Producing Organic Fish and Mint in an Aquaponic System

A Model of Green Technology in Action

A study by: Normala Wahap, Abentin Estim, Annita Yong Seok Kian,
Shigeharu Senoo and corresponding author Saleem Mustafa
Borneo Marine Research Institute, Sabah, Malaysia

Introduction

Aquaponics combines aquaculture and hydroponics to grow fish and plants together in one integrated system. The waste produced by fish serves as manure for the plants and water cleaned this way is made available to fish through recirculation. With the right choice of fish and plant species, aquaponics serves as a model of environmentally compatible and sustainable food production. Because aquaponics is energy-efficient, prevents discharge of waste into the environment, provides organic fertilizer to plants (rather than synthetic chemicals), reuses the waste water through biofiltration and ensures higher production of food per unit area through multiple cropping, it deserves to be treated as a working model of green technology.

This experiment was designed to investigate the effect of combining fish and plants on the output of the integrated recirculating culture system. The selected species of fish was tilapia (*Oreochromis niloticus*) and the plant was mint (*Mentha arvensis* L). Tilapia is a commercially important fish and is widely exploited in aquaculture. Mint is an aromatic herb which is used in food preparations to impart flavor, as an ingredient of traditional medicine and aromatherapy. The popularity of organic herbs is growing due to health benefits, flavor and oil. Due to clean water, and controlled hygienic conditions in aquaponics modules, it is believed that the flavor of herbs would be much higher than those grown in the field. In an earlier publication, Estim and Mustafa (2010) have also discussed the significance of aquaponics application in growing fish and herbs.

Materials and Methods

Experimental trials were carried out in locally designed aquaponics module (Figure 1). The module comprised a fish holding tank (capacity = 200 liters) and two smatter tanks (7 liters and 13 liters) placed at a higher elevation for gravity flow. The smatter of these tanks was filled up with the coral rubble (filter tank) and the other one was maintained for mint plant culture (raft tank). This plant holding tank contained a styrofoam board with 8 pots for placing mint saplings. Water from this tank was airlifted into filter tank from where it moved into raft tank. Through gravity flow the water then drained into the fish tank, and this water recirculation cycle continued. One module (Module-A) was stocked with fish at the rate of 150 specimens/ tank. The other one (Module-B) was devoid of fish.

Results

All the test specimens of the fish survived during the experimental period. The fish maintained a steady growth in body weight over the period of trial but at different rates in the two modules: Module-A (95.4%) and Module-B (68.7%). Dif-

