

Full Length Research Paper

Recirculating aquaponic systems using Nile tilapia (*Oreochromis niloticus*) and freshwater prawn (*Macrobrachium rosenbergii*) polyculture and the productivity of selected leafy vegetables

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A study on the productivity of lettuce (*Lactuca sativa*), Chinese cabbage (*Brassica rapa pekinensis*) and pac choi (*Brassica rapa*) in a recirculating aquaponics system using Nile tilapia (*Oreochromis niloticus*) and fresh water prawn (*Macrobrachium rosenbergii*) polyculture was conducted in a controlled environment. The system was effectively designed by following the “one-pump rule” having the culture water lifted by a 40-watt submersible pump from the 200-L bio-filtration tank, the lowest portion, to the 250-L fish tank, the highest portion, allowing the flow of water by gravity along the 2.44 m x 4.88 m raceway and the over-sized return pipes in a closed loop. Hydroponically germinated seedlings in rock wool received foliar fertilizer daily for 12 days and were transplanted on the rafts at 15-cm spacing 30 days after stocking 22 kg of mixed-sex tilapia in the fish tank and 295prawns in the raceway with 20-cm water depth to permit rafts to float. Fish were fed ad libitum with commercial feeds while excess feeds entered the raceway for the prawn to scavenge. Environmental conditions were maintained and water quality parameters were monitored in a compromise between the ideal requirements of fish, prawn and vegetables including the beneficial bacteria throughout the 108-day culture period. Two sets of data for vegetables and one for tilapia and prawn were gathered after the two 35-day growing seasons of vegetables. Another similar system without prawn was installed as control and received the same cultural management from where similar data were gathered. The two systems provided favorable water quality for tilapia, prawn and nitrifying bacteria with average dissolved oxygen of 5.6 ppm at 98 per cent saturation and 21°C temperature. A pH of 7.1–7.5 was established and total dissolved solids of 250–390 ppm were provided in the system with prawns while 7.4–7.7 pH and 220–350 ppm of total dissolved solids in the control. However, the low concentration of nutrients at high pH, which was far below the crop requirement, triggered the vegetables to exhibit nutrient deficiencies. Results uncovered that the stocking density of tilapia and the ratio of the aquaculture to the hydroponic components were inappropriate which limited the system to accumulate and increase the concentration of nutrients thereby causing chlorosis and necrosis among the vegetables and lessened the yield. Nonetheless, the system with prawns has higher nutrient content that vegetables demonstrated significantly better growth and yield than in the control which disclosed that integrating prawns helped stabilize and diversify the system thus improving yield. Among the three vegetables, pac choi had the highest growth and yield, followed by Chinese cabbage and lettuce. Tilapia also has higher gain in weight and better feed conversion ratio in the system with prawns. Prawns, likewise, has 6.42 g weight gain and 71 per cent survival rate. It was also confirmed that stocking density and component ratio were critical factors in designing aquaponic system.

Keywords: Aquaponics system, vegetable-tilapia-prawn polyculture, tilapia-prawn-vegetable recirculating system, aquaponics in a controlled environment, leafy vegetables production

INTRODUCTION

FAO's optimistic prediction

Amidst the imminent food shortage, the United Nations' Food and Agriculture Organization (FAO) made an optimistic prediction that there will be an abundant food supply in the coming years. The forecast is based solely on the availability of today's technical knowledge that is capable of increasing agricultural productivity (FAO, 2011). This technical expertise will prove that scientific knowledge combined with computerized equipment is more important than hard work and muscle power that traditional agriculture customarily requires (Murphy, 1984).

Smart farming system

Interestingly, policy-makers in the Philippines are cognizant of this prediction and are responsive to address the FAO's call to change the country's age-old agricultural practices. The call is to shift to new paradigm of adopting advanced technologies and practice new techniques to increase agricultural productivity in the country. As such, the Congressional Commission on Science and Technologies and Engineering (COMSTE) challenged the Department of Agriculture and the Commission on Higher Education to cause the immediate advocacy and top-priority implementation of smart farming systems. Smart farming entails the application of new production practices to intensify agricultural production while utilizing and wisely conserving earth's resources. These technologies include those that are employed in other countries which are potentially adoptable in local condition. One of these technologies is aquaponics - the raising of fish and growing vegetables in one infrastructure and system (Tanganon, 2012).

The Philippines: country of meat-eaters

The COMSTE's initiative addresses the report that the Philippines has become a country of meat-eaters and has remained to be one of the lowest vegetable consumers in Asia (Mabutas, 2011). Citing the 2003 data from the Food and Nutrition Research Institute (FNRI), Filipinos have an increasing trend of meat consumption from 20.3 percent in 1978 to 28 percent in 2003. These figures are supported by the report of the National Nutrition Council that Filipinos have only 40 kg annual per capita vegetable consumption in 2003, well below the 146-182 kg per capita recommendation by the World Health Organization. Comparing with the vegetable consumption of China with 259 kg per year, the country's per capita consumption is way below that FNRI recommended that Filipinos should at least consume 69 kg per capita. The

declining vegetable consumption was among the major factors in the increase of incidence of illnesses in the country (Mabutas, 2011). According to the WHO, the low vegetable intake has caused an estimated some 2.7 million deaths each year, and was among the top 10 risk factors contributing to mortality.

The decreasing vegetable consumption in the country can be attributed to its close relationship with the complicated problems of production (Mabutas, 2011). Aside from its seasonality, vegetable production is highly affected by the frequency and intensity of typhoons as caused by the changing climate. However, one of the most aggravating factors is the minimum attention from the government to the country's vegetable industry (Dolan, 1991; Zoe, 2011). Although the pain was felt only in 2002, the industry, unlike the major/traditional agricultural crops, has been neglected for many years, receiving less support from the government in the national food security program. No doubt that the industry is sick and is almost in comatose condition (Aquino, 2004). Another alarming trend is the decreasing area cultivated to vegetables due mainly to declining fertility of the land due to long years of use, erosion, land use and/or crop conversion.

The promotion and implementation of aquaponics technology is an initial step to create a mechanism to heal the vegetable industry. The technology will empower people and communities to take control of their own food security and give household direct access to clean and healthy food while augmenting family income. It can be a groundbreaking move which farmers and investors can mitigate the grave impact of climate change and build the preparedness and adaptive capabilities of the next generation. The technology is also a revolutionary teaching tool for students taking up biology, chemistry, earth science, engineering, fisheries and agriculture subjects to learn and obtain experience in a hands-on setting.

A government's intervention is therefore necessary to transform the vegetable industry. Given preferential attention and top-priority advocacy, aquaponics can make it a reality.

Aquaponics then and now

Aquaponics has many confusing origins. The Hanging Garden of Babylon was believed by many to be the earliest example of aquaponics. Others had thought that it originated in the River Nile of Ancient Egypt. Still, the practice in China and Thailand of feeding farm wastes to cultured fish in flooded rice paddies or in vegetable-fish culture were also considered as the first examples of aquaponics. Overwhelmingly, many believed that the first model of aquaponics was the *Chinampas* or "floating

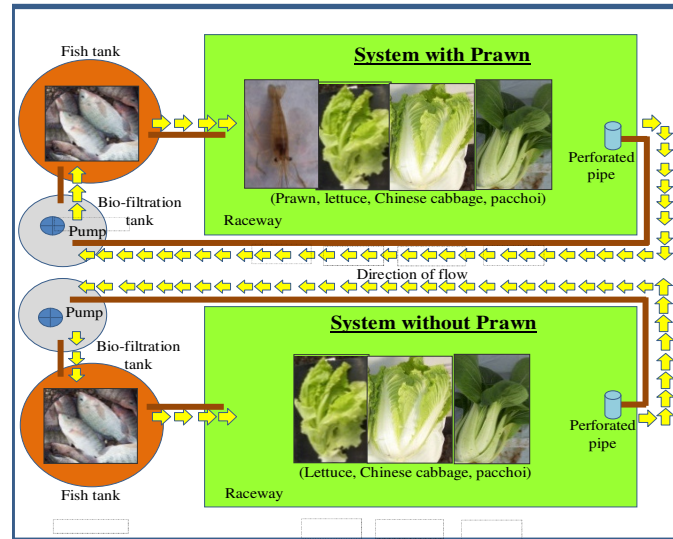


Figure 1. The diagram of the systems showing the different components, crops grown and direction of flow of the culture water

gardens” which were chronicled as the first viable design of sustainable agriculture (Pennington, 2011). It was the Aztecs, an American wandering tribe, who established the system in 150-1130 CE when they were harshly treated by their neighbor sand driven onto the Lake Tenochtitlan. With no land to till, the tribe endured by constructing rafts from reeds and stacking soil scoured from the bottom of the lake. The Aztecs successfully produced various crops that sustained and saved them from hunger. By force of arms, they later overthrew and conquered their oppressors (Rahman, 1994). The *Chinampas*, which were established in a gamble, have prospered to rebuild their lives and met the requirements of the growing empire. Subsequently, the place became a huge and magnificent city, which is known today as Mexico City.

