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Integrated Aquaculture-Hydroponics System with Paddy Nursery on Aquaculture Pond

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Abstract: Large areas of land remain uncultivated after the rainy season due to lack of irrigation facilities in many countries. There are also low lying areas, which remain waterlogged for the major part of the year. The returns from these areas in terms of agricultural crops and revenues are very poor. Adoption of integrated farming technology by incorporating aquacultural ponds in these areas has been found to increase the total yield and fetch higher financial return. Through aquacultural-hydroponic system, by using floating nurseries on aquacultural ponds, many benefits can be obtained, e.g., double use of pond water, control of erosion of the dykes due to wind action, fishes get shade during hot summer days, reduces labour cost, minimizes the loss of pond water due to evaporation, control poaching of fishes, etc. In this study, floating structures of different sizes for the aquacultural tanks were designed and fabricated and used for paddy nursery. The designed outer diameter of PVC hollow pipes (material used for making the floating structures) was found to be 3.0 cm and 4.5 cm for 0.15 m^2 and 0.3 m^2 of floating structures respectively. The optimum area of the floating structures and the number of fish in the tank were 40% and 42 fish/m^2 respectively after maintaining 5.38 mg/L of dissolved oxygen. Tilapia (*Oreochromis mossambicus*) fish and rice plant were found to grow well in the same tank and the total profit in integrated farming was $15,000 per ha of surface area of the pond per year.

Key words: Aquaculture, hydroponics, floating nursery, Tilapia-Rice culture.

Introduction

In many countries including India, sizable amount of land remain uncultivated after the rainy season due to lack of irrigation facilities. Side-by-side there are many areas that remain waterlogged for a major part of the year. The returns from these areas in terms of agricultural crops and revenue are very poor. The previous studies have shown the treatment of municipal wastewater for constructed wetlands (Reed et al., 1995; Kadlec and Knight, 1996) and the significant variations in nutrient removal have been reported for vegetated submerged bed wetlands (Rich, 1988; Findlater et al., 1990; Mankin and Powell, 1998; He and Mankin, 2002). Adoption of integrated farming technology by incorporating aquacultural ponds in these areas has been found to increase the total yield and fetch higher financial return (Little and Muir, 1987).

A large number of aquatic animals and plants have been used for integration of aquaculture with hydroponic system by applying various designs and using different experimental protocols (Rakocy and Hargreaves, 1993; Thompson et al., 1998; Battke et al., 2003). The plant nutrients were properly managed for the integration of aquaculture with hydroponics by using closed as well as recirculating system (Wren, 1984; Nair et al., 1985; Rakocy et al., 1989; Tyson et al., 2007). The study also showed the integrated farming for fish with plants by using swine waste for nutrient recovery (Dontje and

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Clanton, 1999). In the integrated system, the flow of particular nutrients have been examined and a model to predict optimal dietary nutrient inclusion rates has been developed (Seawright et al., 1998).

Most of the farmers in India, generally, do not spare agricultural land for the construction of aquacultural ponds, because they consider agricultural crop as the main crop. So, there is a necessity to develop a technology for integrating aquaculture with agriculture without much shrinkage of the land area. Therefore, the system of using surface area of aquacultural pond as floating nurseries of plants, which are generally transplanted, seems to be an alternative way of using pond water for dual purpose, which is also called re-circulating system (Cui et al., 2003; Leonard and Leonard, 2006). This type of integrated culture system may be termed as aquaculture-hydroponics system. There are many advantages of doing this type of culture, some of which are: maintenance of water quality parameters, double use of pond water, control of erosion of the dykes due to wind action, fishes get shade during hot summer days, minimization of loss of pond water due to evaporation, control of poaching of fishes, etc. For keeping the plant nursery in floating condition, proper design of the floating structure is necessary, otherwise the structure may sink in water or may not be stable. The cost of the floating nursery is also an important factor to make it economically viable. Surface aeration is the major source of dissolved oxygen (DO) concentration in the pond and it helps to maintain the water quality parameters in the pond at the desired levels; therefore area of the floating structure per unit area of the pond is another important factor for consideration. The stocking density of fish in the pond is also dependent on the covered surface area. Therefore, the objectives of this study were to determine the size of the floating structures and number of fish in relation to the pond size and to estimate the total profit from the aquaculture-hydroponics system with paddy nursery.

