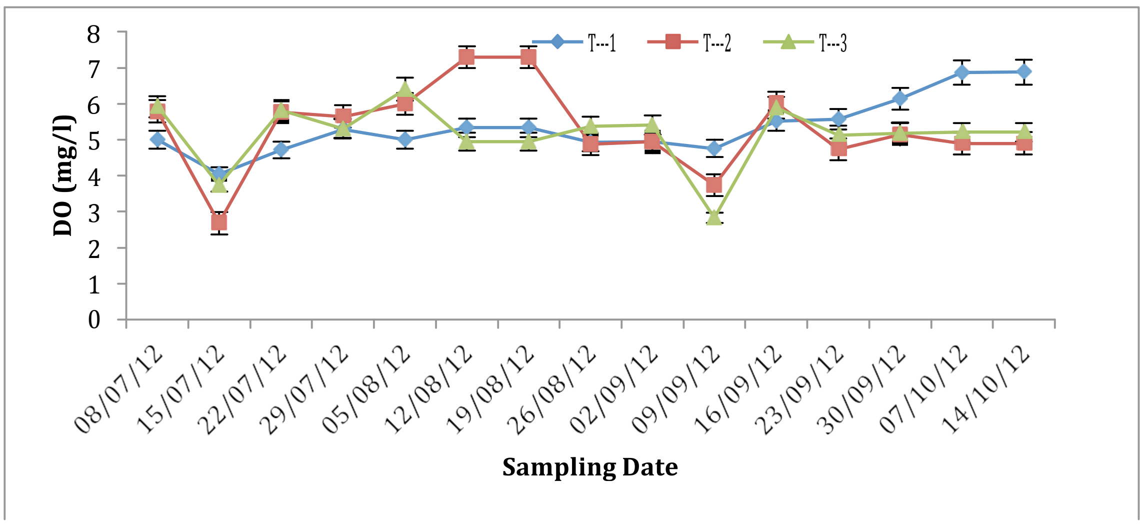


Figure 7. *Weekly variation of Dissolved oxygen among three treatments.*

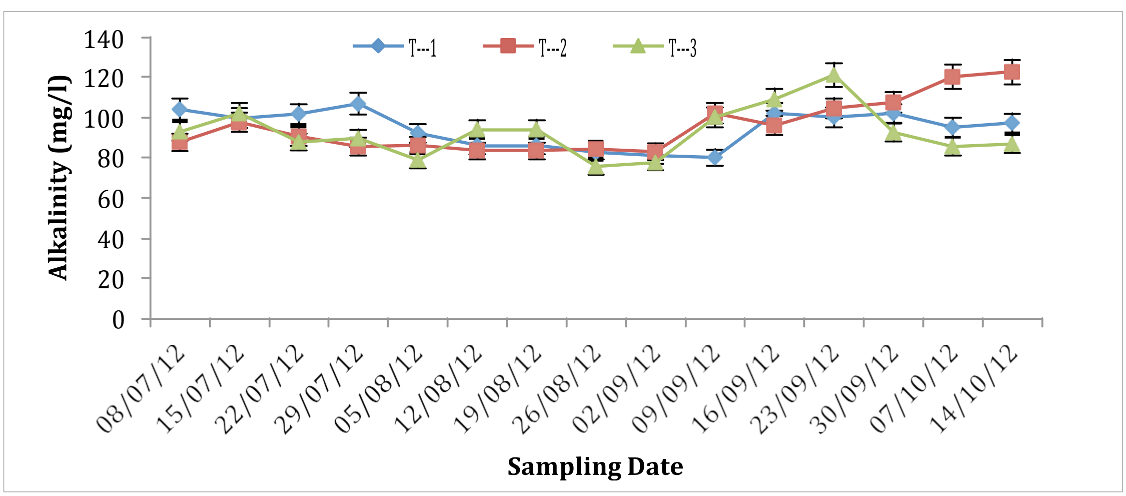


Figure 8. *Weekly variation of Total alkalinity among three treatments.*