Nowadays, floating gardens are being advocated in many parts of the world, particularly in the regularly flooded regions such as Bangladesh. Bangladesh, one of the world’s poorest countries, is battered by fierce tropical storms flooding numerous unstable rivers annually. Provided with training by the Intermediate Technology Development Group, an international development agency in United Kingdom, and GonoUnnayan Kendro, a local non-government organization, rural communities popularized floating gardens by growing vegetables on manure-enriched soil stacked on aquatic weeds and reinforced with bamboo poles. The program has improved the lives and extended the growing capabilities of people in places where land is scarce or unavailable (ITDG, 2007). However, one of the first successful commercial aquaponic systems was established in the University of Virgin Islands where several trials for vegetables production were conducted using tilapia culture (Rakocy, 1989). In the University of Columbia, Dr. Dickson Despommier introduced the new concept of

vertical farming as a sustainable source of fish, poultry, cattle, fruits and vegetables in skyscrapers. The technology is the application of several advanced technologies such as aquaponics, hydroponics and aeroponics in controlled environment and increasing employment opportunities in urban communities. With extensive photographic documentation and several historical books on the subjects, commercial high-rise farm has never been built nor has been diligently pursued although many scholars concluded that it will be the agriculture of tomorrow (Despommier, 1999). In the Philippines, immediate adaption of similar technologies is necessary. With the threats of climate change projected to continue and worsen, smarter adaptation and effective mitigation measures needs to be implemented.

This study aimed to evaluate the productivity of leafy vegetables in an aquaponic polyculture system using Nile tilapia (*Oreochromis niloticus*) and freshwater prawn (*Macrobrachium rosenbergii*) polyculture in a controlled environment. Specifically, it determined the growth and yield response of lettuce (*Lactuca sativa*, variety Balck-seeded Simpson), Chinese cabbage (*Brassica rapa pekinensis*, variety Rubicon) and pac choi (*Brassica rapa*, variety Black Summer). It also assessed the performance of the system.

MATERIALS AND METHODS

System components

Two systems were installed in a controlled environment greenhouse comprising of bio-filtration tank, fish tank and raceway and interconnected with pipes. The systems employed raft cultures for vegetables using tilapia and



Figure 2. The basic components of the systems

recirculating the culture water in a close loop as depicted in Figure 1. One of the systems integrated prawn under the rafts while the other has no prawn to serve as control. With the application of “one-pump rule”, water was lifted from the bio-filtration tank, the lowest point, by a 40-watt submersible pump to the fish tank, the highest point, and allowed to flow by gravity along the raceway passing through return pipes back to the bio-filtration tank. The bio-filtration tank (Figure 2a) contained bioballs to increase substrate area for the nitrifying bacteria. The fish tank (Figure 2b), served as the rearing tank for Nile tilapia while the raceway (Figure 2c) was a pool of culture water where vegetables are grown.

Equipment and controls

The greenhouse was equipped with environmental control systems connected to a computer to record air temperature, relative humidity and photosynthetically active radiation (PAR). Sensors that automatically govern cooling fans, heater and ceiling fans were installed to attain the optimum environmental condition. Hand-held meters to manually monitor water quality parameters such as pH, total dissolved solids, dissolved oxygen, saturation percentage and water temperature were acquired and utilized to achieve a compromised ecosystem for vegetables, prawn, tilapia and beneficial bacteria. Electric heaters were installed in the bio-filtration tanks to raise the temperature during winter season.

Cultural management

Stocking density in tank culture was measured in units of fish biomass per volume of water (Connolly and Trebic, 2010). In this study, 22kg of Nile tilapia with an average weight of 150 g were stocked in the fish tank. It was based from the study of Licameli et al. (2011) at 5 kg per m³ of the total volume of water in the system. Each

system has 4,880 L of water which included the bio-filtration tank containing 220 L and the fish tank and the raceway have 250 L and 4,410 L, respectively. Several tilapia had died in both systems days after stocking due to stress in transporting the stocks. The same quantity was replaced.

Likewise, 295 heads of juvenile freshwater prawn with average weight of 1.67 g and average length of 4.3 cm were stocked under the rafts week later. Commercial feed was fed to tilapia ad libitum with the aid of 12-hr belt feeder while prawn scavenged on the scraps and undigested feed that enters the raceway. F1 seeds of the three vegetables were grown hydroponically using rockwool blocks. Seedlings were transplanted 30 days after stocking tilapia at 15 cm spacing by plugging them onto the holes on the Styrofoam rafts seven days after seeding. Water quality parameters were monitored daily and TDS was found to be below the desired level. In an effort to increase the level, the depth of water in the raceway was maintained at 20 cm reducing the volume to 2,850 L just enough to allow rafts to float. Tilapia was harvested using fish net while vegetables collected after gathering the samples. Water was pumped into the other raceway to fast-track the harvesting of prawns leaving a height of water of about 5 cm. Seeds for the second crop of vegetables were propagated a week before harvesting vegetable using the same procedure and technique of germination applied in the first crop.

A sample of culture water from each raceway was analyzed to determine pH, TDS, nitrite, nitrate, potassium, phosphorus, calcium, magnesium, iron and other elements as supplemental data for comparing the two systems.

Environmental and water quality parameters

Compromised environmental and water quality parameters were desired to create an optimum ecosystem for all the living organisms living in the systems. Data such as air temperature, relative humidity



Figure 3. The Nitrogen Cycle

and PAR were extracted from the computer based on real-time data fed by sensors that were logged at 5-minute interval based on Julian day. Average values were taken.

Water quality parameters such as pH, total dissolved solids (TDS), temperature, dissolved oxygen (DO) and percentage saturation were targeted at a range conducive for the organisms. Data were collected every morning from four stations: the fish tank, the point where culture water entered the raceway, the point where the water leaves the raceway near the stand pipe, and at the bio-filtration tank.

The concept of aquaponics

Aquaponics is relatively a new concept of producing food which addresses complicated problems related to agricultural productivity. It integrates two proven cultures: aquaculture or raising fish and hydroponics or growing vegetables. The technology is a production system which uses minimum water supply in non-soil media even in unproductive space. When applied in backyard scale, aquaponics is a reliable method enough to meet the requirements of a family of inexpensive and nutritious food (Connolly and Trebic, 2010).

The fish give off ammonia through gills and urine, including any fish wastes or uneaten food. As part of its normal protein digestion, ammonia quickly builds up in the water and accumulate in the fish tank adversely affecting the growth of fish. The naturally-occurring beneficial bacteria, the essential but unseen elements of aquaponics, are responsible in converting ammonia nitrogen into fertilizer for the plants to consume (Malcolm,

2007). The bacteria can be found in streams, lakes, ponds, dams, aquariums and in the air and which will populate anywhere where there is water and biological activity (Nelson, 2008). Two main types of autotrophic bacteria carry out the essential work in the nitrification process which occurs in a two-step process: first when toxic ammonia (NH_3 or NH_4^+) is converted to nitrite (NO_2^-) by Nitrosomonas bacteria, and then to nitrate (NO_3^-) by Nitrobacter species. When the system is in balance, the water will be crystal clear and ammonia and nitrite levels will be zero (Tezel, 2009). The process is known as Nitrogen Cycle as illustrated in Figure 3.

The fish are less susceptible to high levels of nitrites and most plants can't absorb nitrites unless converted into nitrates (Rakocy et al., 2006). Controlling the nitrate level is best accomplished by hydroponic crops such as lettuce, pac choi, cabbage and other leafy vegetables are favorite crops to be planted. The water is then returned to the fish tank cleaned of excess nutrients and freshly oxygenated. Both fish and vegetables are regularly harvested at scheduled harvest.

Some vegetables, like tomatoes and cucumbers, requires high concentration of nutrients especially potassium, that a young system may not be able to supply. That is why most growers limit their production to leafy vegetables such as salad greens. However, a mature aquaponic system grows many plants better than can be grown hydroponically (Pennington, 2011). The key to this amazing result lies in three important factors: a healthy bio-filter, a pH within desirable range, and a high-quality fish feed.

