A Pilot Aquaponics Project On An Intermediate Floor Of A High Rise Building In Malaysia

A Pilot Aquaponics Project at The 15th Floor Building in Petaling Jaya, Malaysia

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SUMMARY

This is the first of its kind of Aquaponics system in the world, utilizing town water to raise 6000 Tilapia and Jade Perch fishes, 1000 vegetables and 300 panels of vertical sun shading green walls at the 15th floor of a highrise building in Petaling Jaya, Malaysia. The system is fully integrated as the wastewater from the fishes is treated with a specially designed treatment plant and absorbed by the vegetables and green wall plants themselves before returning to the same channel where the fishes are reared. Both volcanic aggregates and floating boards in trays are used instead of soil for growing vegetables and green wall plants. The fish channel is constructed along the building's balcony that goes round the whole building itself. All the harvested fish and vegetable will travel down by a cargo lift to a " farm-to-plate" restaurant on the 6th floor.

KEYWORDS

Aquaponics, CDS FSS (Fine Screen Separation) Unit, fish, greenwall, lamella clarifier, MBBR, rain water, sustainable development goals, vegetables, waste water

INTRODUCTION

The 1Powerhouse Aquaponics Project is the first of its kind in the world which is introduced at the 15th floor of the 1Powerhouse highrise building at Bandar Utama City Centre, Petaling Jaya, Malaysia to serve a restaurant below which will be operated with the concept of “farm-to-plate”. The vegetables and fishes from the system will be harvested and supplied to the customers, fresh and alive at the restaurant. The greenwall constructed along the balcony provides for the necessary sun shading.

The simplest definition of aquaponics is the combination of aquaculture and hydroponics that grows fishes and plants together in one integrated system. The fish waste provides an organic food source for the plants, and the plants naturally filter the water for the fish.

Besides fish, vegetable and greenwall plant, the microbe (nitrifying bacteria) is another living party involved to convert ammonia from the fish waste first into nitrites, and then into nitrates. Nitrates are in a form of nitrogen family that plants can uptake and use to grow. Solid fish waste is turned into vermicompost that also acts as food for the plants. In combining both hydroponic and aquaculture systems, aquaponics capitalizes on their individual benefits, and eliminates the drawbacks of each.

Trays used in aquaponics are called Deep Water Culture or DWC, and are applied in this system which is a modern variation of one of the most ancient forms of hydroponics as well as aquaponics. This type of aquaponics setup having fairly low maintenance is ideal for fast-growing plants like lettuce and leafy greens, and can be scaled to almost any size easily.

In this aquaponics system, the fish channel was designed as four (4) separate tanks, containing 1500 fishes each. Two of the tanks were used for rearing 3000 tilapias and the other two for 3000 jade perches, making a total 6000 fishes. The dimension of fish tanks was designed with a total length of 366m, width of 1m and depth of 45.5cm. This is the holding tank for the majority of the water in the system and is the habitat for the fish. It also acts as the collection reservoir for the fish waste. The fish tanks are lined by HDPE liner to avoid any seepage and leakage. Another reason of using the HDPE liner is to avoid the effect of concrete wall on the water pH. As part of the aquaponics operation, the tasks of monitor water quality and health of fishes, vegetables and greenwall plants were assigned to the university under-graduates from two local universities under their internship programs at different time.

Figure 2: Views of the High Rise Aquaponics

METHODS

Pumping And Pipework For Water Recirculation

The principle behind aquaponics is that the system will take care of its own water needs. In return for monitoring the water quality and adding some traces of essential nutrients which are not available from the fish effluents, fish stock is gradually increased in proportion to the rate of vegetables and greenwall vegetation growth. Volcanic rocks as a media for the greenwall vegetation instead of soil or other media can help grow bacteria as well as provide some rich minerals thus increasing the growth of plants; besides improving the water quality. It also ensures the cycle keeps going with both the fishes and the plants healthy as the water has to be made available to the plants and then recirculate back to the fish channel.

