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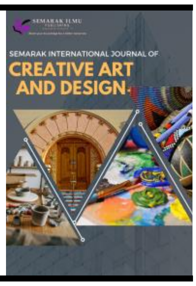

Tiga-ponics – A New Farming System That Combines Hydroponic, Aquaponic, and Aeroponics Methods for Growing Vegetables

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ABSTRACT

Hydroponic is a form of technology that involves growing plants on an inert medium instead of natural soil. Not only does this help eliminate soil-borne diseases but it also helps in improving the crop quality as well. However, most hydroponic systems available in the market are meant for commercial purposes, are very costly, and take up too much space, making it difficult specifically for people who are interested in trying hydroponic as a hobby. This project aims to design a new form of system that combines the technology & benefits of hydroponic, aquaponic, and aeroponic that will be utilized for growing vegetables and herbs. The new system aims to be more efficient, compact, and, most importantly, cost-viable to the general consumers. To gain a better understanding of this topic, extensive research is conducted on the types of sustainable farming methods, hydroponics as well as different aspects of it. A survey is distributed online to gain feedback from potential buyers. Site visits are also conducted on two local farms that use hydroponic/aquaponic technology to learn their firsthand experience in managing a hydroponics system. A total of 6 different concept designs were sketched about the data obtained from the literature review, interview, and survey. The designs are then shortlisted into three concept designs before it is further shortlisted into one design with the aid of design evaluation using Pugh's method. To conclude, a functional prototype of the system has been successfully built that fulfills the criteria of this project.

1. Introduction

Sustainable farming is farming procedures that aim to fulfil the requirements of current and future generations, as well as other aspects including profit, health, and social fairness. These methods can aid in maintaining soil fertility, reduce pollution, and protect biodiversity. Sustainable farming methods also serve to fulfil global objectives such as Sustainable Development Goals and Zero Hunger by the World Health Organization [1-3].

Hydroponics is one of the sustainable farming methods aimed to solve the world's major problems whereby it involves growing crops with water & nutrient solutions instead of soil. This

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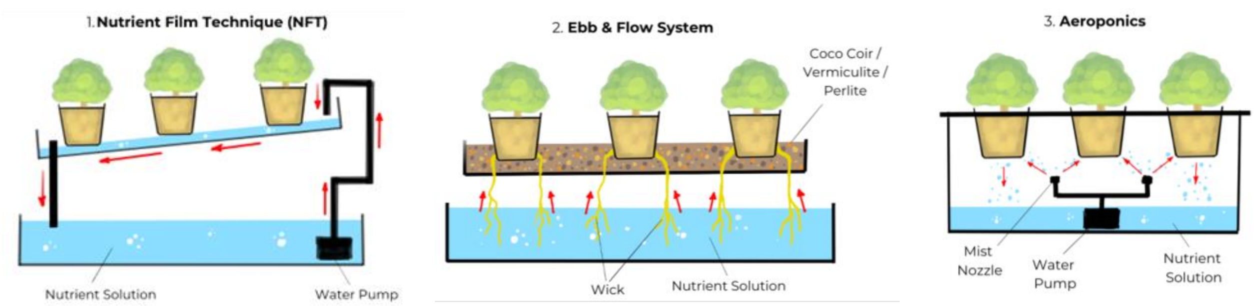
system encourages the rapid growth of crops with stronger yields and superior quality than crops grown with conventional farming methods. [3,4].

1.1 Types of Sustainable Farming Method

In hydroponic, crops are grown using nutrient solution or inert medium instead of soil. Not only does this method allow people to do agricultural activities on limited space but also gives them control over variables such as temperatures. However, farmers must be adequately trained to manage all the necessary equipment and ensure the plants have all the required nutrients. Consecutively, aquaponics is a method that combines aquaculture and hydroponics. In this system, the fish's wastes serve as nutrients which are then absorbed by the plant's roots. Aquaponics allows for a more efficient use of water and allows them to adapt to any harsh climates. However, the initial startup cost is much higher than regular hydroponics. On the other hand, urban agriculture is farming practices to help tackle the demand for localized food systems, requiring farmers to grow their crops closer to their homes. Experts believe urban agriculture has potential to become a new business venture in major cities. However, concerns have been raised that urban soils may not be suitable for farming activities [5-9].

