A Comparison of the Effectiveness of Aquaponic Gardening to Traditional Gardening Growth Method

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Abstract

Land development in Hawaii is a growing problem causing agricultural lands and resources to be limited. Currently, 85-90% of Hawaii's food supply is imported. For centuries, Hawaiians developed ways to be sustainable such as building fishponds and lo'i (taro plantations). Today, modern aquaponics is a viable resource to sustainability that combines aquaculture (growing fish and plants in a controlled environment) and hydroponics (growing plants without soil). The system relies on fish waste to provide organic food and nutrients to help the plants grown; in turn, the plants clean, filter, and recycle the water back to the fish creating a symbiotic relationship (Dunn, 2012).

The purpose of this experiment was to compare and contrast the growth of tomatoes, beans, and pea plants in an aquaculture medium with fish and no fish by monitoring the changes in ammonia, pH, nitrate, phosphate, temperature, and salinity of water overtime. Results showed that there were no significant growth differences by height of peas, tomatoes, and beans when growing between aquaponic vs. traditional soil. However, there were significant differences between growing plants aquaponically vs. the control hydroponic with water only. Data confirmed at Day 7 that nitrates at its peak and as ammonia decreased, caused the aquaponic plants to grow rapidly. Thus the experiment confirmed a correlation between nitrate and plant growth. However, further studies in length and repetition is required to confirm whether aquaponics and nitrates have a direct correlation and direct development for the plant growth.

Introduction

The Hawaiians began agriculture on the Hawaiian Islands by growing taro, sweet potato, breadfruit, bananas, and other staple food to sustain the people of Hawaii. Fishponds were also created along the coasts to raise fish and other seafood as a means of aquaculture. Traditional Hawaiian aquaponics were also in placed with the *lo'i* system where wet taro *(Colocasia esculenta)* were grown in land patches filled with fish and prawns as river water cycled from patch to patch (Figure 1).

Figure 1: Hawaiian Aquaponics- the *Lo'i*

However, as urbanization sprawls and encroaches onto land areas in Hawaii, the precious space for agriculture, fishponds, and for *lo'i* have diminished. Today, Hawaii imports over 85-90% of its food supply from other countries and continental United States (Hawaii Department of Agriculture, 2008). It is very alarming for Hawaii to be very dependent on food, supplies, oil, and energy outside of Hawaii. Thus, it is more imperative for the concept of sustainability that once flourished the islands to be revived and instill to young and future generations to ensure Hawaii will not deplete its resources.

One alternative solution to sustainability is modern aquaponics. Aquaponics technology has been recognized in the U.S. since the early 1980s. Modern aquaponics combines aquaculture (growing fish and plants in a controlled environment) and hydroponics (growing plants without soil). The most common aquaponic systems employ media-filled raised bed, nutrient flow technique for the plant growing area integrated with a recirculating aquaculture tank system (Timmons, Ebeling, Wheaton, Summerfelt, and Vinci, 2002) (Figure 2). The system relies on fish waste to provide organic food and nutrients to help the plants grown; in turn, the plants clean, filter, and recycle the water back to the fish creating a symbiotic relationship (Dunn, 2012). In addition, pollution, pesticides, and use of chemicals are drastically reduced since only fish waste and freshwater are used as the growth medium. Most importantly, modern aquaponics uses a small amount of freshwater and space. So the system can be used in doors, in a green house, back yard, and can be resistant to influxes of natural changes such as temperature, drought, wind, rain, seasonal changes, and other factors if grown in doors. As a result, aquaponics can produce food in small scale and large commercial scale also (Jones, 2002).

Figure 2: Modern Aquaponics

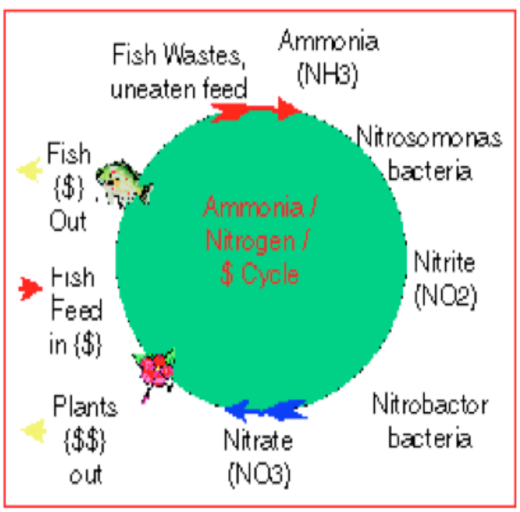


Figure 3: Nitrification Process-Conversion of Ammonia to Nitrate (Jones, 2002).