The circulation of the water is done by two numbers of water pump for each tank. First, the water containing the fish waste is extracted by first water pump from the fish tank and then flows through the water treatment plant and then into the fish channel and DWC with either rafts with vegetables and greenwall plants with grow media. The fish effluents are properly treated while containing the nutrients required by the plants; thus all the plants will absorb the nutrients from the water at the DWC. The water will flow back to fish tank through the overflow pipe when water level is higher than it. Meanwhile, the second water pump distributes the treated water from bypass outlet to every section of fish tank for the purpose of avoiding the contaminants being accumulated and at the same time keeps the water flowing. The flowrate of the pumps has been set up to treat the water with a flow rate of 6 litres per second. One additional pump also serves as a standby in case of any pump breaks down for the whole system with a bypass valve connected to the pipework.

Deep Water Culture

There are more than 3000 Bok Choy grown in the DWC system. The plants are transplanted from small seedling cultured on site in sponge followed by transplanted in net pots to the floating raft of the DWC. Floating boards are constructed from foam or a lightweight material lined with foam. All the net pots must fit the hole openings in the floating boards for added stability and to prevent the plants from falling through. Plants are housed in net pots in the boards, allowing their roots to dangle into the water. Aeration had been provided with the installed air stones in each section of DWC to ensure the supply of dissolved oxygen. The selected sections of DWC were filled with the volcanic rocks which was imported from the China for the purpose of using it as growth media for the greenwall plants; and in this case Morning Glory creepers on galvanised steel mesh has been selected to act as sun shades for this building. The crushed volcanic rocks or aggregates used range between 8mm to 16mm in size. This is small enough to make planting easy, but large enough to ensure there is plenty of air flow round the plants.

Earthworms of African Night Crawler type are also introduced to provide further demineralisation and vermicomposting to nourish the greenwall plants thus indirectly improving the effectiveness of water treatment.

Fish Tanks

There are 3000 tilapia fishes in tank 1 and 2 while 3000 jade perch fishes in tank 3 and 4. The tanks are created by partitioning 4 sections of the fish channel using 4 nos. of sluice gates. Tube diffusers have been installed along the whole length of the tank to provide adequate aeration thus generating enough dissolved oxygen (DO) to the fishes. The aeration system consists of air piping network and 3 numbers of air blowers connected together with 1 extra number as standby.

Wastewater Treatment Plant

The main components of water treatment plant in the aquaponics system are 1 number of fine screen Continous Deflective Separator (CDS) which is self-cleansing and non-blocking (Figure 3), 4 numbers of bioreactor (Figure 4), 1 number of lamellar clarifier (Figure 6), and 1 number of denitrification unit (Figure 7). There are also 4 numbers of water treatment plant, with one for each tank. Since there is a lack of space, the water treatment plant is built on stilt on top of the fish channel and hid behind the lift shaft and greenwall on the balcony parapet.

The principle of the treatment plant is to use water pump to extract the wastewater with fish faeces and solids from un-eaten fish feed from the bottom of the fish tank and force the wastewater through the CDS unit to filter out the floating debris like dead leaves, solid faeces and suspended solids using the CDS's vortex principle in combination of a special design fine screen to deflect the flow in an opposite direction before entering the bioreactors as shown in Figure 3. (A detailed description of how the CDS works can be found in the indicated Reference 4 : Wong, T.H.F., Walker, T.A., Allison, R.A., Wooton, R.M., Removal of Suspended Solids and Associated Pollutants by a CDS Gross Pollutant Trap. 1999, Technical Report 99/2 CRCCH).

Furthermore, a UV light has been installed in the CDS in order to kill any bad and unwanted bacteria and algae in the incoming water before flowing in the bioreactors. UV light is normally switched off and only to be switched on when there is an outbreak of fish disease or algae bloom.

Figure 3: CDS FSS (Fine Screen Separation) unit

The purpose of bioreactors is to culture the bacteria to help in nitrification of fish waste by converting the ammonia generated by fish waste to nitrite followed by further breaking down to nitrate which is food for the plants in the system. In aquaponics, two types of bacteria form a mutual beneficial relationship with fish and vegetables / greenwall plants. Nitrifying bacteria namely nitrosomonas and nitrobacter are important microorganisms that help to keep an aquaponics system in balance. Nitrosomonas converts ammonia to nitrites and nitrobacter converts nitrites to nitrates. Therefore, the incoming water must be filtered by CDS unit and lamellar clarifier before flowing into the tank and DWC in order to avoid the contamination of the cultured bacteria.