Materials and Methods

Experimental Set-up

Experiments were conducted in the Aquacultural Engineering Section, Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India (lat. 22° 12′450″ N, long. 87° 23′39″ E) to study the use of surface area of aquacultural tanks as floating nurseries. Cemented tanks were selected for installing floating nurseries of different sizes covering 20%, 40%, 60%, and 80% of the tank area. All the experimental tanks were of the size of 1.27 m length × 0.6 m breadth with 0.30 to 0.32 m depth of water. Tanks were covered with transparent polythene sheet, thus well exposed to sunlight and were located in an open area, so got exposure to sufficient wind action also.

Design of Floating Structure

Before preparation of the plant nursery bed, floating structures of different sizes were designed. There were four sizes of floating structures covering 20%, 40%, 60%, and 80% of the total tank surface area (127 cm × 60 cm). For fabrication of the floating structures of different sizes, the optimum diameter of PVC hollow pipe was found out through design calculations for sustaining the total weight of the material of the plant nursery bed, weight of plant, and self weight of the structure. Figure 1 shows the aquaculture tank covered with the floating structure (the designed structure covering 40% of the tank area—57 cm × 53 cm), which was made up with PVC hollow pipe frame and polythene sheet. The nursery bed was placed over this structure. The design procedure of the structure has been given below:

Effective area for plant bed = 53 cm × 48 cm = 2544 cm^2

Total length of the pipe (perimeter) = 220 cm

Thickness of the nursery bed (cow-dung + saw-dust) on the floating structure = 0.5 cm

So, volume of the material over the structure = 2544 cm^2 × 0.5 cm i.e. 1272 cm^3.

Density of the nursery bed material = 0.9 g/cm^3

Hence, weight of the plant bed = 1145 g

Suppose, self weight of the floating structure = 1400 g and weight of the plant over the bed = 20% of the plant bed material; then, total weight to be sustained on the floating structure = (1.2 × 1145 + 1400) g = 2774 g.

If the cross sectional area of the submerged PVC pipe is A and the internal angle of the submerged pipe is α,

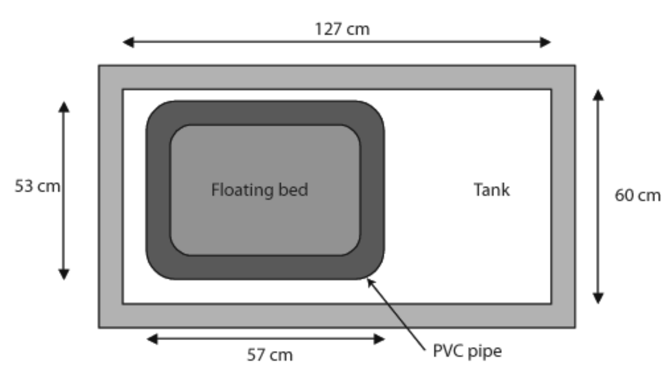

Figure 1: Floating structure on the aquacultural tank covering 40% area.

$A = D^2(\alpha - \sin \alpha)/8.$

If allowable submerged depth of the pipe = 3/4th of the diameter of the pipe, $\alpha = 240$.

Since density of water = 1 g/cm^3, total weight of the floating structure and the material = Weight of water displaced by submergence of the whole structure.

Therefore, $2774 = A \times L$

$$= \frac{D^2(\alpha - \sin\alpha)L}{8}$$

$$= \frac{D^2(\frac{240\pi}{180} - \sin 240)\cdot 220}{8}$$

$$= D^2 \times 0.63 \times 220$$

$$\therefore \; D = 4.467 \text{ cm} \cong 4.5 \text{ cm}$$

Therefore, the designed outer diameter of the PVC pipe for covering 40% of the surface area of the tank = 4.5 cm.

Fabrication of the Floating Structure

After finding the optimum diameters of the PVC pipes, the pipes were cut according to designed sizes and fabricated into rectangular shape with the help of PVC elbows of similar diameter. Subsequently, all joints were hermetically sealed with the help of Araldite adhesive. Black polythene film (2 mm thickness) was spread over the floating structures and tied with the help of nylon twine (1 mm diameter), so that the twine can hold the weight of the plant bed material and plant. A pin hole of 0.5 mm diameter were made (100 nos/m^2) on the polythene sheet for taking water from the tank by capillary action for the proper growth of plant.