1.2 Types of Hydroponics

As shown in Figures 1(a), 1(b), and 1(c), there are different types of hydroponics implemented by farmers and home gardeners worldwide, such as Nutrient Film Technique (NFT), Ebb & Flow System and Aeroponics.



(a) (b) (c)

Fig. 1. Different types of hydroponics implemented by farmers and home gardeners worldwide

Figure 1(a) above shows a simplified Nutrient Film Technique (NFT) that comprises of a channel, water reservoir, and water pump. The system operates by pumping nutrient solution from the reservoir into the channels where it passes the plants' hanging roots before returning to the reservoir. NFT systems are suited for plants with small roots and is relatively easy to set up. In Figure 1(b), the Ebb & Flow is a system that places plants in pots filled with medium such as soil or perlite. A pump is used to flood the grow bed with water for a set period time before it is drained back into a reservoir for the plants to respirate. The process is typically controlled with a timer to imitate natural irrigation and is popular among farmers due to its simplicity and effectiveness. Lastly, figure 1(c) shows a simplified Aeroponics system. In Aeroponics, plants grown are suspended in the air and are sprayed with nutrient solutions periodically. Because of this unique application method, it uses 98% less water than traditional farming techniques and 30% less than other hydroponic systems. However, it has a high startup and maintenance cost [10-12].

1.3 Combination of Farming Methods
1.3.1 Hydroponic and Aquaponic

A study was conducted at IES Joaquin school in Polígono Sur, Spain to assess this gap. The objective of this study was to assess the production of different types of vegetables, herbs and fruits together using tilapia fishes. At the end of this experiment, 62 kg of tilapia and 352 kg of 22 different vegetables and fruits were produced within a year. This study proved that aquaponics could provide sufficient sustenance for a family for a year. Figure 2 shows a simplified system used in the study [13].

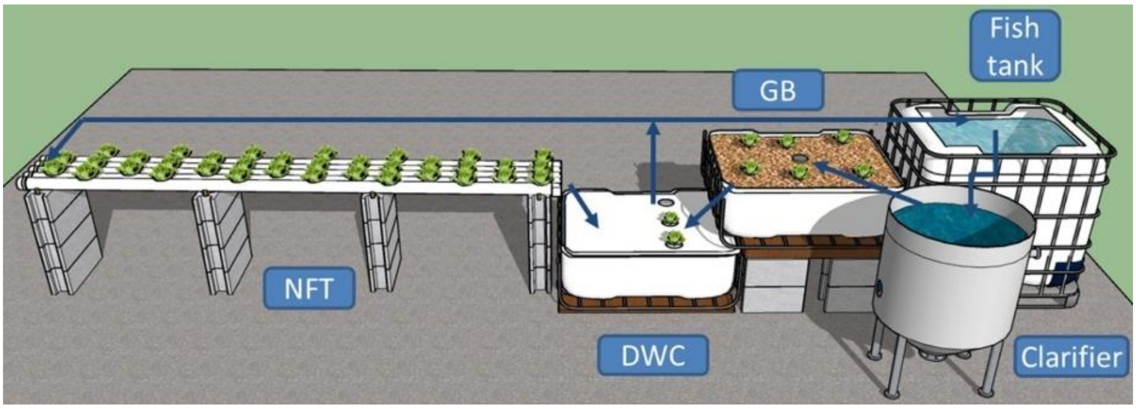


Fig. 2. A 3D model of the micro-scale aquaponic system with the three hydroponic sub-systems

1.3.2 Hydroponic and Aeroponic

A study was conducted at Humboldt-Universität, Berlin to investigate the viability of a hybrid aeroponic/nutrient film technique system for the growth of tomatoes over rock wool substrates. At the end of the experiment, it was determined that the AP/NFT is more viable as the the plants had accumulated more sodium and less phosphorus and sulfur content than the rock wool grown counterparts. Figure 3 shows a simplified diagram of the system used in the experiment [14].