Figure 4: Inside of bioreactors and nanomedia

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All the bioreactors are filled with the nanomedia (Figure 4 above) which provide the habitat for the nitrifying bacteria. The nanomedia has occupied around half the volume of all bioreactors in order to provide sufficient habitat for the required number of bacteria. Due to the porous structure of the nanomedia, it will immobilize enough bacteria to convert both nitrite and nitrate as for the food supply to the vegetable and greenwall plant and without affecting the water flow rate. For the purpose of ensuring the bacteria grow at a maximum rate, the pH and temperature of water need to be monitored regularly. In the addition, aeration is provided for every bioreactor by using air diffuser pipes to ensure the supply of adequate dissolved oxygen.

The treated water from bioreactor tank will flow to the lamellar clarifier (Figure 6 below) which will polish the effluent which comprises mainly of fine sludge particulates before entering to the fish tank and DWC below. The principle of lamellar clarifier is to use the weight of sludge particulates to settle down when water flowing upward via a 50 mm diameter discharge pipe. The discharge position has to be submerged the below the water surface. A venturi device is added in order to tap the potential energy and to create more aeration to the fish tank.

Ammonification

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

Nitrification

$$2\ NH_4^+ + 3\ O_2 \rightarrow 2\ HNO_2 + 2\ H^+ + 2\ H_2O \quad \text{(Nitrosomas)}$$

$$2\ HNO_2 + O_2 \rightarrow 2\ NO_3^- + 2\ H^+ \quad \text{(Nitrobacter)}$$

Net

$$2\ NH_4^+ + 4\ O_2 \rightarrow 2\ NO_3^- + 4\ H^+ + 2\ H_2O$$

Figure 5: Ammonification and nitrification process

Figure 6 : Lamella Clarifier

In general situation of aquaponics, 1 m2 of fish tank can sustain about 10 times the areas of vegetation, hence this system is not in balance. However since this is a mandatory requirement of the client , we have no choice but to use the engineering basis and skills to tailor make the system for them and therefore it was mutually agreed to do a pilot project first before building all the balanced storeys in one go.

We have introduced a Denitrification units to the system based on the principle of Upflow Anaerobic Sludge Blanket (UASB). It is an anaerobic digester that is used for settled sludge treatment. All the sludge collected from CDS and lamellar clarifier will be purged to this UASB unit from the bottom and allow it to flow upward via nanomedia blanket. The sludge trapped will be processed by the anaerobic microorganisms when it flows upward through the blanket. Anaerobic microorganisms aim to convert the organic pollutants into biogas which will eventually escape as mainly methane gas and carbon dioxide. The nanomedia blanket in the denitrification unit provides the habitat for anaerobic microorganisms.

Figure 7 : Denitrification unit

RESULTS AND DISCUSSION

Water Quality Monitoring

Water is the life-blood of an aquaponic system. It is the medium through which all essential macro and micronutrients are transported to the plant, and the medium through which the fish receives oxygen. Thus, some key parameters are required to be monitored regularly since they has an impact on all three organisms in the system i.e. fish, plant and bacteria. The key parameters required to be monitored including ammonia, nitrite, nitrate level, pH, electrical conductivity, temperature and dissolved oxygen. Each organism in an aquaponic unit has a specific tolerance range for each parameter of water quality. The tolerance ranges are relatively similar for all three organisms as shown in Table 1, but there is need for compromise and therefore some organisms will not be functioning at their optimum level.

Organism type	Temp °c	pH	Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	DO (mg/L)
Warm water fish	22-32	6-8.5	<3	<1	<400	4-6
Cold water fish	10-18	6-8.5	<1	<0.1	<400	6-8
Plants	16-30	5.5-7.5	<30	<1	-	>3
Bacteria	14-34	6-8.5	<3	<1	-	4-8

Table 1: General water quality tolerances for fish (warm- or cold-water), hydroponic plants and nitrifying bacteria

The ideal compromise for aquaponics is that the key water quality parameters should follow the value as indicated in Table 2 below. The two most important parameters to balance are pH and temperature.