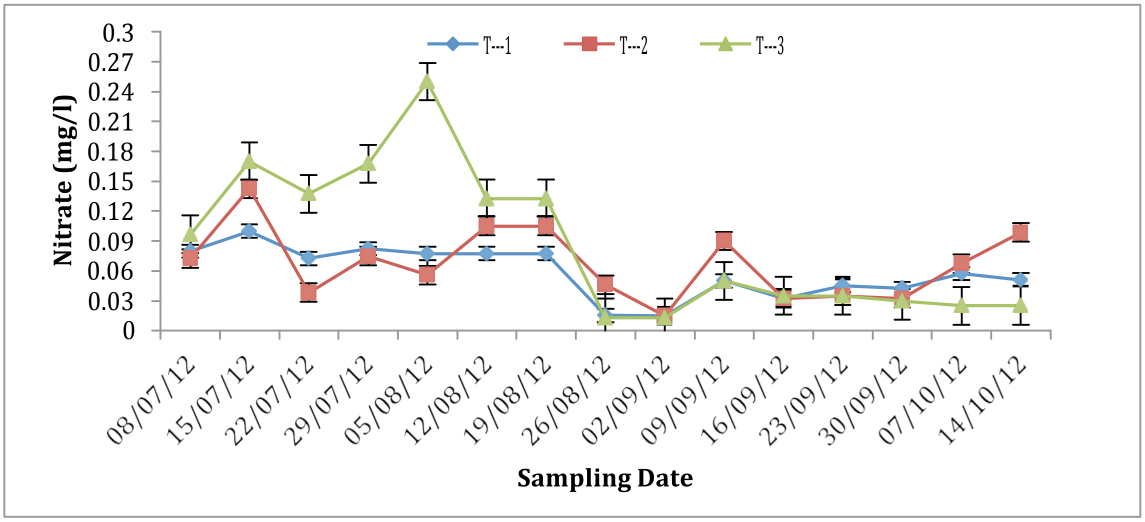


Figure 9. *Weekly variation of Nitrate-nitrogen among three treatments.*

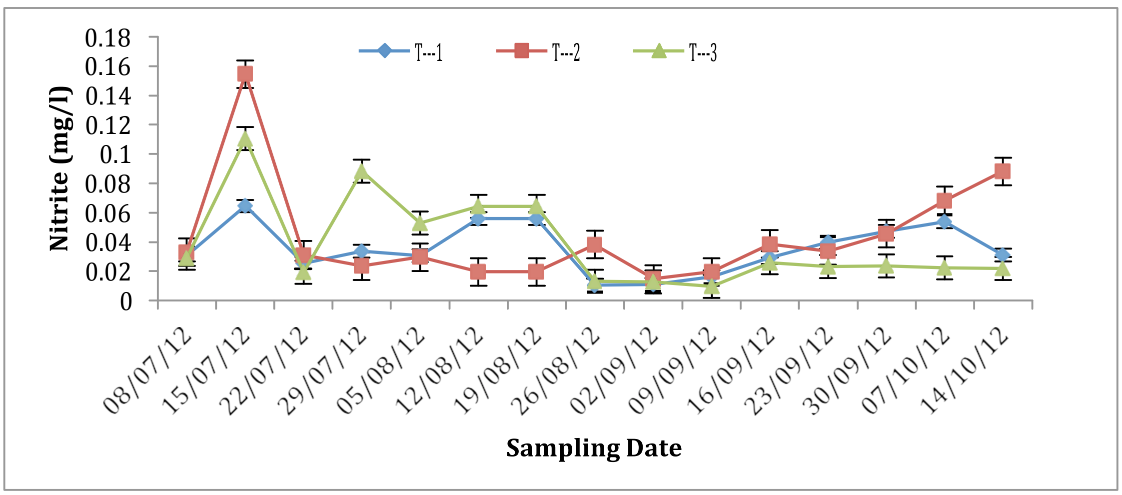


Figure 10. *Weekly variation of Nitrite-nitrogen among three treatments.*