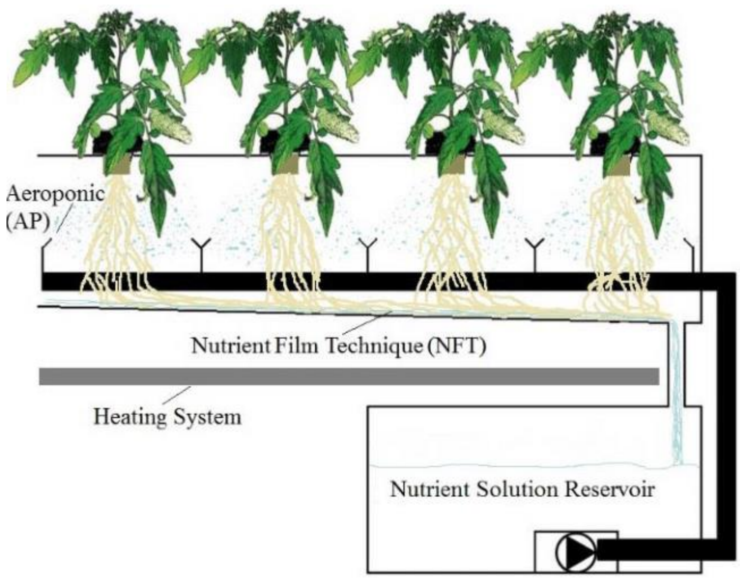


Fig. 3. A simplified breakdown of the Aeroponic & NFT system

1.3.3 Aeroponic and Aquaponic

In Wisconsin, a company called Aqua Garden LLC converted an old warehouse into an aeroponic farm for growing herbs such as wobbly walleye and cocktail mint. The company raises fish and utilize the nutrients produced by them to grow crops using a combination of aquaponic and aeroponic. This leads to improved yields, shelf life, and aroma. The company can grow up to 25,000 pounds of culinary herbs and 1,5000 pounds of walleye every year. Figure 4 shows the flow chart of the various processes implemented in the system [15].

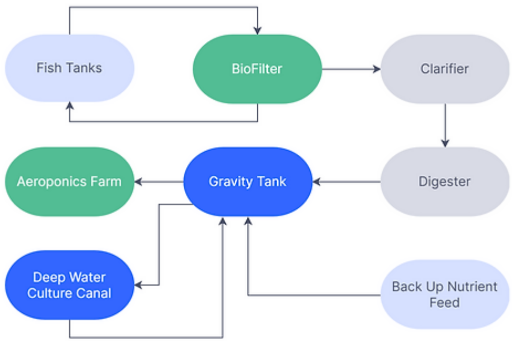


Fig. 4. Aqua Garden flow chart

Despite all the benefits that come with the system, most hydroponic systems that are available in the market are specifically designed for commercial purposes. Not only are they costly, but they also require a lot of manpower to manage and take up too much space. This makes it difficult specifically for people who are simply interested in trying out hydroponic as a simple hobby to grow their fruits & vegetables.

This paper contains several objectives that need to be fulfilled. The first objective is to do in-depth research on existing hydroponic systems and evaluate their respective benefits and downsides, specifically on aspects such as system efficiency, cost-effectiveness, and scalability. The next objective is to visit local businesses that implement hydroponics as part of their business venture. This is to gain insight on their method of using the system, the user satisfaction in general as well as the operational challenges encountered. The third objective is to conduct an online survey to gain feedback from the public potential buyers. While it is important that the device can do its intended function efficiently, it must also be able to fulfill the general customers’ satisfaction. The fourth objective is to draft multiple design ideas that satisfy all the necessary criteria derived from the research, site visits and online surveys prior. Lastly, the final objective of this paper is to prepare a functional prototype of the selected design whereby the end prototype will be consequently used for growing simple crops as part of its testing phase.

2. Methodology

2.1 Information Gathering

To reinforce the literature review prior, additional information is gathered via site visits as well as an online survey.