Aquaponics system	Temp °c	pH	Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	DO (mg/L)
	18-30	6-7	<1	<1	5-150	>5

Table 2: Ideal parameters for aquaponics as a compromise between all three organisms.

The temperature of water affects all parameters of the aquaponic system. Overall, a general compromise range is 18 to 30 °C. Temperature has an effect on DO as well as on the toxicity of ammonia. High temperature have less DO and more unionized ammonia. Also, high temperature can restricts the absorption of calcium in plant. Warm-water fish such as tilapia and jade perch and nitrifying bacteria thrive in higher water temperature of 22 to 29 °C, as do some popular vegetables such as okra, asian cabbage, bok choy, basil and mint. Therefore, the temperature need to be monitored daily and so far the result obtained in this project has been within the acceptable range of 23 to 28°C.

Ammonia, nitrite, and nitrate can be considered as total nitrogen in water. It is required by all life, and part of all the necessary proteins. Nitrogen originally enters an aquaponic system from the fish feed, labelled as crude protein and measured as 32% percentage. Some of this protein is used by the fish for growth, and the remainder is released by the fish as waste. This waste is mostly in the form of ammonia and is released through the gills and as urine. Solid waste is also released, some of which is converted into ammonia by microbial activity. This ammonia is then nitrified by bacteria and converted into nitrite and nitrate. Nitrogenous wastes are poisonous to fish at certain concentrations, although ammonia and nitrite are approximately 100 times more poisonous than nitrate. Although toxic to fish, nitrogen compounds are nutritious for plant, and indeed are the basic component of plant fertilizers. All three forms of nitrogen can be used by plant, but nitrate is by far the most accessible. In a fully functioning aquaponic water treatment plant with adequate biofiltration, ammonia and nitrite levels should be close to zero, or at most 0.25–1.0 mg/litre. The bacteria present in the biofilter should be converting almost all the ammonia and nitrite into nitrate before any accumulation can occur.

The pH of the water also has a major impact on all aspects of aquaponics, especially the plant and bacteria. For plant, the pH controls the plant's access to micro and macronutrients. At a pH of 6.0 to 6.5, all of the nutrients are readily available; however if the pH is outside of this range the nutrients become difficult for the plant to access and absorb. In fact, a pH of 7.5 can lead to nutrient deficiencies of iron, phosphorus and manganese.

Furthermore, nitrifying bacteria experience difficulty below a pH of 6, and the bacteria's capacity to convert ammonia into nitrate reduces in acidic, low pH conditions. This can lead to reduced biofiltration, and as a result the bacteria decrease the conversion of ammonia to nitrate, and ammonia levels can begin to increase, leading to an unbalanced system which is stressful to the other organisms. Fish have specific tolerance ranges for pH as well, but most fish used in aquaponics have a pH tolerance range of 6.0 to 8.5. However, the pH affects the toxicity of ammonia to fish, with higher pH leading to higher toxicity. Therefore, the ideal aquaponic water is slightly acidic, with an optimum pH range of 6 to 7. This range will keep the bacteria functioning at a high capacity, while allowing the plants full access to all the essential micro and macronutrients. However, there are many biological and chemical processes that take place in an aquaponics system that affect the pH of the water, some more significantly than others, including the nitrification process, fish stocking density, and the presence of phytoplankton.

Oxygen is essential for all three organisms involved in aquaponics; plant, fish and nitrifying bacteria all need oxygen to survive. The DO level describes the amount of molecular oxygen within the water, and it is measured in milligrams per liter. It is the water quality parameter that has the most immediate and drastic effect on aquaponics. Indeed, fish may die within hours when exposed to low DO within the fish tank. Therefore, DO need to be monitored daily since ensuring adequate DO level is most crucial to aquaponics. Currently the system is operating without a standby generator as the building is still under construction above this floor. Under this circumstance, it is necessary to man the pilot project with 24/7 monitoring and surveillance with the help of a sensored gadget which will sound an alarm when the air pump stop functioning.