Preparation of Bed for Plant Growth

Plant bed was prepared over the polythene sheet on the floating structure. A 0.5 cm thick layer of saw-dust and cow-dung in the ratio of 8:1 was used, after mixing properly, over the polythene sheet so that the bed material can hold the roots firmly. The selected variety of plants for this experiment was paddy IR-36 (one of the variety of rice), but any other seed can be selected which require transplantation i.e. chilly, eggplant and some other useful vegetables or flowers.

Fish Culture

The fish species Tilapia (*Oreochromis mossambicus*) was selected for culture in the tank. The number of fish (length 4-6 cm and body weight 4-5 gm/pc) selected for different tanks were 15, 20, 25, 30, 35, and 40 fish/tank. The amount of feed supplied to the fish in the tank was 4% of the body weight of the stocked fish.

Management Practices

Sufficient care was taken so that the floating structure did not lose its balance. The stocked fish were fed twice a day. Special care was taken at the time of sampling of fish so that the fish did not get injured. The dissolved oxygen concentration and water temperature in the tank were monitored by using a DO meter.

Experimental Plan

There were six sets of experiments for six different stocking densities of fish 15, 20, 25, 30, 35, and 40 fish/tank. For each set of experiment, there were four sizes of floating structures covering 20%, 40%, 60%, and 80% of the surface area of the total tank and the experiments were conducted in triplicate. One set of the experiment was kept as a control with fish but no covering of the surface area. DO and temperature readings were taken from the 2nd day at 9.00 AM and 4.30 PM daily for six days. It was found from the preliminary experiments that the dissolved oxygen in the tank did decrease significantly after six days. After completion of one set of experiment, subsequent sets of experiments were conducted by increasing equal number of fish in each tank. The first experiment was conducted with 15 fish/tank of stocking density and the subsequent experiments were conducted with 20, 25, 30, 35, and 40 fish/tank.

Cost Analysis for Optimum Floating Area and Optimum Number of Fish

In the tank, the amount of fish and the area covered by plant have been calculated by applying optimization technique. For economical purpose as well as for good growth of plant and return from fish culture, proper balance is required. The cost analysis was obtained through optimization with the help of linear programming, which can be applied to any pond of similar area/depth ratio. The objective function and constraints were obtained for our analysis in the following manner:

Objective function: The objective function consists of maximization of net profit from nursery plants and fish cultured.

$$\text{Max. } Z = N_f W_{f1} R_{f1} + A_p R_{p1} - N_f W_{f2} R_{f2} - A_p R_s C_s - A_p X_s - N_f A_f C_f T_c \quad (1)$$

where N_f is the number of fish in the tank, W_{f1} is the weight of one fish at the time of harvesting (kg), R_{f1} is the value of fish at the time of harvesting (\$/kg), A_p is the area of nursery bed for planting (m^2), R_{p1} is the value of nursery plant ($\$/m^2$), W_{f2} is initial weight of one fish (kg), R_{f2} is initial cost of one fish (\$/kg), R_s is the amount of paddy seed required (kg/m^2), C_s is the cost of paddy seed (\$/kg), X_s is total cost of construction of floating structure ($\$/m^2$), A_f is the amount of feed applied per fish (kg/day), C_f is the cost of feed applied (\$/kg), and T_c is the total culture period (day).

Constraints: It was assumed that the DO concentration (C_{DO}) in the tank was optimum for fish survival. The covered surface area (A_p) and no. of fish (N_f) from a contour plot of A_p vs. N_f for different C_{DO} were observed in the morning and evening time.

Area constraints:

$$A_1 < A_p \quad (2)$$

$$A_2 > A_p \quad (3)$$

Number of fish constraints:

$$N_1 < N_f \quad (4)$$

$$N_2 > N_f \quad (5)$$

DO constraints:

$$U_1 \cdot N_f + V_1 \cdot A_p = C_{DO} \quad (6)$$

$$U_2 \cdot N_f + V_2 \cdot A_p = C_{DO} \quad (7)$$

where A_1 is minimum percentage area for plant bed (m^2), A_2 is maximum percentage area for plant bed (m^2), N_1 is minimum number of fish on the tank, N_2 is maximum number of fish on the tank, U_1 is the corresponding area of floating structure constant for C_{DO} mg/L, V_1 is the corresponding number of fish constant for C_{DO} mg/L, U_2 is the corresponding area of floating structure constant for C_{DO} mg/L, V_2 is the corresponding number of fish constant for C_{DO} mg/L, and C_{DO} is the optimum dissolved oxygen required for fish growth (mg/L).