Three of the primary methods emerging in the industry are based on a hydroponic system. These are the raft system, the nutrient film technique and the media culture.

Table 1. Compromised environmental and water quality parameters

Parameters	Compromised Level*	Level Achieved by the System			
		With Prawn		Without Prawn	
		1st Crop	2nd Crop	1st Crop	2nd Crop
Environmental monitoring					
Air temperature, °C	22–30	20–32	18-30	20–32	18-30
Relative humidity, %	40–90	55–85	58-87	55–85	58-87
PAR, nm	390–760	435–685	410-645	435–685	410-645
Water quality					
pH	6.0–7.5	6.5–7.5	7.1-7.9	6.7-7.7	7.3-8.2
Total dissolved solid, ppm	>300	246–344	240-393	228-328	261-344
Water temperature, °C	>20.0 – 30.0	18.8–22.9	16.3-23.5	19.2-23.9	18.5-24
Dissolved oxygen, ppm	>3.0 –7.0	3.2–6.9	2.8-7.3	3.2-6.7	3.0-7.2
Saturation, %	60-125	58–125	51-123	52-123	56-127

*values compiled from various literatures

Utilizing the principles that apply to geponic and hydroponic productions, the level of concentration and the functions of each of the elements play a vital role in the growth and development of the plant (Barry, 1996). These levels, when not met often result in nutrient deficiencies, symptoms of which are visible by merely observing the plant (Sorenson and Relf, 1996).

Tilapia is one of the most cultured species (Popma and Masser, 1999). That is why it has become the most important fish of the 21st century and could be accurately described as the “aquatic chicken” of today because of its wide acceptance across all cultural, religious and economic groups similar to chicken. It has become the shining star of aquaculture with farms starting and expanding across the globe. The most domesticated fish, it is uniquely reared in all any levels of production systems providing welfare for the poorest farmers, and at the same time is sold in international markets. Second only to carp, tilapia is a popular cultured species that has a significant role similar to a livestock animal grown by subsistence farmers in the developing Countries (Fitzsimmons, 1997).

The three most common species cultivated are the Nile tilapia (*Oreochromis niloticus*), which is known for its high yield, the Mozambique (*Oreochromis mossambicus*) and the Blue tilapia (*Oreochromis aureus*), which is a cold resistant strain. Although the Nile tilapia is also the least tolerant to cold water conditions, it is potentially the most profitable of the grown species.

Data gathered

The growth and yield of vegetables and the performance of the systems were evaluated by comparing the performance of the two systems. These vegetables were replicated five times in order to maximize the floor area of the raceways. With this, each experimental unit had 33

plants or 165 plants per treatment with a total of 495 plants for three treatments in every raceway. A set of data were collected for each system every harvest. The circumference of crowns, length of leaves and roots of the vegetables were collected to evaluate the growth while fresh weight was used to evaluate the yield. Six plants were taken as representative samples of every experimental unit by carefully removing the plants from the rafts as roots were entangled under the rafts. Measuring tape was used to determine the circumference and length while a digital weighing scale was used to determine the yield. Data were carefully recorded, and statistically analyzed and interpreted using single-factor Analysis of Variance (ANOVA) and Duncan Multiple Range Test for the comparison among means.

Likewise, the growth and gain weight of aquacultural crops were determined from 10 samples of tilapia and prawn. Growth was evaluated by determining the increase in length from head to the end of the tail based from initial measurements. Similarly, gain in weight was computed by subtracting the initial weight from the final weight during the first and second harvest of vegetables. Feed conversion ratio (FCR) was also computed by dividing the gain in weight of tilapia by the weight of feeds consumed by the fish. The water consumption of the systems was determined by adding the daily evaporation losses since the onset of the experiment with the total volume of water left in the system.

RESULTS AND DISCUSSION

Environmental factors and water quality parameters

Environmental factors and water quality parameters designed to meet the requirements of a compromised ecosystem conducive to all species were shown in Table 1. These parameters were compared to the actual

Table 2. Optimal pH and TDS requirements of lettuce, Chinese cabbage and pac choi

Vegetable	pH	Total Dissolved Solids, ppm
Lettuce	5.5–6.5	560–840
Chinese cabbage	6.5–7.0	1,750–2,100
Pac choi	7.0	1,050–1,400

conditions. Environmental factors were obtained from the data logged on the computer. Water quality parameters such as pH, TDS, temperature and dissolved oxygen were monitored daily. Data were collected early in the morning when the sun was not yet set. At this time, photosynthesis stops at night while respiration continues (Francis-Floyd, 2011).

Air temperature

Air temperature designed at a range of 22–30°C was recorded at 20–32 °C. Overhead heater was triggered, cooling fans and ceiling fans stirred the air to create a uniform environment in the bay. Fluctuations of outside temperature created variations in the interior environment conditions of the greenhouse by approximately ± 2 °C.

Relative humidity

Relative humidity which was aimed at 40–90 per cent was within the desired range during the first and second growing seasons having 55–85 and 58–87 %, respectively. These fluctuations were the effects of low night temperature during the winter season, though ideally the relative humidity of the air surrounding plants should be maintained around 70% at night and 85% during the day (Rorabaugh, 2011).

The PAR

Crop production in Tucson, Arizona was affected by both day length and angle of the sun as season changes (Rorabaugh, 2011). On June 21 for example, the day length was 14 hr and 15 min as compared to December 21 with only about 10 hr. PAR is normally between 400–700 nm, but the quantity was gradually reduced after the equinox (September 23, 2011). The quality and quantity of light directly affected plant growth. PAR was recorded at 410–685 nm which was within the normal range.

The pH

The pH of water used in the systems fluctuated over time.

Taken from the city's water supply, it has an average pH of 7.97 when collected into the system. This level declined at an average of 6.72 after one week of stocking the tilapia and prawn while the other system had an average pH of 6.75. At the time the vegetables were transplanted, reading in the system with prawn was 6.8 and 6.90 in the other system.

Throughout the first growing season of vegetables, the range of pH in the system with prawn 6.5–7.5 while a range of 6.7–7.7 in the system without prawn. During the second growing season, pH range was 7.1–7.9 in the system with prawn while 7.3–8.2. These values were above the recommended values and were detrimental to the vegetables (Rahman, 1994), but were within the recommended levels for tilapia, the nitrifying bacteria (Rakocy et al., 2006) and for freshwater prawn (New, 2002). The high levels of pH were the primary cause of nutrient deficiencies, particularly nitrogen, as plant leaves in both systems were yellowish with veins obviously visible. Most hydroponic plants grow best at a pH of 5.8 to 6.8 (Barry, 1996; Anderson et al., 1989). In addition, solubility of nutrients such as iron, manganese, copper, zinc and boron, are less available to plants at a pH higher than 7.0 while that of phosphorus, calcium, magnesium and molybdenum sharply decrease at a pH lower than 6.0. (Jensen, 1991; Rakocy, et al., 2006). However, the growth of nitrifying bacteria was not affected at these levels as the optimum pH range for nitrification efficiency is greater at the higher end of this range. Compromise between nitrification and nutrient availability is reached by maintaining a pH close to 7.0. As shown in Table 2, lettuce, cabbage and pac choi require a pH from 5.5–7.0 which had been exceeded in the system.

The TDS

The TDS level throughout the growing season in system with prawn was within 267–336 ppm, while system without prawn has slightly lower range of 240–393 ppm. These values increased throughout the second growing season ranging from 228–328 ppm for system with prawn while 261–344 ppm was recorded for system without prawn. These readings were far below the average requirements of the three crops that were grown in the system. As shown in Table 2, lettuce, cabbage and pac choi grow well with TDS of 560–840 ppm, 1,750–2,100 ppm and 1,050–1,400 ppm, respectively.