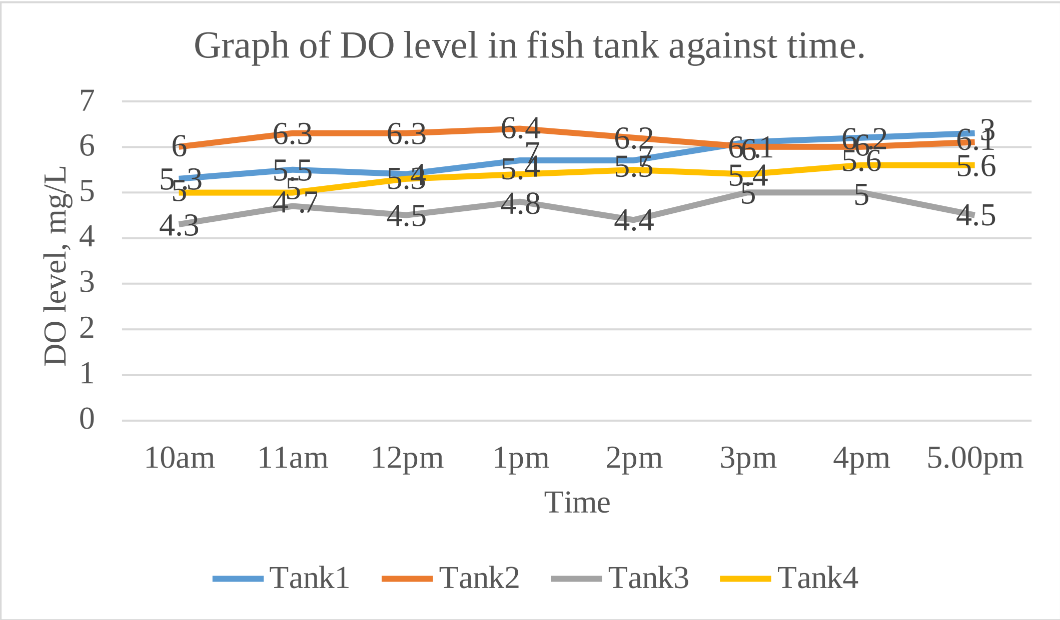

Figure 8 : Graph of DO level in fish tank against time.

Based on the graph in Table 8, tank 3 could be noticed containing lowest DO level which is below 5mg/L all the time. Therefore, inspection need to be conducted on this tank to identify the problem. The problem had been identified whereby the sluice gate was accidentally opened resulting in large amount of fishes from tank 4 swimming to tank 3. Therefore, the oxygen demand at tank 3 has increased. The problem had been solved by closing the sluice gate and put back the fishes to their original tank.

Salinity indicates the concentration of salts in water, which include table salt, as well as plant nutrients, which are in fact salts. Salinity levels will have a large bearing when deciding which water to use because high salinity can negatively affect vegetable production, especially if it is of sodium chloride origin, as sodium is toxic for plant. Therefore, the electrical conductivity (EC) must be maintained below 800ppm to avoid any negative effect on the plant growth rate. The Seasol solution which containing the nutrients needed by the plant will be added to the system if the EC level is lower than required level.