Results and Discussion

The relationship between the covered area of tank with temperature and DO concentration were taken for each tank and for each set of experiments separately. The reading for one set of experiment is shown in Table 1. It shows the DO concentration and temperature of water in the tanks with 15 numbers of fish in each tank, but surface area covered varied from 20%, 40%, 60%, and 80% and control (without covering surface area). It was found that DO concentration didn't show much variation on the 2nd day by increasing the area of the floating structure i.e. 6.7 mg/L in the morning (9.00 AM) and 6.8 mg/L in the evening (4.30 PM), but it decreased continuously on the subsequent days when the area of floating nursery was increased. In the tank without covering, there was no change in DO concentrations. In the tank with 20% covering, DO was decreased at a lower rate and on the 6th day it went down up to 6.5 mg/L. In the tank with 40% covering by the floating nursery, DO decreased continuously up to 6.1 mg/L. Similarly, in the tank with 60% covering, DO concentrations decreased at a greater rate and on 6th day it reached the level 5.4 mg/L and in tank with 80% covering, DO concentration on 6th day was 4.8 mg/L. After the 6th day, DO concentration of the tank water did not decrease significantly.

The change in temperature mainly depends on variation in daily sun light hour. The temperature of water decreased when the covered area (floating structure) of the tank was increased on any day, but it didn't change much within the same day, such as temperature of water on the 2nd day remained same. But temperature of water increased on the 4th day. Temperature of water on the 2nd, 3rd, 4th, and 6th day increased in the evening

Table 1: Relationship between dissolved oxygen and % area covered by floating nursery with 15 nos. of fish.

Data taken	*Tank area covered (%)*	*Dissolved oxygen (mg/L)*		*Temperature (°C)*	
		At 9.00 am	*At 4.30 pm*	*At 9.00 am*	*At 4.30 pm*
2nd day	0	6.8	6.8	28.4	29.0
	20	6.7	6.8	28.3	28.9
	40	6.7	6.8	28.2	28.8
	60	6.7	6.8	28.0	28.7
	80	6.6	6.7	27.9	28.6
3rd day	0	6.7	6.8	28.3	28.6
	20	6.6	6.8	28.3	28.6
	40	6.4	6.7	28.3	28.5
	60	5.9	6.3	28.2	28.4
	80	5.2	5.8	28.0	28.3
4th day	0	6.7	6.8	29.3	29.6
	20	6.6	6.7	29.2	29.5
	40	6.3	6.5	29.2	29.4
	60	5.6	5.9	29.1	29.4
	80	4.9	5.4	29.0	29.3
5th day	0	6.6	6.7	29.8	29.4
	20	6.5	6.7	29.7	29.3
	40	6.2	6.4	29.6	29.2
	60	5.5	5.8	29.5	29.1
	80	4.8	5.4	29.5	29.1
6th day	0	6.6	6.7	28.5	28.8
	20	6.5	6.8	28.4	28.7
	40	6.1	6.4	28.3	28.6
	60	5.4	5.8	28.2	28.5
	80	4.8	5.3	28.2	28.5

compared to the morning temperatures, but on the 5th day it decreased in the evening compared to the morning temperature (Table 1). The water temperature of the tank decreased when the surface areas of the floating nurseries were increased. There was also variation in temperature readings on morning hours than during evening. It increased/decreased/remain constant throughout the day depending upon the weather conditions of that particular day (Table 1).

In other set of experiments, DO concentrations varied daily with the change in area of floating nursery (Figures 2 and 3). It was found that DO concentration was almost constant on day 2 at 9.00 AM as well as 4.30 PM in tank with any number of fish. The DO concentration decreased rapidly in the tank with higher number of fish. It was also noticed that DO concentration decreased after day 2, then it remained constant or did not show much change (Figures 2 and 3).