Table 3. Effects of different levels of dissolved oxygen in ppm and % saturation

Dissolved oxygen			
Level, ppm	Effect	Level, %	Effect
0-2	not enough to support most organisms	<60	poor quality
2-4	only few can survive	60-79	acceptable for most organisms
4-7	good for all organisms	80-125	excellent for most organisms
7-11	very good for all organisms	>125	too high

Based from: Cary Institute of Ecosystem Studies, Dissolved Oxygen Reading, Changing Hudson Project

Table 4. Laboratory analysis of culture water in systems with and without prawn

Items	Parts Per Million		Usepa Guidelines
	With Prawn	Without Prawn	
Nitrates	30.8	24.6	N03 = 25 PPM
Nitrate nitrogen	7.0	5.6	N = 10 PPM
Sulfates	41.0	38.0	250 PPM
pH	7.5	7.8	6.5 - 8.6 Secondary std.
Calcium	180 (10.5 g/gal)	155 (9.1 g/gal)	
Magnesium	45 (2.6 g/gal)	35 (2.0 g/gal)	
Sodium	48	46	PPM
Chlorides	70	68	250 PPM
Total dissolved solids	311	292	500 PPM Secondary std.
Hardness	225 (13.1 g/gal)	190 (11.1 g/gal)	
Total iron	0.5	0.1	0.3 PPM Secondary std.
Phosphates	25	19.75	
Phosphorus	8.3	6.6	0.400 PPM Secondary std.
E. coliform	N/A	N/A	<1/100 mL
Total coliform	N/A	N/A	<1/100 mL
Copper	N/A	N/A	1 PPM Secondary std.
Zinc	N/A	N/A	5 PPM Secondary std.
Manganese	0.07	0.038	0.05 PPM Secondary std.
Potassium	N/A	N/A	
Comments:	N/A	N/A	

These amounts were not provided by the system. Further, the high pH levels limited the roots from absorbing the nutrients in the culture water (Barry, 1996). These nutrients are required to support the metabolic processes such as respiration, photosynthesis and transpiration (Rorabaugh, 2011). Unlike in hydroponics where nutrients are made readily available in the solution of inorganic fertilizers (Barry, 1996), the amount of nutrient generated in an aquaponic system is highly dependent on the excretion and excess food supply of the aquacultural crops (Pennington, 2011). It is a function of the stocking density of fish and proper management of the system (Rakocy et al., 2006).

Water temperature

Throughout the first growing season, the temperature at the surface and bottom of water in the two systems was almost identical with an average of 21.4°C with variations of $\pm 2^\circ\text{C}$. During the second growing season, the temperature was maintained at these levels and the effect of winter cold temperature was abated by using water heaters placed in the bio-filtration tank. These values are within the acceptable recommended temperature for aquacultural crops (Rakocy et al., 2006) and also were still favorable to hydroponic crops. The absorption of available nutrients was also affected by water temperature (Bhikajee and Gobin. 1997). Nutrients

are absorbed by plants at a temperature range 18–22°C when water is warm enough to stimulate good growth rates but at the same time cool enough to carry maximum oxygen content (Morgan, 2008). However, an increase in temperature also increases the metabolic rates of fish as physiological demand for oxygen increases. According to Francis-Floyd (2011), at approximately 33.3°C, water can only hold 7.4 ppm DO at saturation, whereas water at 7.2°C can hold 11.9 ppm DO at saturation.

Dissolved oxygen

The average DO level in the system with prawn was 5.7 ppm at 102% saturation and 21.4°C temperature, while the system without prawn has an average of 5.6 ppm at 103% saturation and 21.2°C temperature. The maximum and minimum DO levels for the system with prawn were 6.9 ppm and 3.2 ppm while 6.7 ppm and 3.2 ppm in the system without prawn, respectively. These high values of DO manifested that the systems were well-aerated and with high dissolved oxygen in water that was primarily supplied to the systems by an aerator. These values were excellent for most organisms as related to Table 3. Part of the supply was derived from photosynthesis produced by the roots of the vegetables floating and algae on the rafts, walls of the raceways, sides of the fish tanks and bio-filtration tanks and on the bio-balls (Rakocy et al., 2006).

Water analysis

Water samples taken from the center of the each raceway after the first harvest of vegetables and analyzed by a reputed agricultural laboratory for water analyses, substantiated the data collected daily. As shown in Table 4, results confirmed that the pH in the two raceways was above the recommended levels for vegetables and were appropriate for the aquacultural crops. On the other hand, TDS in both systems was far below the requirement of the three vegetables. The same analyses validated that the system with prawn had lower pH than the system without prawn. Results also verified that the TDS in the system with prawn was higher than in the system without prawn. Further, the analyses also revealed that the system with prawn contained higher amount of nitrogen, nitrate nitrogen, sulfates, calcium, magnesium, sodium, chlorides, iron, phosphates, manganese and hardness as compared to system without prawn. No wonder plants in the system with prawn were heavier, greener and taller than those planted in the system without prawn. Although nutrient deficiencies were both seen in plants in both systems, plants in the system without prawn had more obvious signs and appeared more chlorotic and necrotic.

Deficiency symptoms were highly noticeable in

Chinese cabbage so that its eating quality was reduced.

System design

System components

The 40-watt submersible water pump has a capacity of 50 liters per minute and a total dynamic head of 3.20 m. With this, water in the fish tank was moved in more than 5 minutes and less than 50 minutes in the raceway. The rapid movement of water in the system enables the quick and continuous exchange of nutrients and movement of freshly aerated water in circles.

The design of the aquaponic systems followed the “one-pump rule”: the culture water must be recirculated by one pump starting from the lowest point and allowing the system to flow by gravity in a close loop. The rule was given by a wise man and former owner of Seagreenbio in Palms Spring, California, USA, Mr. Dean Farrel, who claimed that systems designed in this way saved energy and aggravation (Rakocy et al., 2006). That is why both systems were operated by one pump submerged in the bio-filtration tank, the lowest point, to raise the culture water to the fish tank, the highest point, and allowed to flow by gravity through the raceway and back to the bio-filtration tank.

The temperature of the culture water in each system was raised to a recommended level with the installation of water heaters. Initially, a 300-watt heater was able to maintain a temperature of 21.2°C with the aid of cooling fans, ceiling fans and overhead heaters to establish a uniform of a favorable environment inside the greenhouse. However, another heater was added to each system when temperature dropped brought on by the winter season. In addition, the thermal energy absorbed by the culture water in the fish tank, raceway, and bio-filtration tank during the day with sunlight aided in maintaining the water temperature and balanced the effects of low night time temperature. Interestingly, the temperature varied as water flowed from the fish tank to the raceway and to the bio-filtration tank. The average temperature of culture water in the system with prawn while in the fish tank was 21.5°C, then cooled down to 21.3°C as it entered the raceway and cooled further at 21.2°C as it reached the outlet in the raceway and rose again in the bio-filtration tank to 21.6°C where the heaters were installed. The system without prawn had a slightly lower temperature than the system with prawn with an average temperature in the fish tank of 21.3°C and cooled down to 21.0°C and regained a higher temperature to 21.2°C in the bio-filtration tank. This was because the direction of hot air from the overhead heater was flowing to the system with prawn including the heat transmitted by the sun to the polycarbonate glazing.

The installation of a water heater in the bio-filtration tanks maintained the temperature to desirable level at the

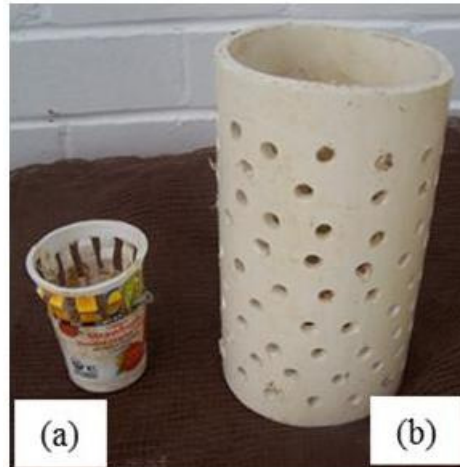


Figure 4. Fabricated stand pipe filter made from discarded cup (a) and perforated PVC pipe (b)

same time and created a factor of safety for the fish, prawn and the vegetables from overheating. An excessively high temperature is possible scenario when a pump continuously draws water until the water in the bio filtration tank dries out. This situation can occur especially when the stand pipe in the raceway is clogged up preventing water to flow from the raceway.

In the same way, DO levels regularly fluctuated as water flowed along the four observation stations in the systems. The level in the fish tank in the system with prawn was normally the lowest at 3.8 ppm. This was because most of the excretion of tilapia was produced in the fish tank. This increased to 5.9 ppm at the entrance in the raceway and further increased to 6.7 ppm at the exit in the raceway. The highest values of DO happened in the raceway because water was highly aerated. Plant roots also added oxygen as part of respiration. DO slightly decreased to 6.2 ppm in the bio-filtration tank. In the system without prawn, the average DO in the fish tank was 4.2 ppm then fluctuated to 5.6, 6.3, and 6.3 in the entrance and exit of the raceway and in the bio-filtration, respectively. These values were within the recommended limits (Rakocy et al., 2006).