During the process of fish respiration, oxygen (O_2) and carbon dioxide (CO_2) are exchanged, while ammonia (NH_3) is released by the fish. To keep the fish healthy, nitrosomous bacteria convert the ammonia to nitrate (NO_3) and nitrite (NO_2), which in turn is used by the plant as the medium for growth (Ochmanski, 2008) (Figure 3). This process is called nitrification.

Research showed that nitrification transforms 93% to 96% of nitrogenous fish wastes into nitrate (Prinsloo Roets, Theron, Hoffman, and Schoonbee, 1999). Un-ionized ammonia nitrogen at concentrations as low as 0.02-0.07 mg/L had shown to slow fish growth and cause tissue damage to fish (Masser, Rakocy, and Losordo, 1999). Since nitrate is the primary source for Nitrogen for plants in hydroponic or aquaponic systems, the management of the nitrification process for aquaponic systems is important for the maintenance of water quality and the production of nitrate nitrogen.

In addition to nitrate, pH is also an important water quality parameter that can affect the nitrifying bacteria in aquaculture biofilters. The pH recommendations for aquaculture systems range between 6.5 and 8.5 (Timmons, et. Al, 2002), whereas, the pH tolerances of plants can range from 5.0 to 7.6 depending on the species (Maynard and Hochmuth, 1997).

Tilapia (*Oreochromis niloticus)* and goldfish (*Carassius auratus auratus)* are the most common fish used in aquaponic systems. Tilapia and goldfish both produce high levels of ammonia, which is good for maintaining nutrient levels for the aquaponic process. Both fish are also very resilient to changes in pH, pollutants, and temperature (Johanson, 2009). In addition, Tilapia grows quickly, has a good food conversion rate, and can be eaten as well (Childress, 2003).

Thus, the objective of this experiment was to compare and contrast the growth of tomatoes, beans, and pea plants in an aquaculture medium with fish and no fish by monitoring the changes in ammonia, pH, nitrate, phosphate, temperature, and salinity of water overtime.

Research Question:

With the decreasing of farming land and land space, will Aquaponics be an alternative growth medium for the plants such as tomato (*Solanum lycopersicum*), bean (*Phaseolus vulgaris*), and the pea (*Pisum sativum*) and result in food production?

Hypothesis

If aquaponics is used to grow tomatoes (*Solanum lycopersicum*), beans (*Phaseolus vulgaris*), and peas (*Pisum sativum*), then the nitrate converted from fish waste will enhance plant growth in the aquaponic system.

Materials & Procedures

Seedlings and Cups:

- Prior to starting the experiment, sixty seeds of each type- tomato, peas, and beans were germinated under a 32-watt Philips fluorescent light for 3 days. About 5 seeds were placed on a petri dish with moist paper towel on top and on the bottom of the petri dish to allow the seeds to grow. The fluorescent light was on for 24 hours for 3 days to allow the seeds to germinate. Each day the seeds were checked and water was added on the paper towel to moisten the seeds. (Figure 4)

Figure 4: Germination of Seeds

- A total of 72 Gatorade water cups were drilled with holes. Four pencil size holes were drilled on the bottom of the cup and 3 rows of 8 holes on the sides of the cup were also drilled to allow water to drain.
- The cups were labeled by type of seed and numbered from 1-8. Specifically, the cups were labeled from Pea 1-8, Bean 1-8, and Tomato 1-8. A total of 3 sets of cups were labeled - one set for traditional growth, one set for hydroponic control with tap water, and one set for aquaponics with goldfish.