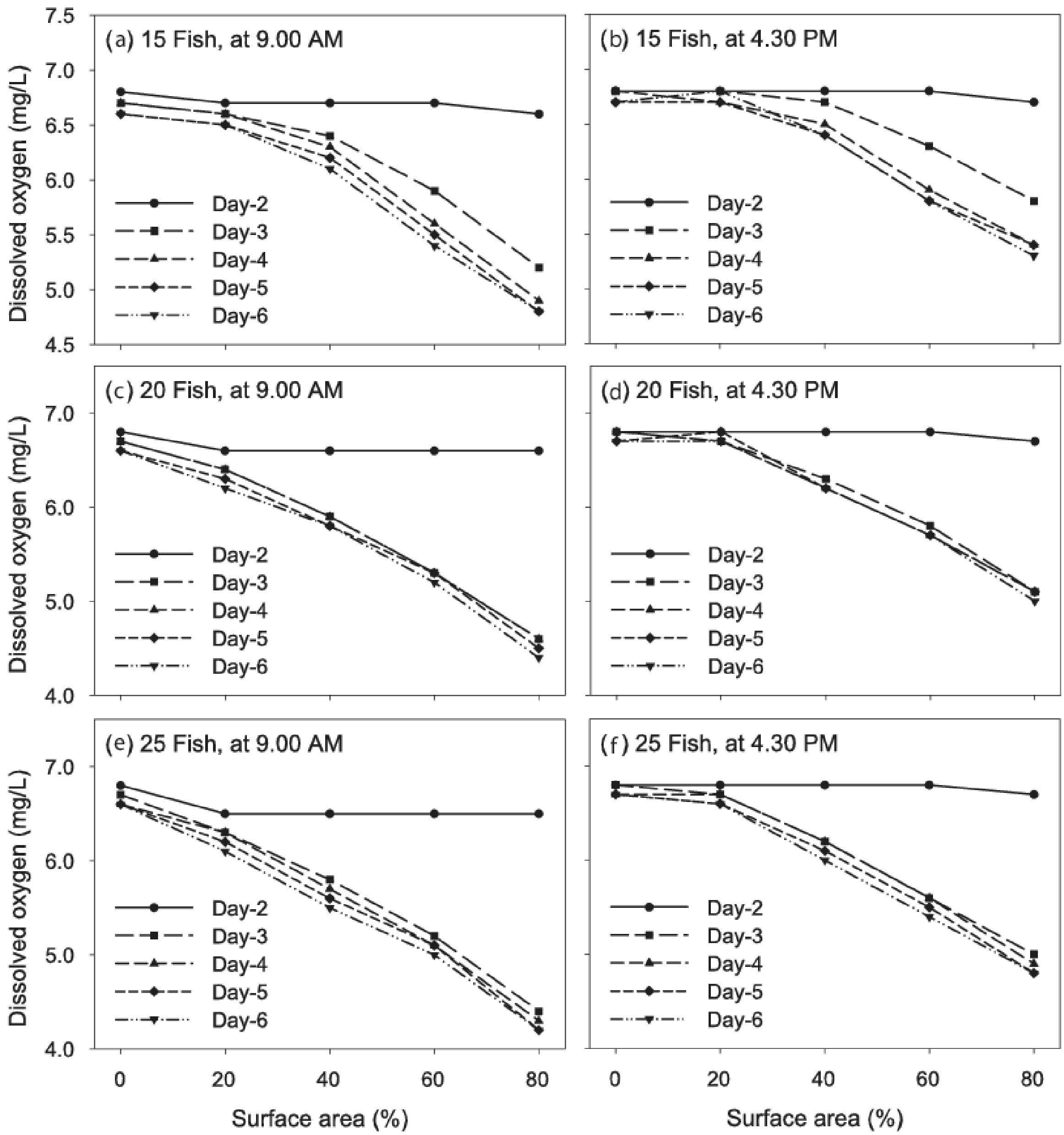

Figure 2: Relationship between % surface area of the tank covered to the dissolved oxygen of water on daily basis for (a) 15 fish, at 9.00 AM; (b) 15 fish, at 4.30 PM; (c) 20 fish, at 9.00 AM; (d) 20 fish, at 4.30 PM; (e) 25 fish, at 9.00 AM; and (f) 25 fish, at 4.30 PM.