The design of the raceway, being rectangular, has poor flow characteristics. Although easier to construct, the incoming water flowed directly to the drain short-circuiting the tank. Waste and organic matter accumulated in some part of the raceway while other areas remained stagnant with pockets of lower oxygen levels. This was one of the disadvantages of having a rectangular raceway as compared to circular design that could create a current to collect the organic matter to the center and out to the drain.

During the course of time conducting the experiment, it was experienced that system failure is possible if a filter in the stand pipe at the exit of water in the raceway is

improperly designed. The filter is necessary to prevent the prawn from escaping and find their way to the bio-filtration tank. The possibility that clogging the ordinary filter (Figure 4a) can occur is not far as roots and other debris blocked the filter. In addition, the vortex of water coming out of the raceways can eventually create a sucking pressure on the raft, preventing water to flow. The weight of the vegetables and roots as they hang on the raft adds up to the problem. Hence, a perforated pipe (Figure 4b) was fabricated to allow water to flow freely and efficiently recirculate the culture water. Several holes on the pipe allowed the flow without restraint.

Stocking density

According to Rakocy (1989), intensive tank culture can produce a very high yield of tilapia by stocking 50-100 g tilapia at a rate 100-200 fish per m^3 of culture water or even as high as 250 fish per m^3 . At this rate, 5-20 kg of fish or even as high as 25 kg/m^3 is possible to be reared in a cubic meter of culture water provided that a higher degree of environmental control over parameters is provided by aeration and frequent or continuous water exchange. This is to renew dissolved oxygen supplies, and remove waste and increase the growth of beneficial bacteria in the system. Using these proven facts to compare the stocking density used in the experiment, stocking as many as 71 fish with 309.9-g average weight in a $0.25 m^3$ tank was far too high a stocking density that corresponded to 42 kg/m^3 . This condition had resulted in a slower growth rate and a low FCR. With this stocking density, DO was low and fish had less space to swim around and finding food became difficult. This indicated that the volume of the fish tank was inadequately matched with the stocking density. The stocking density

Table 5. Average circumference of crowns of vegetables in systems with and without prawn during the first and second growing season

Vegetables	With Prawn		Without Prawn	
	1st harvest	2nd harvest	1st harvest	2nd harvest
Lettuce	11.5	10.3	11.1	10.6
Chinese cabbage	20.3	19.3	19.5	18.7
Pac choi	24.2	20.2	20.3	19.2

is an important parameter for growing fish for several reasons (Connolly and Trebic, 2010). High fish density proportionally decreases water quality, partly due to a higher production of waste which increases the levels of toxic substances such as ammonia and nitrite. Secondly, higher stocking density often results in more oxygen depletion which eventually stunt growth and reduces health of fish. However, under stocking the system result in a lower FCR and reduce the performance of the system.

Tank-bed ratio

The component ratio, the proportion of the aquaponics component to the hydroponics component or tank:bed ratio is one of the factors that can spoil production or can benefit greater outputs of either vegetable or fish production or both. The ratio of 1:1 is commonly used in early systems. However, the ratio of 1:2 or even as high as 1:4 are now widely employed. The Speraneo system, for example, is designed for a component ratio of 1:2 using pea gravel as growing bed media. The variation is dependent on several factors such as configuration of hydroponic culture, plant and fish species, stocking density and feeding rate, and others. The variation often results in a significant increase in the growing area when the depth of water is reduced (Diver, 2006). Reducing the depth of water would increase the tank:bed ratio.

The component ratio used in this experiment was based on the conclusion made by Licameli et al., (2010) in a study to evaluate the optimal stocking density of tilapia for lettuce production. Licameli's system was comprised of two raceways exactly the same size and made of the same materials as the one used in this study. It has three units of 1.0 m³ fish tanks, a high pressure filter and a settling pond. The raceways maintained a water depth of 50 cm keeping a volume of culture water approximately equal to 6.0m³ each (Licameli et al., 2010). The tank:bed ratio resulted to 1.4.

For this experiment, a density of 5 kg of fish per m³ and the total volume of culture water in the system of 4.40 m³ resulted to 22 kg of Nile tilapia. This volume was later decreased to 2.85 m³ when the depth of water in the raceway was reduced from 30 cm to 20 cm without changing the stocking density. This was done to increase the concentration of nutrients produced by the fish in the

system as an attempt to remedy to nutrient deficiencies manifested in the plant leaves. At this depth, the volume of water in the raceway becomes 2.38 m³. Using the fish tank volume of 0.25 m³, the resulting tank:bed ratio was 1:9.5. This ratio was an exaggeration and was far too big for growing vegetables. With this ratio, there was no doubt that plants were chlorotic and necrotic. This also proves true that component ratio therefore can devastate production or can favor greater outputs of either hydroponic produce or fish protein depending on the system design (Diver, 2006). However, using the ratio 1:4, a fish tank of 0.25 m³ requires a volume of 1.0 m³ of the raceway. In the same case, the raceway of 2.38 m³ should have required a 0.6 m³ fish tank.

Growth and yield of hydroponic crops

Growth parameters

The growth of hydroponic crops was evaluated using the circumference of crown, length of leaves and length of roots. The yield, on the other hand, was evaluated using the fresh weight of leaves. The data from the first harvest of vegetables were gathered 35 days after transplanting the vegetables (October 17-November 24, 2011). The second crop was harvested 35 days after transplanting (November 29, 2011- January 3, 2011). Adding 7 days of cleaning the raceways and preparing the system, there was a total of 108 days of culture period since the tilapia was stocked in the fish tank or 101 days when the prawn was stocked. The quality and quantity of harvest during the first growing season was better compared to the second season. The combined effects of environmental factors like air temperature, relative humidity and PAR, and water quality parameters like pH, and TDS including the materials and construction of the greenhouse affected the growth and yield of the vegetables (Rorabaugh, 2011). Plants grown in the system with prawn received more nutrients at lower pH while the system without prawn had slightly higher pH at lesser TDS. Further, the system with prawn received more sunlight since it was near the end wall glazed with double-walled polycarbonate material and was at the other end of the bay receiving less PAR.

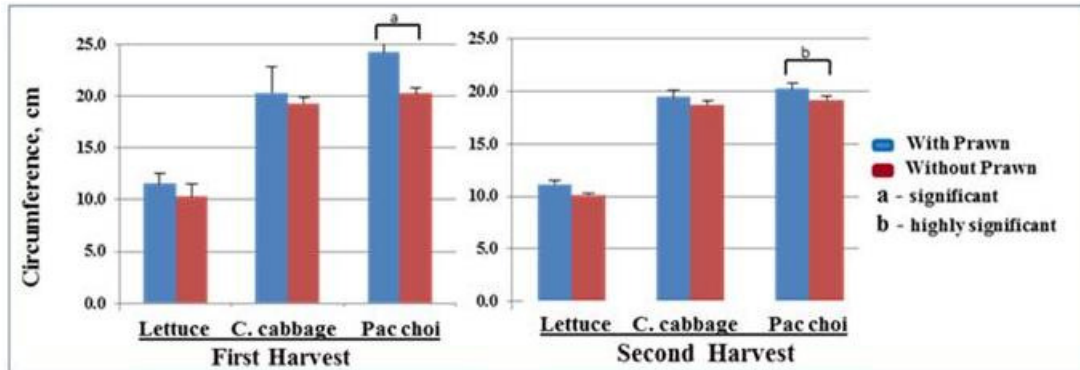


Figure 5. The average circumference of crowns of lettuce, Chinese cabbage and pac choy grown in systems with and without prawn during the first and second harvests.



Figure 6. The circumference of crowns of lettuce (a), Chinese cabbage (b) and pac choy (c) after harvesting

Average circumference of crown

The average circumference of crown of the three vegetables for the two systems during the first and second harvests, was determined using a measuring tape and was summarized in Table 5 and depicted in Figure 5.

The average circumference of crowns of lettuce and Chinese cabbage in systems with prawn was bigger than in systems without prawn during the first and second harvests. Interestingly, the circumference was bigger during the first harvest when pH was not high and the weather was not as adverse as in the second season. Consequently, the result of the single-factor ANOVA showed no significant differences among the means of the circumference of lettuce and Chinese cabbage in both systems and during the two growing seasons.