2.1.1 Site visit

Site visits are conducted with two local businesses in Brunei. The first one is IAM Food Agritech which is a large aquaponics farm that uses I.O.T technology to manage the whole farm. The second company is Kabunku Aquaponics which is a small farm that uses a more conventional version of aquaponics.

IAM Food is an Agritech Farm that was built at KKP Tungku Rimba in the year 2020. The farm uses Aquaponics, Fertigation & Outdoor Natural Farming methods that work in tandem with I.O.T. technology to help enhance the efficiency & output of their agricultural works. The company uses pink tilapia in their aquaponics farm due to their hardy nature. Ever since its inception in the year 2020, the company has sold a wide variety of high-quality products such as Melon Royale, chilis, capsicums and herbs. To tackle the constantly changing market demands, IAM Food also sells hand-made food products including fruit jams and spicy chili sauces to diversify their product choices.

Kabunku Aquaponics is a local aquaponics farm located at Jalan Pasir, Berakas. It was first established in 2020 during the first wave of COVID-19. The company uses hydroponics and aquaponics as their main farming methods in which the aquaponics uses a mix of koi and tilapia fishes. Alongside the fish, they also breed black soldier flies to help convert food wastes to compost and to be used as feeds for the fish. The company produces a wide variety of green produce including Basil, Red Cos, Red Coral, Sweet Mint, and Cape Gooseberry. Kabunku Aquaponics is focused on building a strong foundation for the country's self-sustaining agricultural sector and offers knowledge and experience to any interested locals through community engagement and internships.

2.1.2. Survey

A survey questionnaire is made using Google Forms and distributed online and through social media. The questions included in the survey are directed toward potential customers who might be interested in using hydroponics for their gardening needs. Figure 5 shows the flowchart of the survey.