- 40 grams of potting soil were added into each cup. Only seeds of tomato, beans, and peas that germinated and contained roots were planted on top of the soil, and another 20 grams of potting soil were placed on top of 3 day germinated seed. The type of seeds used consisted of tomato (*Solanum lycopersicum*), garden beans (*Phaseolus vulgaris*), and peas (*Pisum sativum*)
- 100 mL of tap water was added to each cup by using a graduated cylinder to moisten the soil and seeds and allowed to drain

<u>Aquaponics and Hydroponic (Control with H_20 only) set -up</u>

- 2 Plastic black tub with dimensions 60cm x 85 cm and depth 19 cm were used. (Figure 5)
- A 4 cm wide hole was drilled in the center of both black tubs
- Each hole was plugged with rubber and a 20 cm white PVC pipe to act as drainage. An additional 6 cm PVC pipe with holes was added above the hole so that water would drain properly in the tub and prevent rocks from clogging the hole.
- Two Plastic stands were used to hold aquaponic tub.
- Two plastic 18 gallon blue tubs were used and filled with 60 L of tap water
- Each plastic blue tub had a water pump to recycle water back to tub.
- Each tub consisted of 1 and ½ bag (60 lbs = 27.2 kg each) of blue rocks that were thoroughly rinsed and sun dried days prior to the experiment. The blue rocks were approximately 10 cm in height in the tub and above the water line of the pump.
- The cups with the germinated seeds were placed in order (Peas 1-8, Beans 1-8, and Tomatoes 1-8) in the tub so it will be easily read to take data and held by the blue rocks (Figure 6).
- Both aquaponic and hydroponic experiments were placed in the same 32 watt Phillips fluorescent light throughout the experiment
  and in the same room temperature. This was also the same light fixture as the traditional growth. The fluorescent light was on 24 hours throughout the experiment.
- The aquaponic experiment contained 20 goldfish and an Aqueon Quiet Filter ™ Power Filter 55/75.

Figure 5: Plastic tubs, pump, blue rocks, PVC pipe, blue tubs for water and fish, and two stands

Figure 6: Set-up of cups in aquaponic and hydroponic experiment

Control Traditional Growth set-up

- The germinated seedlings cups were placed in the same 32-watt Philips fluorescent light as aquaponic and hydroponic (control water only) and same room temperature as hydroponic and aquaponic experiments.
- The seedlings were watered with 100 mL of tap water every two days. Note that the water was drained in the sink before placing the cups back in the light.

Height Measurements

- Each plant growth height was measured every two days with the exception of Day 5 due to holiday weekend. An average height was taken for each type of plant (tomatoes, bean, and peas) in centimeters.
- In addition, qualitative observations were also taken for each plant for comparison.

Water Quality

- pH and salinity were measured using Vernier software logger pro probes. Ammonia, phosphate, and nitrate test kits were used. A standard thermometer was used to measure temperature in Celsius

T-Tests

- T test were calculated to ensure significance of data $p = < 0.05$.
- T-test for average height for bean, peas, and tomatoes for aquaponic vs. hydroponic (control) were compared. T-test for average height for bean, peas, and tomatoes for aquaponic vs. traditional growth were also compared
- T-test for nitrate, pH, salinity, ammonia, phosphate, temperature for aquaponic water and hydroponic control were also compared.