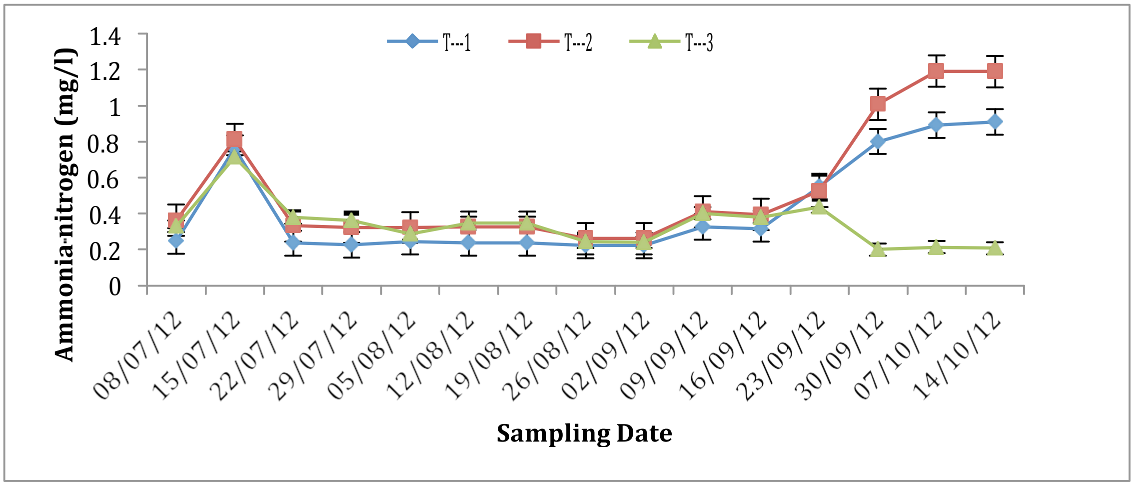


Figure 11. *Weekly variation of Ammonia-nitrogen among three treatments.*

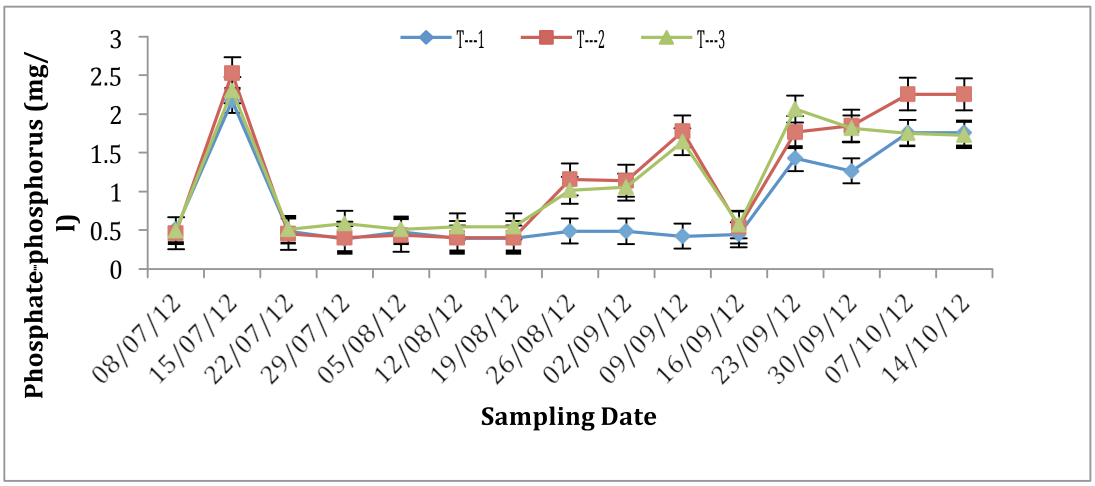


Figure 12. *Weekly variation of Phosphate-phosphorous among three treatments.*