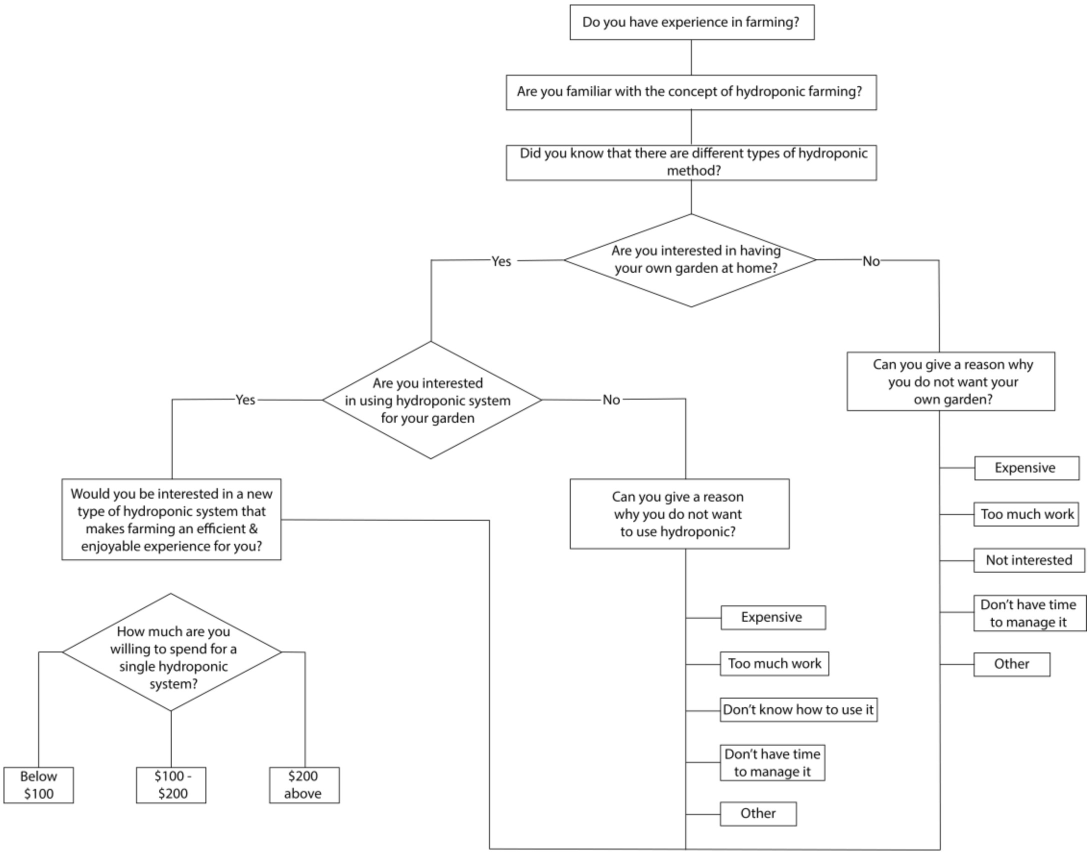


Fig. 5. Survey flowchart

2.1.3. Survey analysis

The important details derived from the results obtained from the interview and survey questionnaire are as follows:

- 77% (96 out of 124 people) of the respondents want to have their garden at home.
- 83% (80 out of 124 people) of the respondents replied yes when asked if they wanted to use a hydroponic system for their garden.
- 84% (105 out of 124) of the respondents showed interest in purchasing a new type of hydroponic system that is more efficient and makes it an overall enjoyable experience.
- According to the survey, 40% (6 out of 16) of the respondents do not want to use the hydroponics method because they are not familiar with how to use it, 20% (3 out of 16) say that they will not have the time to manage it and lastly, 26% (4 out of 16) says they do not want to use hydroponics because it is too expensive.
- The majority wants the hydroponic system to be cost-affordable with 53% (67 out of 124) wanting the price to be below BND$100 and 37% (47 out of 124) respondents wanting it to be between $100 and $200. The remaining 10% of respondents (10 out of 124) are willing to spend $200 and above.

2.2 Concept Generation

As part of the ideation process, several concept design sketches have been made about the information obtained from the literature review as well as additional data received from surveys and interviews. The designs are also partially inspired by existing hydroponic designs including DIY made by gardeners who use a combination of recycled and shop-available materials and resources.

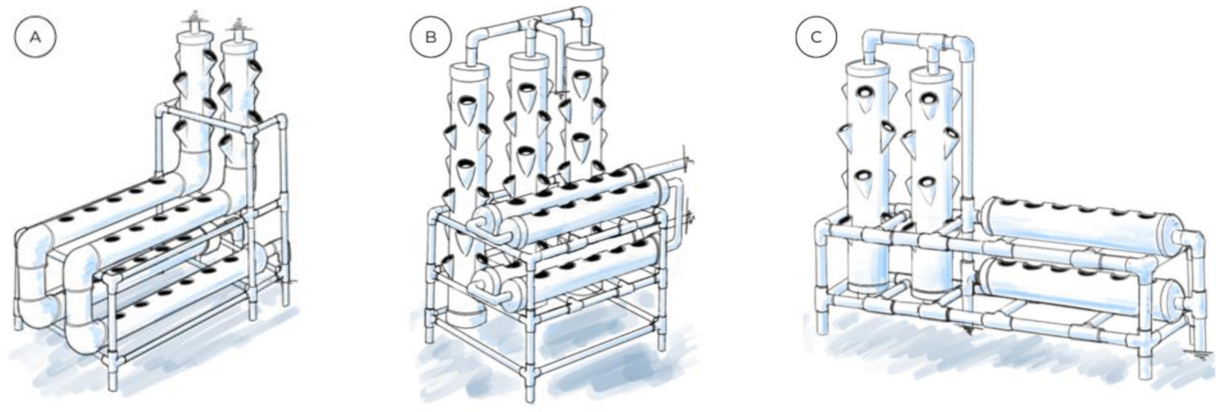


Fig. 6. Design a, design b, and design c

As shown in Figure 6, the NFT channels in concept design A are placed against the vertical towers to reduce the space size and make it more stable. The water tank and pump are located elsewhere to make the whole system more, this leaves a space below the NFT channels that can be used for installing additional NFT channels or for temporarily storing tools and equipment. This design helps with tackling lack of space problems. However, it may be difficult to reach the NFT channel located on the lower level and the holding frame may also obstruct accessibility to the bottom portion of the vertical towers.