Fish Harvesting

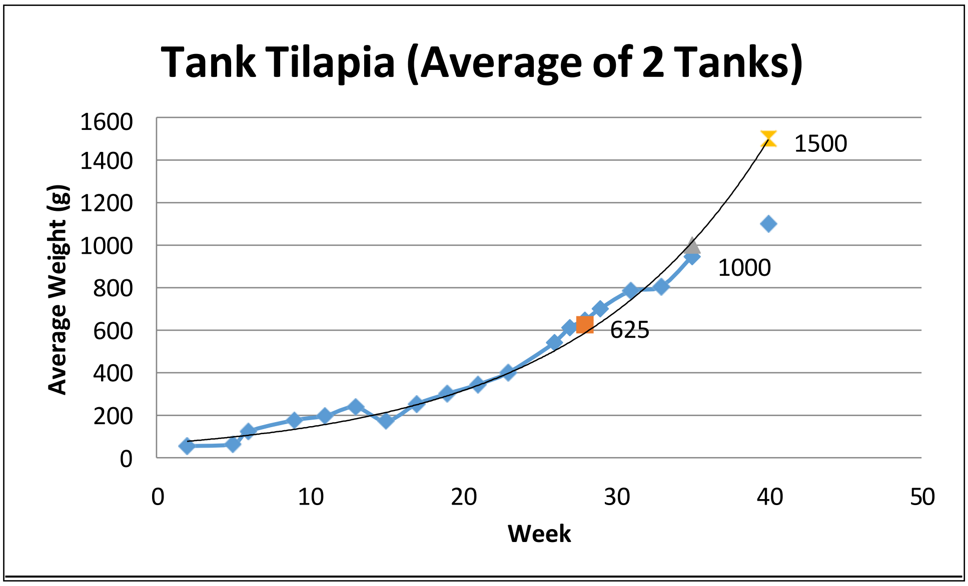

Figure 9 : Graph showing Tilapia growth rate

The blue line shows the actual growth which is more or less meeting the targeted weight.

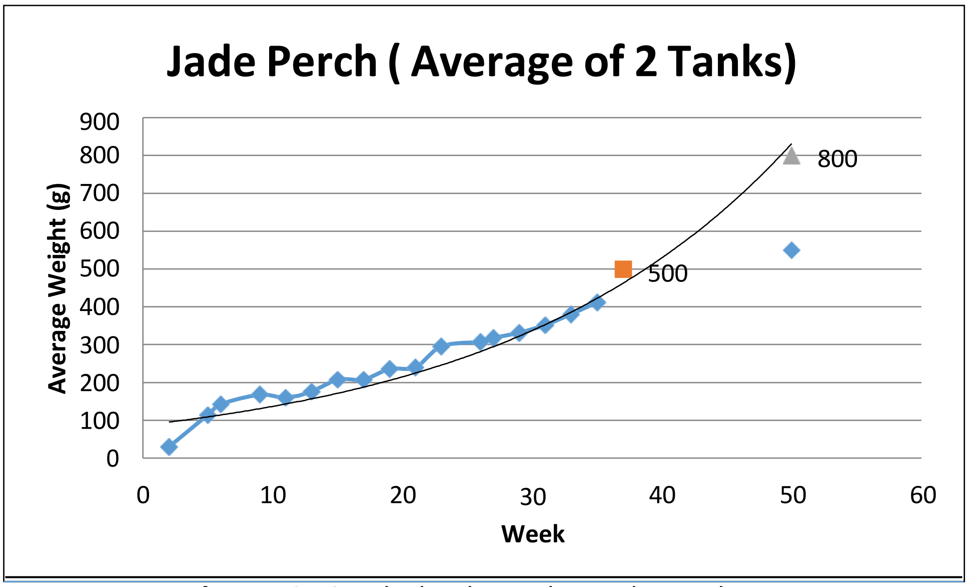

Figure 10 : Graph showing Jade Perch growth rate

The blue line shows the actual growth which is more or less meeting the targeted weight.