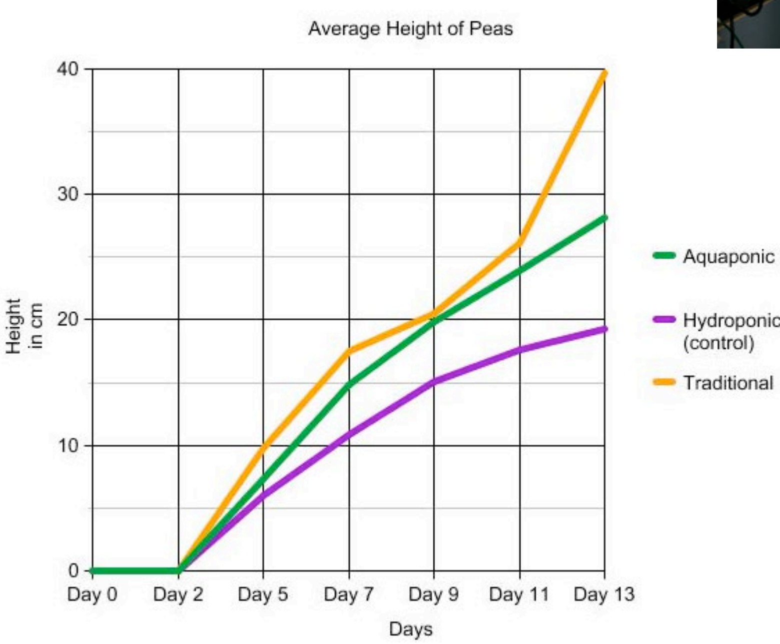
Results

Table 1: Average Height of Plants (Tomato 1-8, Peas 1-8, & Beans 1-8) for Aquaponics, Hydroponic-No fish, and Traditional Growth with Soil.

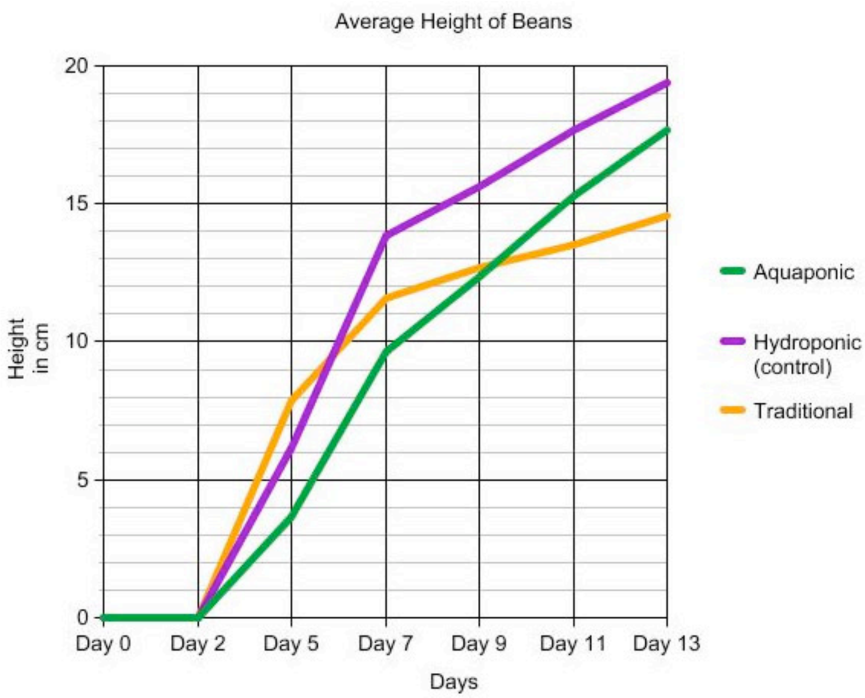
Height Plant with Fish in cm								
	Day 0	**Day 2**	**Day 5**	**Day 7**	**Day 9**	**Day 11**	**Day 13**	**T=test**
Peas Average Height	0	0	7.30625	14.875	19.7875	23.9875	28.1625	**0.01464103**
Beans Average Height	0	0	3.675	9.655625	12.375	15.26875	17.6625	**0.000748905**
Tomato Average Height	0	0	3.40625	4.0375	4.7625	5.39375	6.075	**0.01980695**
Height Plant with No Fish (Hydroponic) in cm								
	Day 0	**Day 2**	**Day 5**	**Day 7**	**Day 9**	**Day 11**	**Day 13**	
Peas Average Height	0	0	5.9375	10.9	15.0875	17.6625	19.3125	
Beans Average Height	0	0	6.125	13.875	15.6375	17.6625	19.41875	
Tomato Average Height	0	0	3.4375	4.24375	5	5.575	6.13125	
Height of Plant Traditional Growth in cm								
	Day 0	**Day 2**	**Day 5**	**Day 7**	**Day 9**	**Day 11**	**Day 13**	**T=test**
Peas Average Height	0	0	9.8	17.525	20.5375	26.1875	39.2625	0.05448427
Beans Average Height	0	0	7.875	11.55625	12.7125	13.525	14.59375	0.40169031
Tomato Average Height	0	0	3.4625	4.6625	4.85	5.2875	6.375	0.0967402