As shown in Figure 6, design focuses on integrating the vertical towers and NFT system whereby they are merged as a single unit instead of two separate entities. Nutrient solution is pumped into the top of the vertical tower via the inlet pipe. It then flows to the C-shaped NFT channels and eventually goes to the outlet pipe which returns to the water tank. This design is intended to reduce the material usage. Production yield can be further increased by stacking multiple units in parallel to each other.

Lastly, Figure 6 shows concept design C which is another iteration whereby the vertical tower and NFT channels are placed in line with each other. This makes the design more easily accessible from both sides and is viable in long and narrow spaces. Nutrient solution is pumped through a single pipe which splits to the vertical tower and NFT channel systems. The pipe is then further split between the units before returning to the water tank via separate outlet pipes.

2.3 Concept Selection

As shown in Table 1, a design evaluation is performed on the three concept designs a, b and c using the Pugh's methods based on several criteria that are important in a hydroponic system. This includes efficiency & yield, initial cost, maintenance, build complexity and space requirement.

Table 1
Design evaluation of concept designs using Pugh's method

Evaluation Criteria	**Weight (1 – 5)**	**Concept Design**			
		NFT System	**A**	**B**	**C**
Efficiency & Yield	4		+1	+1	-1
Initial Cost	3		-1	+1	-1
Maintenance	3		-1	+1	+1
Complexity	2		-1	+1	+1
Space Requirement	1		+1	-1	+1
Results	Plus (+)		2	4	3
	Same as (s)		0	0	0
	Minus (-)		3	1	2
	Total		-3	11	-1

Based on the result of the design evaluation, it is concluded that concept design B has the highest score with a score of 11 points with concept design c with a score of -1 points and concept design A with a score of -3. Hence, the project will proceed with further development using concept design B.

3. Result & Discussion

3.1 Final Concept

Following the design evaluation, further development is done on concept design B until a final iteration is made. As displayed in Figure 7, attention is focused on the water filter system which will be located below the hydroponic system as a means of conserving space and making the Tiga-ponics more compact.