However, pac choy had different and interesting growth in both systems. It has bigger and bulkier circumferences of crowns, one of its unique varietal characteristics compared to the two vegetables as shown in Figure 6. During the first harvest, those planted in the system with prawn had 24.2 cm while the other system had 20.2 cm. During the second harvest, pac choy that was grown in the system with prawn had an average circumference of 20.3 cm while the system without prawn had 19.2 cm,

smaller than the first harvest. The ANOVA showed that there were significant differences among the means of circumference of crowns of pac choy during the first and second harvest. This indicates that pac choy can establish bigger circumference of crown in a system with prawn. Although subjected to pH higher than the optimum level and lower than that of the other system, the system with prawn provided greater nutrients with the prawn helping in converting the excrement and excess food of tilapia that flowed through the raceways into a consumable form of fertilizer. The integration of prawn helped enhance the capability of the system to increase stability (Diver, 2000).

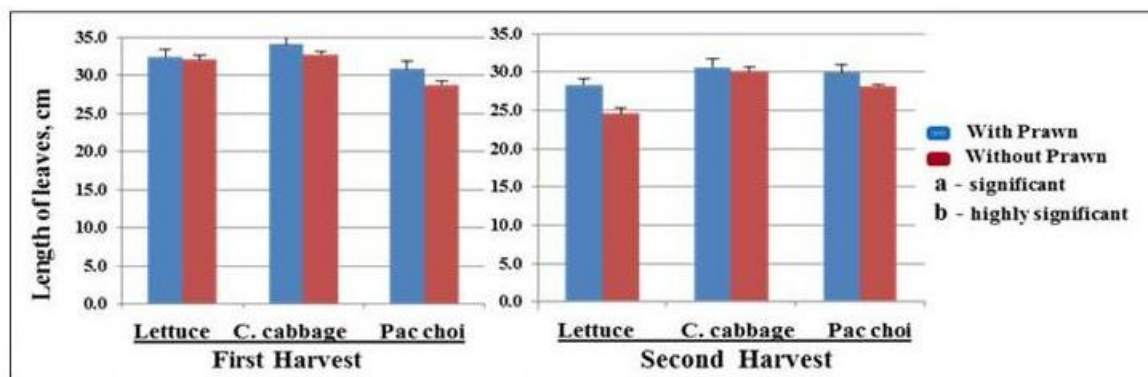
Average length of leaves

The average length of leaves of the three vegetables for both systems and during the first and second harvests was measured using a foot rule. A summary was presented in Table 6 and described in Figure 7.

The average length of leaves during the first harvest for the three crops was longer in the system with prawn. It was during the first growing season when the average pH was slightly lower and still more conducive for plant growth as it was during the second growing season when the pH went up.

Table 6. Average length of leaves of vegetables in systems with and without prawn during the first and second growing season

Vegetables	System With Prawn		System Without Prawn	
	1st season	2nd season	1st season	2nd season
Lettuce	32.4	28.4	32.1	24.6
Chinese Cabbage	34.1	30.6	32.8	30.1
Pac choi	30.8	29.9	28.8	28.1

**Figure 7.** The average length of leaves of lettuce, Chinese cabbage and pac choi grown in systems with and without prawn during the first and second harvest.**Table 7.** Average length of roots of vegetables in systems with and without prawn during the first and second growing season

Vegetables	System with prawn		System without prawn	
	1st season	2nd season	1st season	2nd season
Lettuce	54.4	24.2	46.0	21.9
C. Cabbage	71.7	65.7	56.1	54.2
Pac choi	76.1	96.8	66.9	88.0

ANOVA revealed no significant differences in the means of the length of leaves of the three vegetables in both systems and during the first and second harvest seasons. This means that the lengths of leaves of the three crop during the first and second growing seasons were almost the same when grown in systems with or without prawn.

Average length of roots

The average length of roots of the three vegetables was tabulated in Table 7. In Figure 8 roots were shown hanging entangled on the raft. It was determined using a carpenter's rule by measuring the end of the crown to the tip of the roots.

During the first harvest, the average length of roots of the three crops grown in the system with prawn was longer than that of those planted in the other system. Lettuce, Chinese cabbage and pac choi, when grown in the system with prawn, have developed roots with an average length of 54.4 cm, 71.7 cm and 76.1 cm,

respectively. Those that were planted in the system without prawn have roots with an average of 46.0 cm, 56.1 cm and 66.9 cm, respectively. Similar results happened during the second harvest where the plants established longer roots in the system with prawn where lettuce, cabbage and pac choi have lengths of 24.2 cm, 55.6 cm and 96.8 cm while those that were planted in the system without prawn had shorter roots of about 21.9 cm, 53.0 cm and 88.0 cm, respectively. Interestingly, some measurements proved that pac choi developed roots as long as 120.1 cm in the system with prawn during the first growing season while that of Chinese cabbage and lettuce was 110.2 cm and 76.2 cm, respectively.

ANOVA revealed significant differences among the means of the length of roots of plants grown in the two systems and during the two growing seasons (Figure 9). This indicates that the three plants grew longer roots in the system with prawn than those planted in the system without prawn during the two growing seasons. The pH, though above the recommended levels in both systems, had this adverse effect on the development of roots with

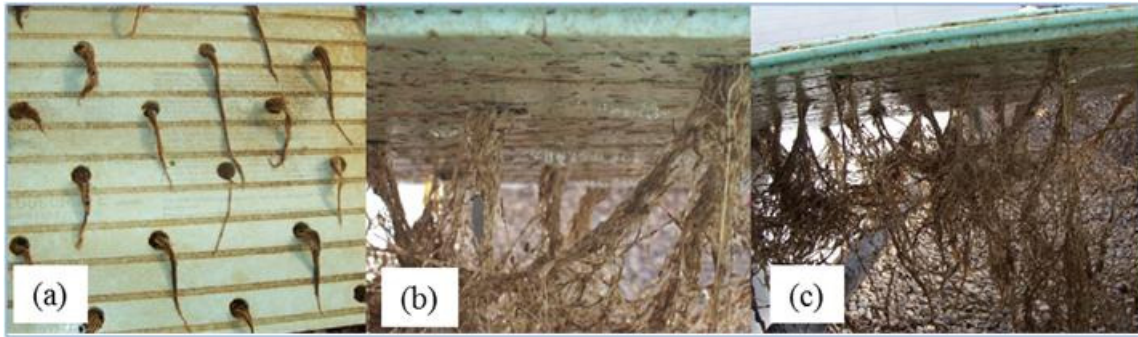


Figure 8. The root systems of lettuce (a), Chinese cabbage (b) and pac choy (c)

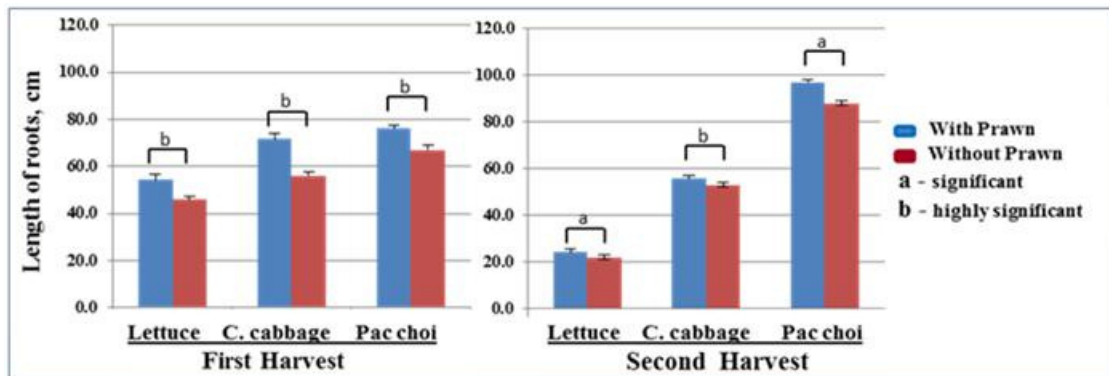


Figure 9. The length of roots of lettuce, Chinese cabbage and pac choy grown in systems with and without prawn during the first and second harvests

Table 8. Average yield of vegetables in systems with and without prawn during the first and second growing season

Vegetables	System with prawn		System without prawn	
	1st season	2nd season	1st season	2nd season
Lettuce	77.5	75.5	78.5	73.1
Chinese Cabbage	166.6	154.2	153.5	151.7
Pac choy	167.9	171	155.9	161.2

greater effect on system without prawn for having higher values (Barry, 1996). Lettuce proved to be severely affected.