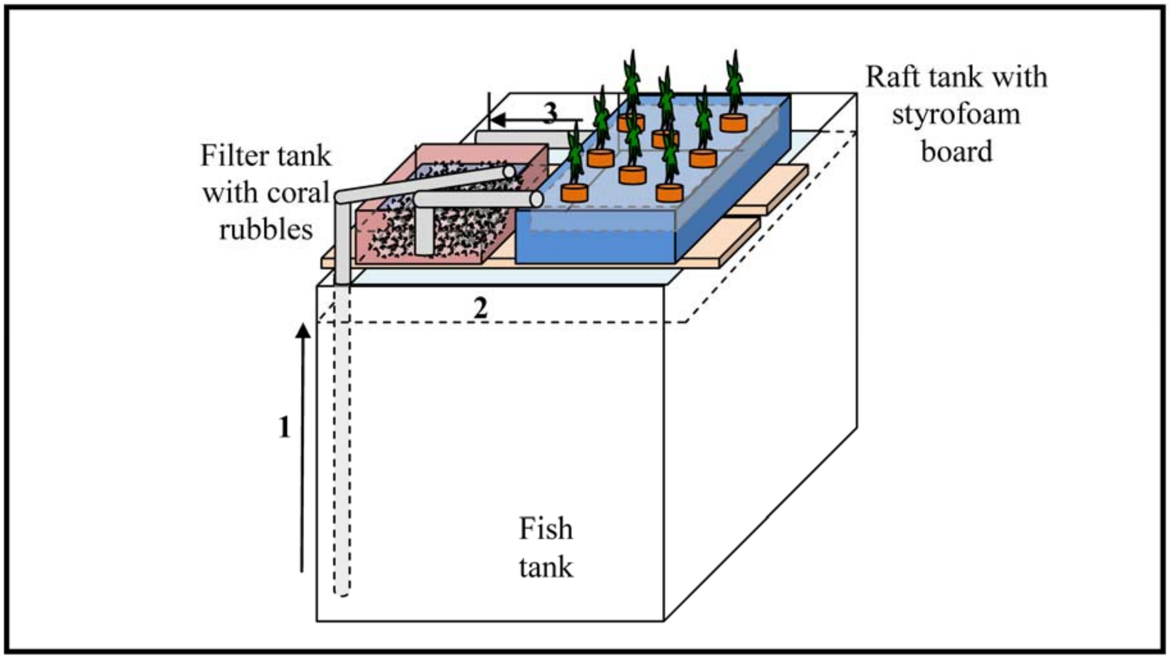

Figure 1. The aquaponics assembly. Tilapia juveniles (4.26±0.04 cm total length and weight 2.23± 0.03g) were obtained from captive breeding of hatchery acclimated broodstock (Figure 2). They were conditioned to the rearing tank environment for 2 weeks before commencement of experimental trials. Mint plants were collected from farms and also adjusted to conditions of aquaponics modules.

ference in growth under these treatments was significant ($P<0.05$). In Module-B, the mint plant also showed a progressive growth (95.4%) compared to that in Module-A (but the growth rate was higher (26.7%) when integrated with fish (Module-A). After 2 weeks of trial the mint leaves started losing their green color and turning yellow (Figure 4, right), which appeared to be a symptom of nutrient deficiency. By the end of 4 weeks, 15.6% of the leaves were yellow in Module-A. The percentage of yellow leaves was almost double (30.3%) in Module-B.

Figure 2. Tilapia broodstock in a tank. Dissolved oxygen and temperature were measured using the multiprobe Dissolved Oxygen/ Temperature Meter model DO300 and pH was recorded by pH/mV/ Temperature Meter model pH300/310 (Eutech Instruments) (Figure 3). Nitrate was determined by the help of Multiparameter Bench Photometer model C99-C200 HI83000 Series (Hanna Instruments).

In both the modules, water temperature averaged in the range of 26.4°C –28.9°C. Dissolved oxygen concentration varied from 5.77±1.17 to 6.82±1.12 (Module-A) and 6.71±0.93 to 7.54±0.69 (Module-B). Examination of pH also showed differences in the two modules. In Module-A, pH varied from 6.61±0.99 to 7.12±1.30, whereas in Module-B, the rage was 6.71±0.93 to 7.13±1.30. Apparently, the presence of fish influenced the oxygen level as well as pH of the water.

Nitrate concentration was tested to examine the degradation of nitrogenous waste in the two culture systems. While there was no significant difference in the nitrate level in Module-B during the 4-week trial (1.166 – 3.504 mg/l), the level was higher and gradually increased in Module-A (3.504-19.366 mg/l).

Discussion

The results suggest that aquaponic systems can support multiple crops and high survival if fish and plants are properly integrated in especially designed culture modules. A successful outcome of such a farming system owes to the ability of plants to assimilate the fish waste, the efficiency of biological filtration in converting harmful ammonia and nitrite into nitrate, and the ability of fish to tolerate the biodynamic conditions of the culture module. Mint grows well in rich, slightly acidic pH environment (pH of about 6.5) and in well drained condition. Acidity that develops in the tank due to fish is therefore not a growth-restraining factor for mint. Further, since mint roots are always kept moist in the raft tank, they have the ability to tolerate this condition.

Tilapia is one of the fish species well suited to aquaponics. It is hardy, resistant to diseases, euryphagic, accepts pelleted diet and is air-breathing. With pellet feeding it is more practical to prevent food wastage and to control water quality. The air breathing habit of the fish enables it to easily withstand fluctuations in the dissolved oxygen concentration of the water; the fish increases the rate of surfacing when oxygen level in the water declines.

When fish are cultured, only 25-30% of the feed is converted to useable energy and the remainder of nutrients is excreted in solid or gaseous form (Rakocy and Hargreaves, 1993). The fish waste comprises fecal matter (metabolic waste), organic matter (undigested protein, fat and carbohydrates), ash and some other substances, and non-fecal products (ammonia, urea, orthophosphate and carbon dioxide) (Schneider, 2006). All these waste products are released into the water where fish are held and they have to be removed to maintain the water quality in a range acceptable to fish for its survival and growth.

Accumulation of nitrogen, phosphate and carbon dioxide is hazardous to fish, if not removed, and a problem for the environment (eutrophication and greenhouse effect), if they are released outside. While solid wastes can be removed by filtering devices such as screen filters or other variants, the gaseous wastes require treatment that involves converting harmful ammonia and nitrite to nitrate using biological filtration. Although bacteria can achieve it but the end products (nitrates and phosphates) that build up in the recirculation system can cross the threshold of tolerance and impair the water quality. They are diluted by water renewal. A better way is through their uptake by plants integrated into the water recirculation system. In this aquaponics module where tilapia was combined with mint, these substances were taken up by the plant and transformed into useful biomass. Those still remaining in water were acted upon by useful bacteria (*Nitrosomonas* to transform ammonia into nitrite and *Nitrobacter* to convert nitrite to nitrate). The coral rubble placed in the filter tank provided the surface for these bacteria. The submerged roots of the mint plant could also provide surface area for nitrifying bacteria. The possibility of direct uptake of a fraction of ammonia and nitrite by the plant cannot be ruled out, and if it is confirmed to happen, it can make up for biofiltration deficiency by bacterial activity. The maximum value of nitrite in Module-A (19.3 mg/l) which is well within the acceptable level for fish culture, indicated the efficiency with which the nutrients were picked up by the plant.