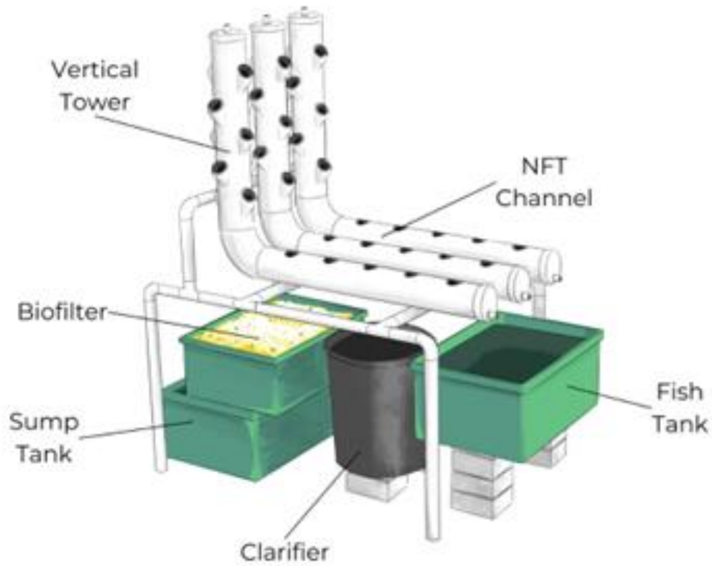


Fig. 7. Final iteration of Tiga-ponics based on concept idea b

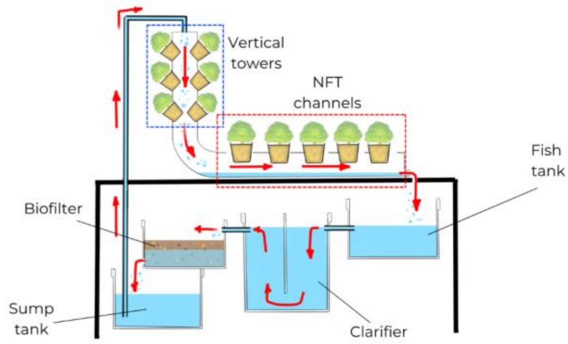


Fig. 8. A simple flow diagram of the Tiga-ponics

As shown in Figure 8, the Tiga-ponics comprised of several main components. The vertical tower serves as the aeroponics part of Tiga-ponics. It can be used to grow any types of crops but preferably smaller herbs and shrubs that does not produce tall shoots. It allows for a higher crop output per unit area compared to other hydroponic methods. The NFT channel can be used to grow crops with tall shoots or wide crowns as well as short root systems. This ensures that the plants' leaves have enough room to receive adequate sunlight. The fish tank is refurbished from a normal storage container. To save budget, other forms of container mediums can also be used so as long as its large enough to house enough fish to supply nutrients to the whole system.

The clarifier is one of the two most crucial component of the hydroponic system as it helps separate heavy solid waste particles from the fish water. As the water flows into the clarifier from the fish tank, the solids sink into the bottom of the drum whilst clean water rise to the other side of the separator. The solids built up at the bottom can then be drained out to be used as makeshift garden fertilizers. The biofilter is a container filled with LECA and clay pebbles, the beneficial bacteria within the container helps to convert ammonia inside fish waste into nitrites and nitrates that serves as good nutrients for plants. Lastly, the sump tank is just a container used for storing water that has been filtered by the clarifier and biofilter. A submersible water pump located inside the tank is used to pump the water to the growth beds.

3.1.1 Final prototype

Figure 9(a) shows the front view of the Tigaponics prototype where the fish tank, clarifier, NFT channel are visible. On the other hand, figure 9(b) shows the back view of the prototype where the biofilter and sump tank can be. Lastly, figure 9(c) shows the prototype housing several Kangkong seedlings for testing purposes.

(a) The front view of the prototype
(b) The back view of the prototype
(c) Kangkong seedlings transplanted onto the prototype

Fig. 9. Final Prototype

3.2 Prototype Testing & Result

After its completion, the Tiga-ponics prototype is tested over the span of five days for growing several kangkong seedlings. During this period, the pH, PPM value and temperature of the nutrient solution in the system is measured using a digital pH/TDS meter. The values obtained are then compiled into a table as shown in Table 2.

Table 2
The pH and ppm of Tiga-ponics' nutrient solutions over 5 days

Day	Time	pH value	PPM	Temperature (℃)
1	11:52 PM	7.44	115	26.9
2	11:06 PM	7.67	117	27.6
3	12:38 AM	7.65	124	26.6
4	12:16 AM	7.43	133	26
5	10:38 PM	7.55	154	27
6	9:38 PM	7.57	162	28.8
7	11:54 PM	7.71	167	26.7
8	11:34 PM	7.35	172	25.9