The average yield of vegetables

The fresh weight of leaves was referred to as yield. It was determined by obtaining the weight of fresh leaves and is actually the total biomass less the weight of roots. It was presented in Table 8 and depicted in Figure 10.

The yields of lettuce grown in the two systems during the first and second harvests were almost identical as shown in Figure 11. During the first harvest of vegetables, each lettuce plant grown in the system with prawn had an average weight of 77.5 g while 78.5 g for

each lettuce from the system without prawn. During the second harvest, each lettuce plant grown in the system with prawn weighed an average of 75.5 g while those that were grown in the system without prawn had an average of 73.1 g. This average yield per plant was very low compared to those of Chinese cabbage and pac choy. Each Chinese cabbage plant grown in the system with prawn yielded an average weight of 166.6 g and 154.2 g during the first and second harvests, respectively. When grown in the system without prawn, each Chinese cabbage plant yielded 153.5 g and 151.7 g during the first and second harvests. Similarly, pac choy had good yield during the first and second harvests averaging 167.9 g and 171.0 g per plant when grown in the system with prawn and 155.9 g and 161.2 g, respectively. The good root systems of these two crops enabled the plants to



Figure 10. The lettuce, Chinese cabbage and pac choi before harvest

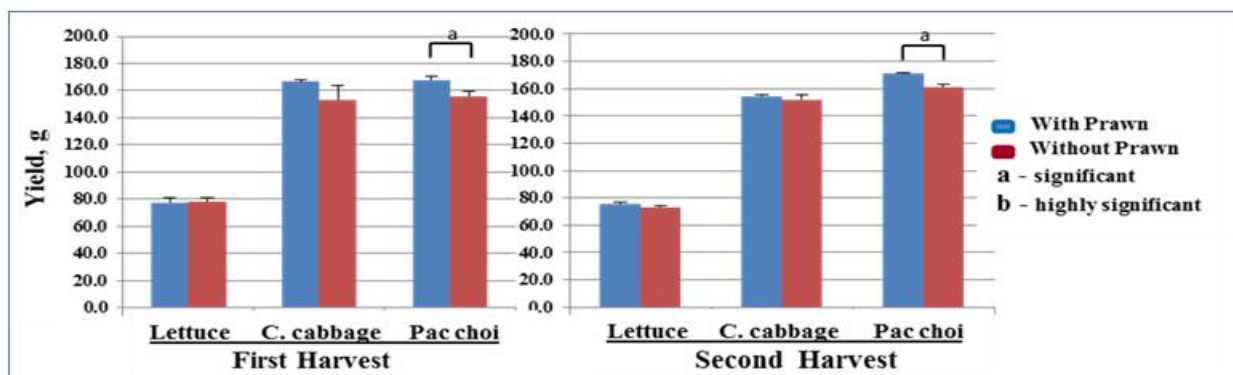


Figure 11. The average yield of lettuce, Chinese cabbage and pac choi grown in systems with and without prawn during the first and second harvest.

absorbed more nutrients as compared to the roots of lettuce that had a poor root system.

ANOVA revealed no significant differences among the means of lettuce and Chinese cabbage both grown in the two systems and during the first and second harvests. This means that each lettuce and Chinese cabbage plants yielded the same quantity either planted in the systems with or without prawn during the first and second harvests. However, significant differences were observed in the means of pac choi planted in the two systems during the first and second harvests. These indicate that pac choi had better yield when grown in the system with prawn during the two growing seasons because pac choi was able to develop a good root system due to the addition of prawn that enhanced diversity in the system. With roots as long as 120.10 cm, pac choi can scour and absorb more nutrients at the bottom of the raceway and from the water being recirculated in the system.

Growth and yield of tilapia and prawn

The growth and yield of aquacultural crops were deter-

ined based on the 108-day culture period of tilapia. This is also equal to the 101 days of prawn or the second harvest of vegetable which included the seven days of cleaning the rafts in preparation for the next growing season. The yield was determined using the gain in weight by subtracting the average initial weight from the average final weight. Similarly, growth was determined using the average growth rate by dividing the gain in weight by the number of the culture period. The FCR was computed by dividing the gain in weight by the feed consumption. These data were summarized in Table 9.

Fish during harvest looked healthy and in good condition with no lesion and disease as shown in Figure 12. It was found out that there were 71 heads of tilapia in the fish tank of the system with prawn which initially weighed 22,040 g and 31,610 g during harvest. The gain in weight was 9,570 g while the growth rate was 88.90 g/day. There were 60 heads of fish in the system without prawn with initial and final weight of 22,017 g and 31,409 g, respectively. The gain weight and growth rate was 9,392.0 g and a growth rate of 86.96 g/day. This indicates that fish in the system with prawn grew slightly faster than the fish in the other system.

Table 9. Growth and yield of aquacultural crops

Crop	Weight	System with prawn				FCR
		Initial, g	Final, g	Gain, g	Growth rate, g/day	
Tilapia (71 pcs)	Total	22,040.00	31,610.00	9,570.00	88.61	1.69
	Individual	310.42	445.21	134.79	1.25	
Prawn (208 pcs)	Total	494.00	1,631.00	1,137.00	19.27	0.06
	Individual	1.67	8.00	6.32	0.06	
System without prawn						
Tilapia (60 pcs)	Total	22,017.00	31,409.00	9,392.00	86.96	1.72
	Individual	366.95	523.48	156.53	1.45	

**Figure 12.** The Nile tilapia during harvest**Figure 13.** The freshwater prawn during harvest

Individual fish in the system with prawn had an initial weight of 310.42g and final weight of 445.21g. The gain in weight and growth rate was 134.79 g and 1.25g/day, respectively. The fish in the system without prawn initially weighed 367.83 g and final weight of 523.5g and had gained an average weight of 155.67g and grew at a rate of 1.45g/day. The fish in the system with prawn has slower growth because there was a greater number of fish in the tank than in the system without prawn.

The FCR for tilapia in the system with prawn was 1.69 and 1.72 for the system without prawn. This means that the fish in system with prawn were more efficient in converting the food into body weight than those in the system without prawn (Ridha, 2000). It is believed to be

due to addition of prawn in the system that enhanced conversion of the extra feeds that flowed in the raceway. It was also observed that there was lesser unconsumed feeds collected in the bio-filtration tank of the system with prawn since the feeds that flowed in the raceway were eaten by the prawn. Unlike in system without prawn, more excess feeds were collected in its bio-filtration tank causing foaming in the surface of the water. The foaming was caused by the accumulation of protein from the feeds.

The prawn was in good condition during harvest with the males and females showing their distinct characteristics as shown in Figure 13. From 295 heads that were stocked in the system initially weighing 494g



Figure 14. The elongated leaves of lettuce (a) and chlorotic and necrotic leaves of Chinese cabbage (b) and pac choy (c)

and having an average weight of 1.67g, there were only 208 recovered equal to 71% survival rate. The prawns had a total weight of 1,631g and gained a weight of 1,137.0g resulting to an average growth rate of 19.27g/day. Individual prawn now had an average weight of 6.32g.

Water consumption and productivity

Approximately 10% of the water of the bio-filtration tank or about 22 L of each system was lost every day due to evapotranspiration. This amount when projected up to the 108-day culture period would amount to nearly 2,376 L of water. This volume when added to the volume of 2,850 L contained in the system would make a total of 5,226 L. With this volume, as much as 71 heads of tilapia and 495 heads of vegetables can be produced in each raceway. The addition of the freshwater prawn increases the water productivity and the performance of the system.

Other Observations

The growth of lettuce, Chinese cabbage and pac choy had been affected by water quality parameters such as high pH, low TDS, high stocking density and high component ratio. Though the environmental conditions were held to their optimal levels, these parameters were seen to have caused nutrient deficiencies that were observed in the vegetables in the two systems during the two growing seasons. However, comparing the three, pac choy stood the best with less visible signs of deficiency. Mostly affected was Chinese cabbage with the entire plant being light green in color with yellow lower leaves, a sign of chlorosis or severe nitrogen deficiency (Figure 14). Some leaves were also deficient in potassium and zinc having papery appearance with dead areas along the edges of the leaves, a clear proof of necrosis. Magnesium deficiency was also observed as lower leaves were wilted with yellowing along the tips and

margins and between the veins. Likewise, iron and manganese deficiencies were observed as leaf tissue appeared yellow, while the veins remain green. Some lower leaves have checkered patterns of yellow and green, and stunted growth. Lettuce also showed pale and thin leaves with elongated internodes (Sorenson and Relf, 1996).