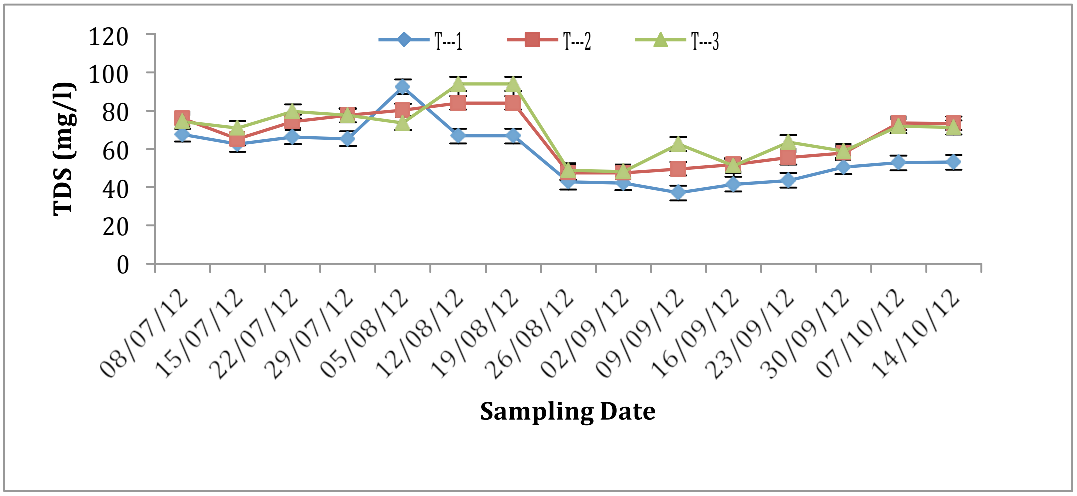


Figure 13. *Weekly variation of Total Dissolved Solid among three treatments.*

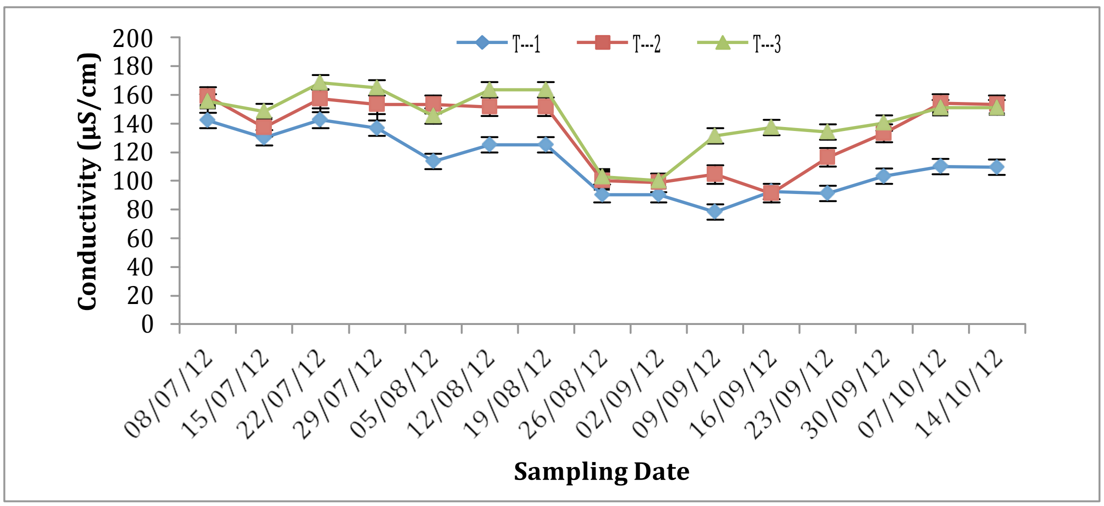


Figure 14. *Weekly variation of conductivity among three treatments.*