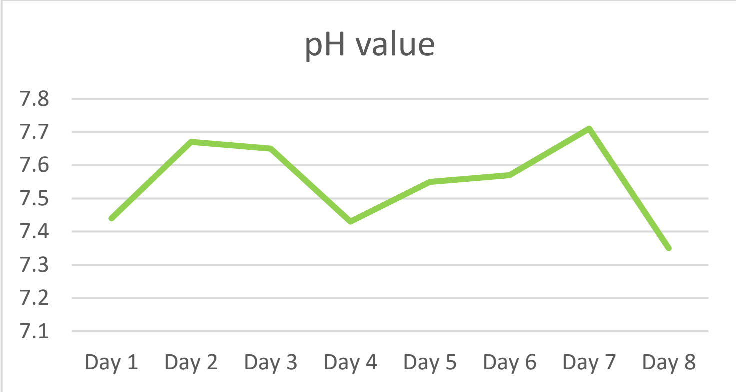


Fig. 10. pH value of Tiga-ponic's nutrient solutions over 5 days

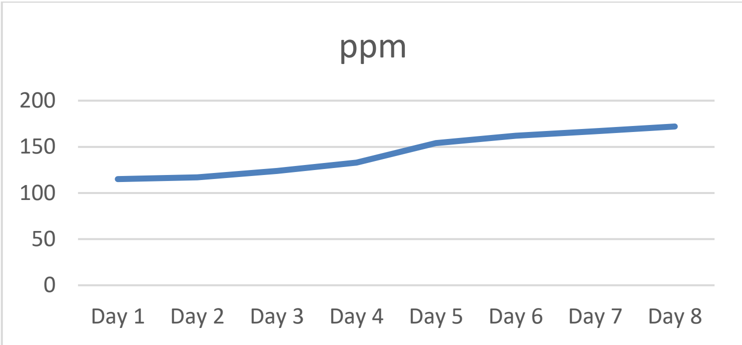


Fig. 11. PPM value of Tiga-ponic's nutrient solution over 5 days

Figure 10 shows the changes in the nutrient solution's pH value whilst Figure 11 shows the PPM value over the span of 5 days.

Throughout the 5 days of testing, Tiga-ponic's nutrient solution was able to maintain pH range value of 7.43 - 7.67 and a PPM range value of 115 – 154. For comparison, tilapia fishes can survive in water of pH range of 5.0 to 10.0 whereas most plants grow well when the pH levels are below 6.5. While the nutrient solution's current concentration allows for Tilapia fishes to survive, it does not contain enough nutrients to support most plants' healthy growth with the lowest being 560 for lettuce and 600 for Kangkong. Alternatively, the incremental increase in PPM value over each days indicate that with more time, the PPM can possibly increase to a sufficient level for plant growth. Hence, more time is required for the test to achieve a more viable result.

4. Conclusion

Hydroponic and its variations are some of the more popular sustainable farming methods that involve growing plants in an inert medium instead of natural soil to boost plant growth while also eliminating most problems associated with traditional methods. As demand for local produce increases and fertile land for farming purposes becomes more limited, hydroponic has the potential to become the main farming method within the country and replace the traditional farming methods implemented by the locals. However, most hydroponic systems available in the market are costly and inefficient and require a lot of manpower to handle. Hence, it is not a feasible option for the locals just yet. The Tigaponics is designed to solve this problem. By combining hydroponics, aquaponics, and aeroponics altogether to create a small-scale farming system that is more efficient and self-sustaining. Several learning institutes and business companies worldwide have attempted to integrate multiple types of hydroponic systems in the past and were able to yield positive results in the form of crops. Local agritech companies such as IAM Food and Kabunku Aquaponics are also implementing hydroponics to grow their crops. They are also focused on enriching the agricultural sector by offering community engagement & internship opportunities for those who are interested. An online survey is conducted to gain insight from the public, particularly on the price as well as what features the hydroponics should have. Several concept designs have been made about the data collected from various sources, each design having its respective advantages and disadvantages. A design evaluation is performed, and the design undergoes several iterations before it is eventually shortlisted into one final design that fits all the necessary criteria a hydroponic must have. A functional, one-to-one scale prototype of the final design is fabricated and, as testing, is used to grow several Kangkong for several days. Tilapia fingerlings are utilized as a source of nutrients to supplement the plants' growth. Despite various limitations, the Tiga-ponics prototype was able to successfully the Kangkong seeds to a considerable size.

In future iterations of Tiga-ponics, several changes can be made to further improve its design & functionality performance. For starters, the design should also be altered to give the Tiga-ponics a more unique silhouette that differentiates it entirely from other hydroponics systems that are available in the market. Biomimicry can be used as a source of inspiration to aid in the ideation process. With most hydroponics systems being composed mainly of plastic materials, uncommon materials such as wood and metal should also be incorporated into the Tiga-ponics. Not only will this enhance its appearance, but it will also make it suitable to be displayed in commercial locations such as office spaces & shopping spaces. As the Southeast Asia region continues to experience harsh hot weather, a roof shade or other form of cover must be implemented to protect the plants from wilting. The fish tank and subsequent filter system must also be properly shielded to prevent the water temperature from rising to harmful levels.

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