Vegetables Harvesting

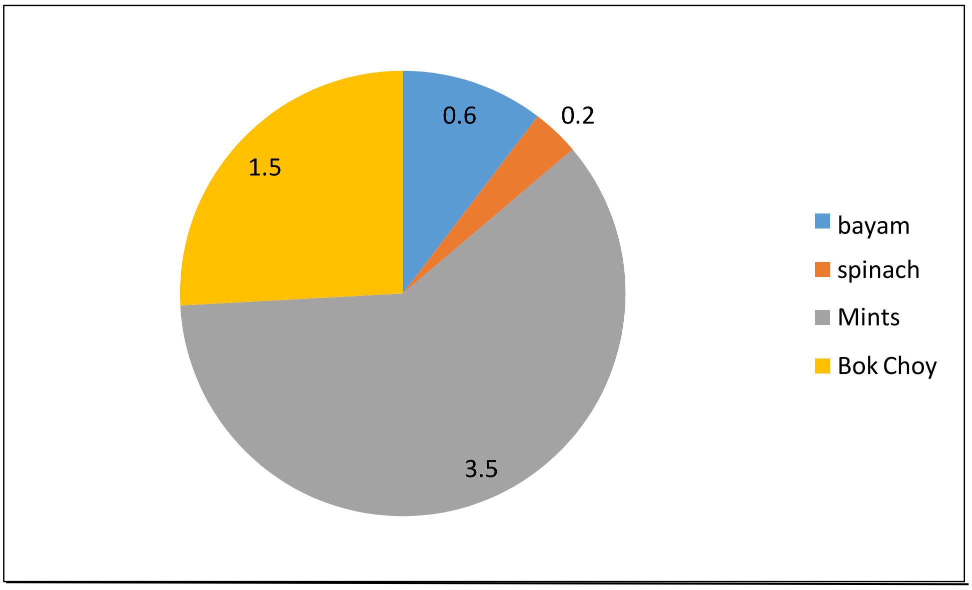

Figure 11 : The pie chart for vegetables harvested in kg for a week

The chart shown the amount of vegetables harvested within a week. The type of vegetable harvested include Mints weighing 3.5 kg, followed by Bok Choy 1.5 kg, Bayam 0.6 kg and Spinach 0.2 kg.

CONCLUSION

The encouraging results and performances of the Pilot Aquaponics Project at 1Powerhouse Building in Petaling Jaya, Malaysia prove that aquaponics can be successfully implemented in highrise building.

The sustainability of an aquaponics system depends on the environmental, economic and social factors. Economically, such system requires substantial initial investment, but are then followed by low recurring costs. The long term combined returns from both fishes and vegetables must be able to cover both the Capex and the Opec.

Environmentally, aquaponics prevents aquaculture effluent from escaping and polluting the waterways since all the wastes produced from this system will be treated by well-designed wastewater treatment plant. At the same time, aquaponics enables greater water and production control. Aquaponics does not rely on chemicals for fertilizer, or use of chemicals for control of pests or weeds which makes food safer against potential residues which might hazardous to human. There is no need for soil, and aquaponics avoids the issues associated with soil compaction, salinization, pollution and disease. Similarly, aquaponics can be used in urban and sub-urban environments where no or very little land is available, providing a means to grow dense crops on small balconies, patios, indoors or on rooftops.

Socially, aquaponics can offer quality-of-life improvement because the food is grown locally and culturally appropriate crops can be selected. At the same time, aquaponics can integrate livelihood strategies to secure food and small income for landless and poor household. Domestic production of food, access to markets and the acquisition of skills are invaluable tools for securing the empowerment and emancipation of women in developing countries, and aquaponics can provide the foundation for fair and sustainable socio-economic growth. Fish protein is a valuable addition to the dietary needs of many people, as protein is often lacking in small-scale gardening.

Certainly, aquaponics system will be relevant to countries like Singapore as it will meet the following objectives:

As the fishes and vegetables will travel zero road-mile, they will remain clean, fresh and pure which most Singaporean can afford to purchase even though it may be sold at a premium price. Moreover, the fish is much tasty and the vegetable more crunchy compared to those that are normally grown and reared in the traditional ways.

Many buildings with corridors can be turned into a community based urban farming projects, especially those residential areas that are occupied by senior citizens and retirees whereby the project can be run by the community without high investment.

As the water to be used can be obtained from rainwater harvesting, and the wastewater is treated and reused, there will be a significant saving of water in Singapore.

If greenwall plants are creeping vegetable like okra, cucumbers etc., they will also double up as sun shading screens against the sun thereby cooling down the building and cut electricity consumption for air-conditioning.

For commercial building, often the condensate from the aircons can be fed to the fish tank to chill the water resulting in breeding more high valued fish such as the exotic tempura fish, bamboo fish, etc.

The green features added to the building will enhance the look of the building thus adding its aesthetic value, reduce carbon dioxide and increase oxygen content and may even mitigate to a certain extent the affect of haze. This will make Singapore cleaner and greener without addition costs.

The wide spread adoption of aquaponics will certainly make Singapore as the latest showcase to the world as the nation which meets all the sustainable development goals (SDGs), particularly SDG number 11 which is Sustainable Cities and Communities !

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