An advantage of floating culture is that the minerals present in the water and those released into it will more freely and efficiently buffer the changes in the pH unlike when hard substrates, including gravel, which are also placed in some aquaponics systems. While the gravel also provides substrate and releases micronutrients from slow but constant erosion which can help in the buffering process, but the buffering is done at the gravel surface rather than in the whole water column where it can be more efficient.

Earlier studies have reported the importance of nitrogen, phosphate and potassium on growth rate of mint and also noticed how these nutrients increased the general uptake and assimilation of required nutrients when present in the fertilizer (Rahman *et al*., 2003). The qualitative and quantitative improvement of mint that was noticed in Module-A was the outcome of not only absorp-

Figure 3. Measurement of water parameters. Total length and body weight of the test specimens of the fish were recorded before the commencement and after the completion of experimental trials. Fish were provided dry pellets at the rate of 3% of their body weight. Condition of fish and plants was monitored and any apparent changes were recorded. The experiment was conducted triplicate for a period of 4 weeks.

tion of these two nutrients but a general increase in assimilation of growth-promoting substances that fish waste water contained. Chand *et al.* (2006) have also discussed the nutrient uptake in mint plant from organic waste of farm animals and its effect on production.

Mint plant is known to grow best in shaded and humid conditions where temperature ranges from 15.5 – 21.1^{o}C. However, the fact that the plant was observed to grow in aquaponic system where temperature was higher, it was evident that nutrients and culture conditions modulated the thermal tolerance of the plant.

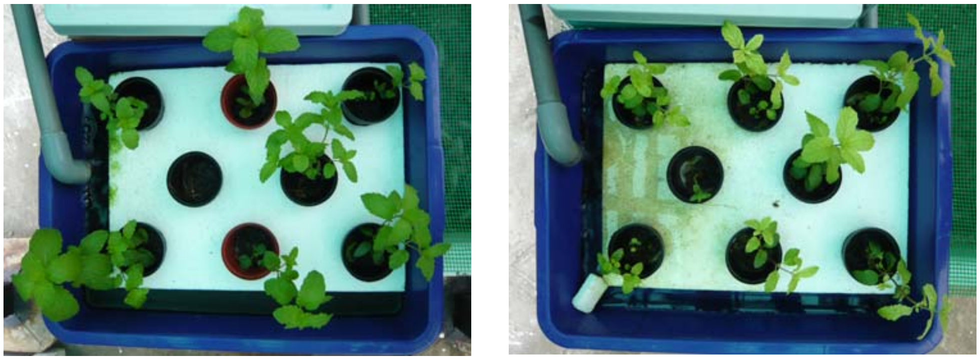

Figure 4. Mint integrated with fish stock (left) and without fish stock (right). In both the modules, water temperature averaged in the range of 26.4^{o}C–28.9^{o}C. Dissolved oxygen concentration varied from 5.77±1.17 to 6.82±1.12 (Module-A) and 6.71±0.93 to 7.54±0.69 (Module-B). Examination of pH also showed differences in the two modules. In Module-A, pH varied from 6.61±0.99 to 7.12±1.30, whereas in Module-B, the rage was 6.71±0.93 to 7.13±1.30. Apparently, the presence of fish influenced the oxygen level as well as pH of the water.

It is evident from the data that while fish culture can be carried out in the aquaponics module over extended periods, mint stocks have to be harvested at shorter intervals, preferably every fortnight, and replaced by fresh stocks. Keeping the same plant in the system leads to fall in biomass and would impair the water quality since nutrient uptake in unhealthy plants is slower and may even cease if the culture continues. In fact, mint should be harvested before leaves start turning yellow. They become yellow due to shortage of certain nutrients such as iron, calcium and potassium in soilless culture. While most of the nitrogen and phosphate requirements are met from the fish waste, there could be deficiency of potassium and some micronutrients, including iron and magnesium.