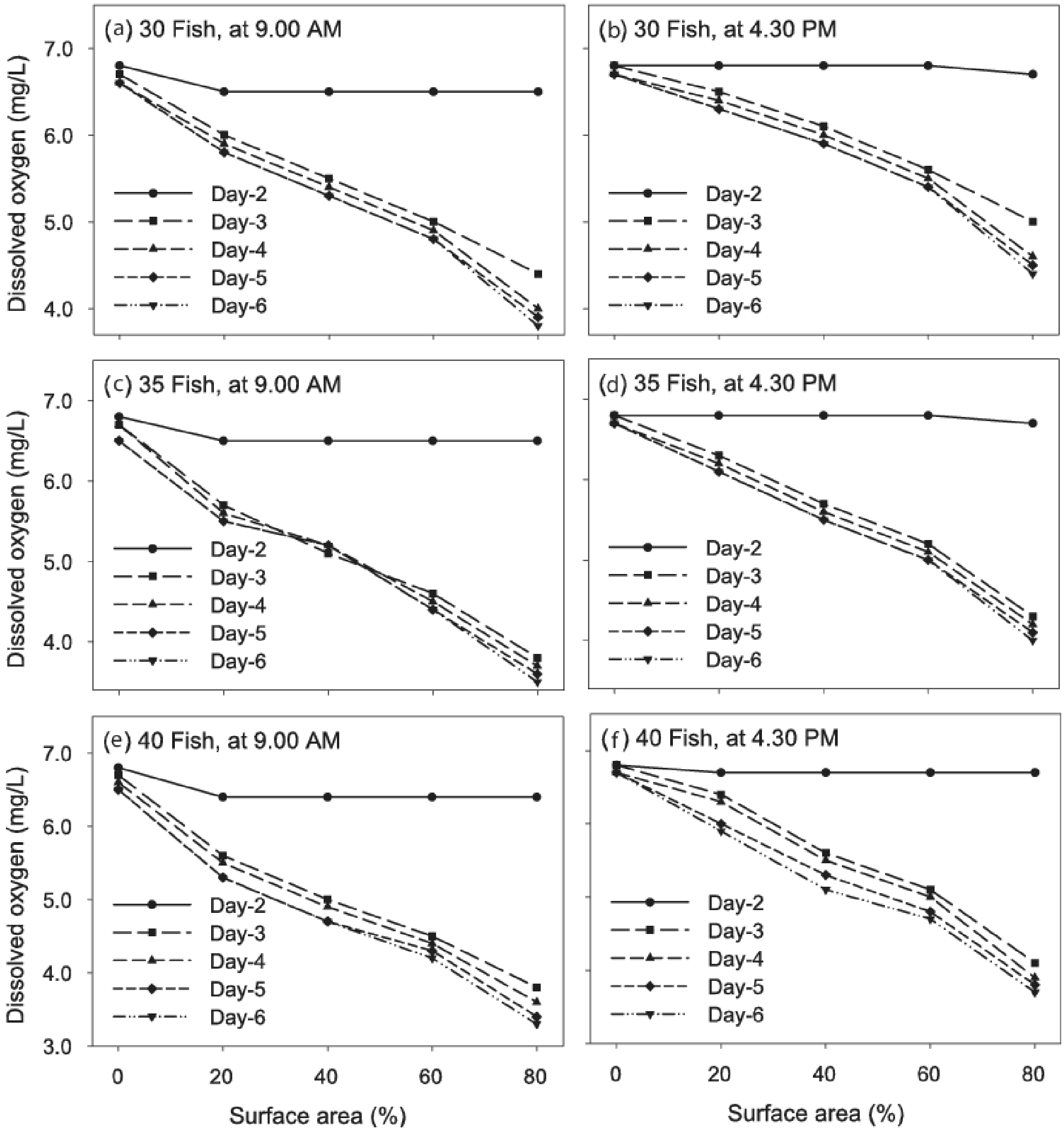

Figure 3: Relationship between % surface area of the tank covered to the dissolved oxygen of water on daily basis for (a) 30 fish, at 9.00 AM; (b) 30 fish, at 4.30 PM; (c) 35 fish, at 9.00 AM; (d) 35 fish, at 4.30 PM; (e) 40 fish, at 9.00 AM; and (f) 40 fish, at 4.30 PM.

Relationship between the Area of the Floating Nurseries and the Stocking Density of Fish with the DO Concentration

The combined effect of surface area of the tank covered by the floating nurseries and the number of fish in the tank on the dissolved oxygen of water for morning and evening time were monitored. DO concentrations decreased by increasing the area of the floating nursery and also by increasing number of fish in the tank. These relationships were represented by 3-dimensional contour plots separately (Figures 4a, b). Figure 4 was used and the optimum dissolved oxygen for fish survival (C_{DO} = 5.98 mg/L) was taken into account to get a relationship between the no. of fish and the surface area covered for the morning as well as the evening time. The equations are as follows:

$$0.04 \times N_f + 4.4 \times A_p = 5.48 \quad (8)$$

and

$$0.07 \times N_f + 10.8 \times A_p = 5.48 \quad (9)$$

The above equations were used for the profit maximization by optimization technique in order to