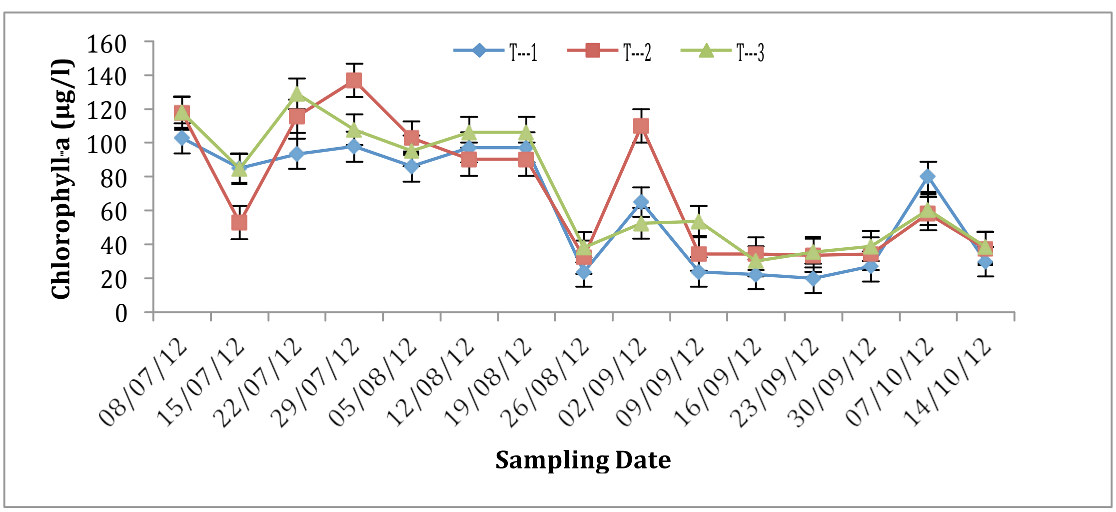


Figure 15. *Weekly variation of Chlorophyll-a among three treatments.*

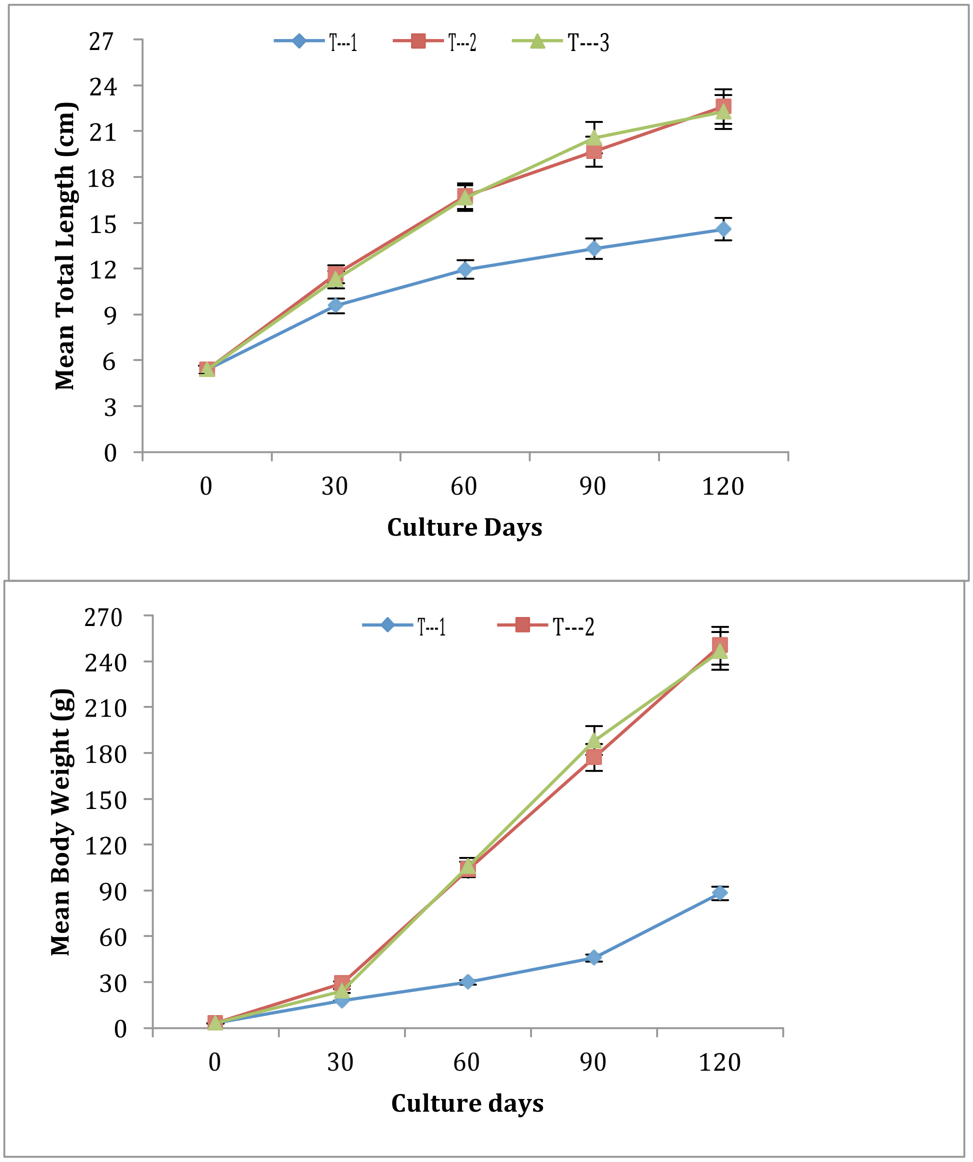
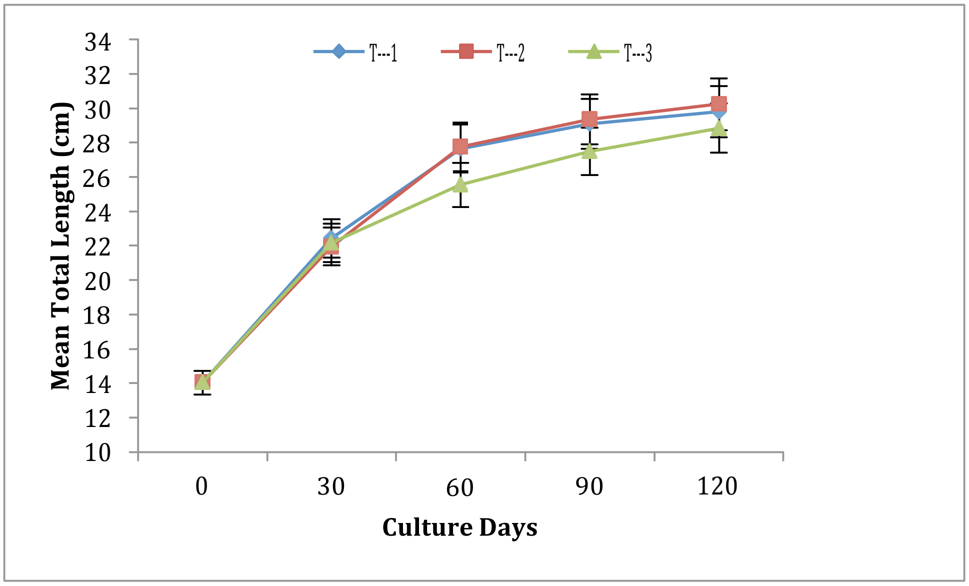