Potassium deficiency interferes with photosynthesis. Shortage of magnesium causes stunted growth and impairs metabolism. Iron is involved in chlorophyll and carbohydrate production. Detailed information on micronutrient requirements of mint plant is not available to identify all the possible causes of health impairment. A delayed yellowing of leaves in Module-A containing fish suggests that fish waste contains many though not all the nutrients, and they provide the nourishment enough for at least two weeks. Some critical micronutrients are still needed for sustaining a healthy culture beyond 2 weeks. A mixture of micronutrients given in the required doses may help overcome these deficiencies, and boost the stamina and growth rate. Probably, this will enable healthy growth of mint over longer periods of time than was noticed in this experiment.

Gains from aquaponic system can be multiplied by better designs and required inputs. Specialized modules that are more efficient in tackling fish waste, especially by reducing the residence time of ammonia and nitrite in the system, altering the stocking rate of fish and plants, and facilitating better biomass gains in plants by additional inputs will increase the production of plants as well as fish.

At ambient temperatures, ammonia tends to occur in unionized form (NH_3) which is more lethal than the ionized ammonia (NH_4^+). It converts to nitrite which eventually transforms into the nitrate as the end product. Unless this pathway is rapid, the toxic elements will accumulate and prove detrimental to fish and plants. While comparing the performance of different aquaponic systems, Lennard and Leonard (2006) have discussed the influence of design components on the organic production efficiency of bio-integrated modules. Although coral rubble was used to facilitate biofiltration, innovative products such as the ‘Crystal Bio’ should also be integrated for accelerating the breakdown of nitrogenous substances into nitrate.

The on-going trials using the aquaponics module manufactured by Nelson and Pade, Inc., Montello, WI (www.aquaponics.com) will be able to demonstrate the importance of innovative designs in improving production of organic food from aquaponics systems.

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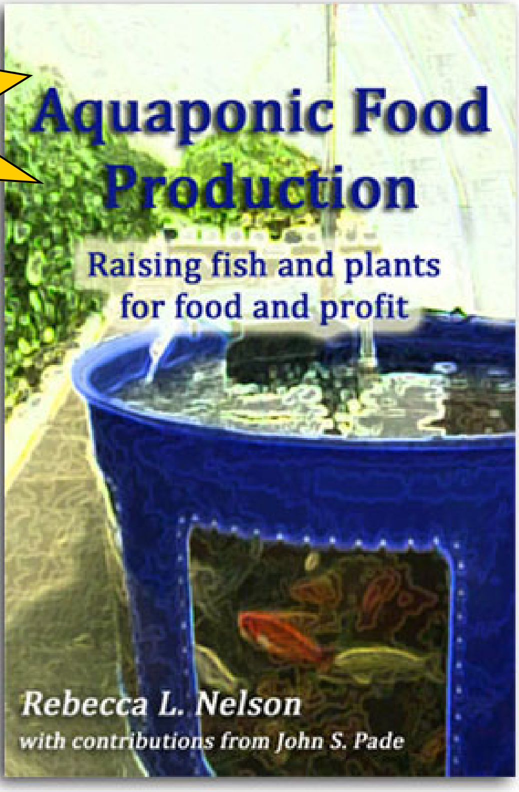

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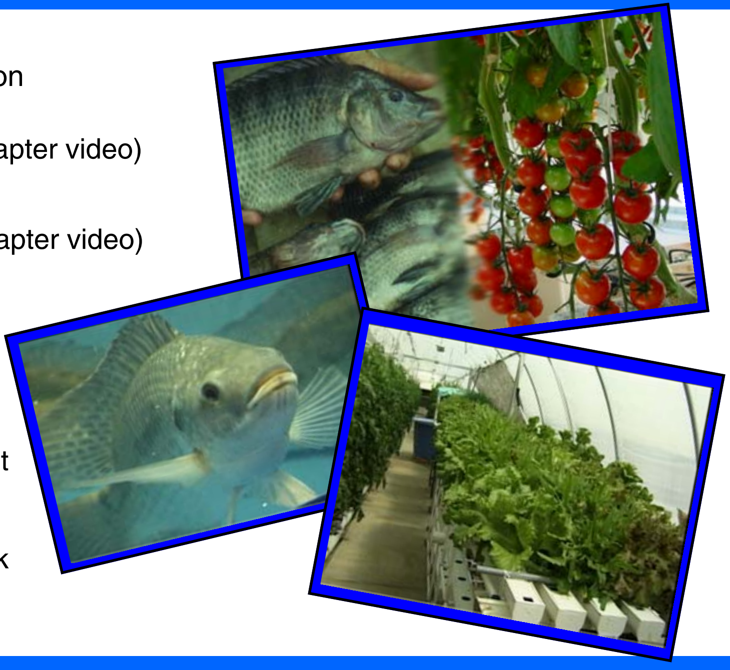

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