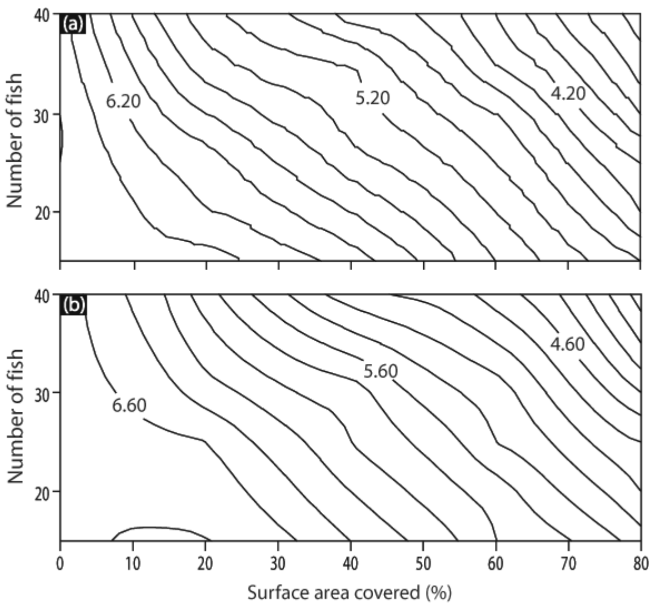

Figure 4: Effect of number of fish and % surface area of the tank covered on dissolved oxygen (in contour line) of tank water on 6th day at (a) 9.00 AM and (b) 4.30 PM.

obtain the particular surface area of the floating nursery and number of fish.

Profit Maximization

The following data for objective function and constraints were obtained by actual verifications in the local market:

$W_{f1} = 15 \times 10^{-3}$ kg; R_{f1} = \$0.67/kg; R_{p1} = \$0.45/m^2; $W_{f2} = 5 \times 10^{-3}$ kg; R_{f2} = \$1.11/kg; R_s = 0.4 kg/m^2; C_s = \$0.11/kg; X_s = \$0.11/m^2; $A_f = 8.33 \times 10^{-5}$ kg/day; C_f = \$0.27/kg; T_c = 60 days

By putting all the values in the objective function and constraints equations:

Objective function:

$$\text{Max. } Z = 0.01 \cdot N_f + 0.44 \cdot A_p - 5.56 \times 10^{-3} \cdot N_f - 0.04 \cdot A_p - 0.11 \cdot A_p - 1.35 \times 10^{-3} \cdot N_f$$

$$\Rightarrow \text{Max. } Z = 3.11 \times 10^{-3} \cdot N_f + 0.29 \cdot A_p$$

Constraints:

$A_p > 0.15$; $A_p < 0.60$; $N_f > 15$ and $N_f < 40$

$$0.04 \times N_f + 4.4 \times A_p = 5.48$$
$$0.07 \times N_f + 10.8 \times A_p = 5.48$$

By solving this problem by optimization technique (solving Linear Programming using Qsb software), final solutions were obtained directly for the number of fishes and tank area covered by the floating nursery. Therefore, for culturing fish in a tank (0.762 m^2 area) with floating nursery, the required number of fish was found to be 32 and area of floating nursery was 0.3 m^2 , i.e. 40% of the surface area of a tank. From the optimization technique, the values of objective function is 0.19, i.e. for the experimental tank of area 0.762 m^2, the total profit was \$0.19. This information is enough to apply at larger scale pond with similar width/depth ratio as selected experimental tanks. Hence, the total profit from the aquacultural hydroponics system with paddy nursery was \$2493.4 per hectare per season (≈ \$15000/ha/year).

Conclusions

The decrease in dissolved oxygen was less in all the cases after three days of experiments and there was not significant decrease in DO after six days. The designed outer diameters of PVC pipes (material used for making the floating structures) were found to be 3.0 cm and 4.5 cm for 0.15 m^2 and 0.30 m^2 of floating structures respectively. Tilapia (*Oreochromis mossambicus*) fish and paddy (IR-36) seeds were found to grow well in the same tank and the total profit in integrated farming was \$15000/ha/year of surface area of the pond. The optimum area of the floating structures and the number of fish in the tank were 40% and 42 fish/m^2 respectively after maintaining 5.38 mg/L dissolved oxygen concentration.

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