Figure 16. *Mean total length (cm) and mean body weight (g) of tilapia stocks.*



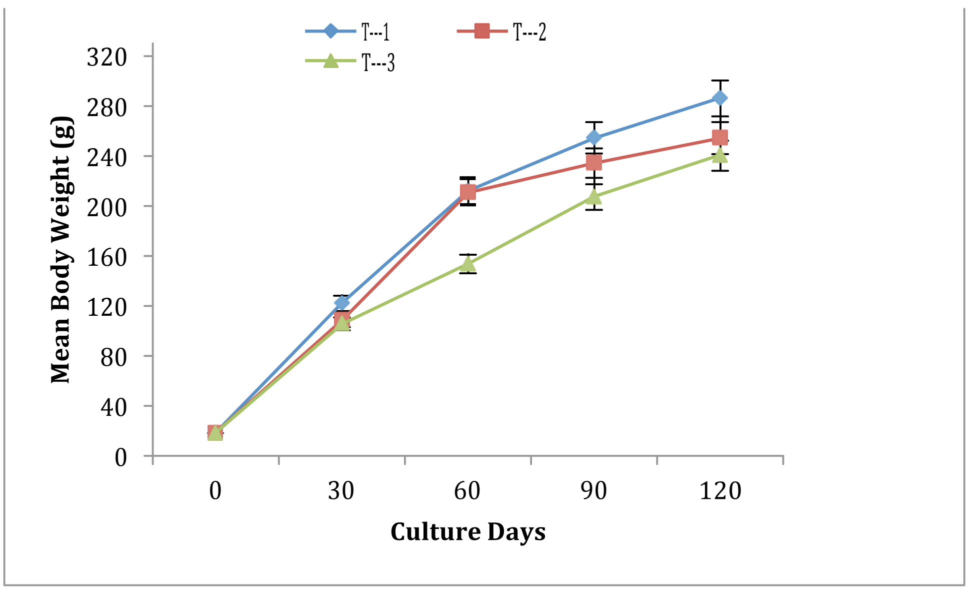


Figure 17. *Mean total length (cm) and body weight (g) of silver carp stocks.*