The growth and yield parameters of hydroponic crops were generally higher in the system with prawn than in the system without prawn, except the length of leaves which was longer in the system without prawn. The elongated internode of most of the lettuce plants in system without prawn was due to the lesser amount of PAR compared to those in the system with prawn due to its proximity to the end walls of the greenhouse. The end wall was made up of polycarbonate material that permits transmission of light.

CONCLUSIONS

The aquaponic system was effectively designed using one pump to recirculate the culture water from the bio-filtration tank, lowest portion, to the fish tank, highest portion, and allowed to flow by gravity in a close loop. The use of perforated pipe filter in the stand pipe of the raceway improved the movement of water. The integration of prawn in the raceway improved the performance of the system by breaking down the fish excrements and unconsumed feeds. Pac choy has the best growth and yield performance among the three vegetables tested. The performance could have been better had the pH was maintained at optimum level and the total dissolved solids increased to the requirements of the vegetables. High pH and low level of nutrients caused nutrient deficiencies that led to chlorosis and necrosis. These were attributed to the significance of stocking density and component ratio in designing an aquaponic system. Aquaponics can be an alternative production system that could provide direct access to clean and healthy food aside from extra income even in urban

setting. Enhancing the system with organic source of fertilizer like vermiculture is suggested for further study.

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REFERENCES

- Anderson M, L Bloom, C Queen, M Ruttenburg, K Stroad, S Sukanit, D Thomas (1989). Understanding Hydroponics. VITA Publication. Arlington, Virginia 22209 USA
- Aquino C (2004). The Philippine Industry Almost Comatose. Retrieved from <http://focusweb.org/oldphilippines> on August 2, 2012
- Barry CB (1996). The Handbook to Hydroponic Nutrient Solutions. Casper Publications Pty Ltd. Narabeen, NSW, Australia
- Bhikajee M, P Gobin (1997). Effect of Temperature on the feeding rate and growth of a red tilapia hybrid. pp. 131-140. In: K. Fitzsimmons (ed.). Proceeding of the Fourth International Symposium on Tilapia in Aquaculture. Orlando, Florida, USA.
- Connolly K, T Trebic (2010). Optimization of a Backyard Aquaponic Food Production System, McGill University, Montreal, Canada
- Despommier D (2010). Growing Skyscrapers: The Rise of Vertical Farms. Retrieved from <http://www.scientificamerican.com/article.cfm?id=the-rise-of-vertical-farms> on January 17, 2013
- Diver S (2000). Integration of Hydroponics with Aquaculture. ATTRA Horticulture System Guide. www.attra.ncat.org
- Dolan RE (1991). Philippines: A Country Study. Washington: GPO for the Library of Congress. Philippines: Agriculture, Information about Agriculture in Philippines. <http://www.nationsencyclopedia.com/economies/Asia-and-the-Pacific/PhilippinesAgriculture.html#ixzz1mTyV9fnp>
- FAO (2011). The State of Food Insecurity in the World. Food and Agriculture Organization of the United Nation. Rome
- Fitzsimmons KM (1997). Tilapia Aquaculture: Proceedings of the Fourth International Symposium on Tilapia in Aquaculture. Editor. Northeast Regional Agricultural Engineering Service Publication No. NRAES - 106. Ithaca, N. Y. 808pp.
- Francis-Floyd R (2011). Dissolved Oxygen for Fish Production. Fisheries and Aquatic Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.
- ITDG (2007). Intermediate Technology Development Group, <http://www.itdg.org.pe/>
- Jensen MH (1991). Hydroponic culture for the tropics: Opportunities and Alternatives. Department of Plant Sciences, University of Arizona, Tucson, Arizona 85721, U.S.A., 1991-05-01. 12p.
- Licameli J, KM Fitzsimmons, GA Giacameli (2010). Optimal Fish *Oreochromis niloticus* to Plant *Lactuca sativa* cv Rex for a Controlled Environment System. University of Arizona, Tucson, Arizona, <http://www.aquaculturehub.org/group/aquaponics/forum/topics/optimal-fish-oreochromis?commentId=4021269%3AComment%3A6307&groupId>
- Mabutas GS (2011). Philippines One of Lowest Vegetable Consumers in Southeast Asia. Manila Bulletin Publishing Corporation. January 31, 2011 Retrieved from <http://www.mb.com.ph>. on January 14, 2013
- Malcolm J (2007). Backyard Aquaponics Magazine, Issue 1, Summer 2007. (Retrieved from http://www.byapmagazine.com/BYAP_Magazine_Issue1.pdf on July 2009)
- Morgan L (2008). Nutrient temperature- oxygen and pythium in hydroponics. Simply hydroponics and organics. Florida, USAorgan
- Murphy WB (1984). The Future World of Agriculture. Walt Disney World EPCOT Center. Grolier Incorporated, USA.
- Nelson RL (2008). Aquaponic Equipment: The Biofilter. Aquaponics Journal. Issue # 48. First Quarter 2008. Nelson and Pade, Inc.
- New MB (2000). History and global status of freshwater prawn farming. In M.B. New & W.C. Valenti, eds. Freshwater prawn culture: the farming of *Macrobrachium rosenbergii*. pp. 1-11. Oxford, England, Blackwell Science.
- New MB (2002). Farming freshwater prawns: A manual for the culture of the giant river prawn (*Macrobrachium rosenbergii*) FAO Fisheries Technical Paper, Marlow, United Kingdom
- New MB, WC Vanlenti (editors) (2009). Freshwater Prawn Culture: the farming of *Macrobrachium rosenbergii*. Blackwell Science, Oxford, England. 512p.
- Pennington D (2011). The History of Aquaponics. International Aquaponics and Tilapia Aquaculture Course: http://www.uvi.edu/sites/uvi/Pages/AES-Aquaculture-International_Aquaponics.aspx?s=REcited
- Popma T, M Masser (1999). Tilapia: Life History and Biology. Southern Regional Aquaculture Center. Publication No. 283
- Rahman MF (1994). Crop Production by Hydroponics. Biotechnology Centre, Malaysian Agricultural Research and Development Institute (MARDI), Serdang, Malaysia.
- Rakocy JE (1989). Tank Culture of Tilapia. SRAC Publication No.282, September, 1989. (Retrieved from http://aquanic.org/publicat/usda_rac/efs/srac/282fs.pdf on June 2009)
- Rakocy JE, MP Masser, TM Losordo (2006). Aquaponics- Integrating Fish and Plant. Recirculating Aquaculture Tank Production Systems, SRAC Publication No. 454. (Retrieved from <http://extension.ag.uidaho.edu/twinfalls/Aquaculture/Aqua%20Pubs/SRAC454AquaponicSystem.pdf> on June 2009)
- Ridha M (2000). Preliminary Study on Growth, Feed Conversion and Production in Non-improved and Improved Strains of the Nile tilapia (*Oreochromis niloticus*). Fisheries and Marine Environment Department, Kuwait Institute for Scientific Research, P.O. Box 1638, Salmiyah 22017, Kuwait (Retrieved on November 25, 2012 from <http://ag.arizona.edu/azaqua/ista/ista6/ista6web/pdf/060.pdf>)
- Rorabaugh PA (2011). Introduction to hydroponics and Controlled environment Agriculture (Manual-PLS217). Controlled Environment Agriculture Center, University of Arizona, Tucson, Arizona, USA
- Sace CF, IC Agulto, ME Agulto, AN Espino, Jr., RB Gaino, EV Sicat (2008). Water Management System for Honeydew Melon (*Cucumis melo* L.) Production Grown in Hydroponic System under Tropical Greenhouse Condition. Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines, 175p.
- Sorenson R, D Relf (1996). Home Hydroponics. Virginia Polytechnic Inst. and Univ. Publication Number 426-084
- Tanganon GT (2012). R and D Direction for the Innovation Clusters. Congressional Commission on Science & Technology and Engineering. <http://www.comste.gov.ph>

Tezel M (2009). Aquaponics Common Sense Guide. San Antonio, Texas, USA Retrieved from http://backyardaquaponics.com/Travis/Aquaponics_Common_Sense_Guide.pdf on January 17, 2013

Zoe J (2011). More Food Doesn't Solve World Hunger. Pulitzer Center. Medill School of Journalism. Northwestern University. Evanston, Illinois, USA