Figure 7: Experiment Set-up Day 0

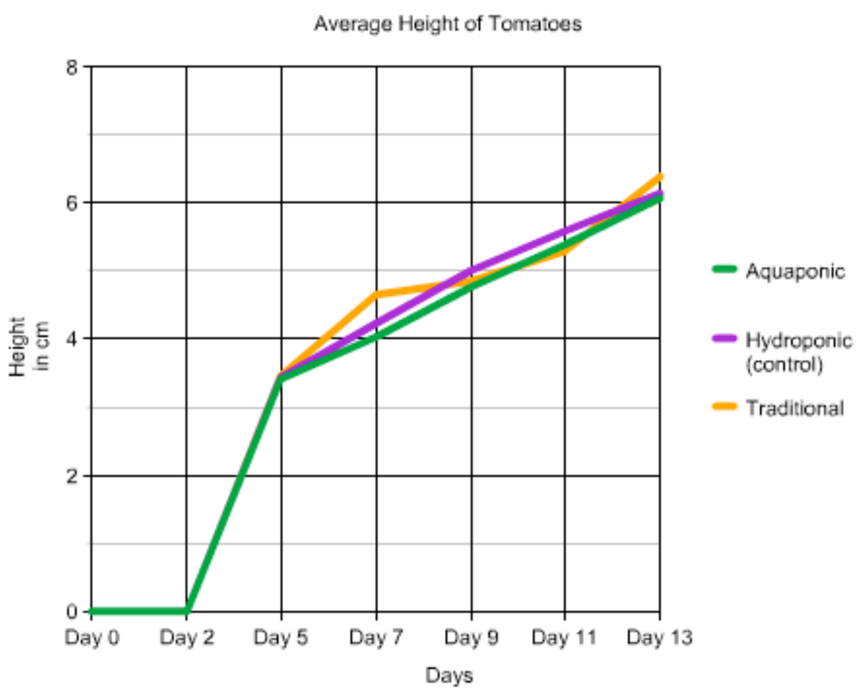
Figure 8 & 9: Day 13 Results for Growth of Peas, Beans, Tomatoes for all three growth mediums (aquaponic, hydroponic, & traditional).



Graph 1: Traditional Growth was much more successful in overall growth height for Peas than both aquaponic and hydroponic, but T-test does not confirm the growth with result 0.05448. However, aquaponic had an overall healthier appearance, vibrancy in color, and much more effective in growth than hydroponic medium with T-test= 0.01464103 confirming growth.



Graph 2: Hydroponic was more successful in overall growth height for Beans than both aquaponic and traditional growth with T-test = 0.000748905 confirming the growth. However, aquaponic had an overall healthier appearance and vibrancy in color.

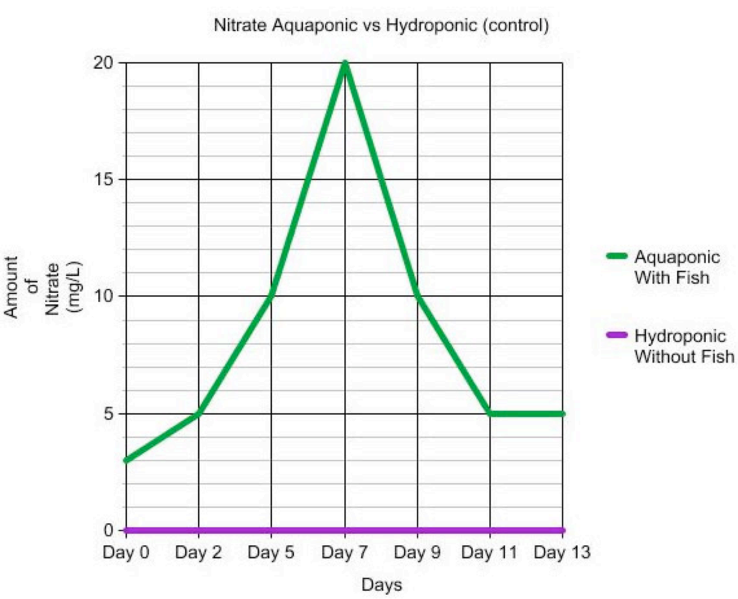


Graph 3: Based on the graph, there is no significant difference in growth based on all three mediums. However, T-test confirmed that there was a difference growth between aquaponic vs. hydroponic with T-test = 0.01980695.

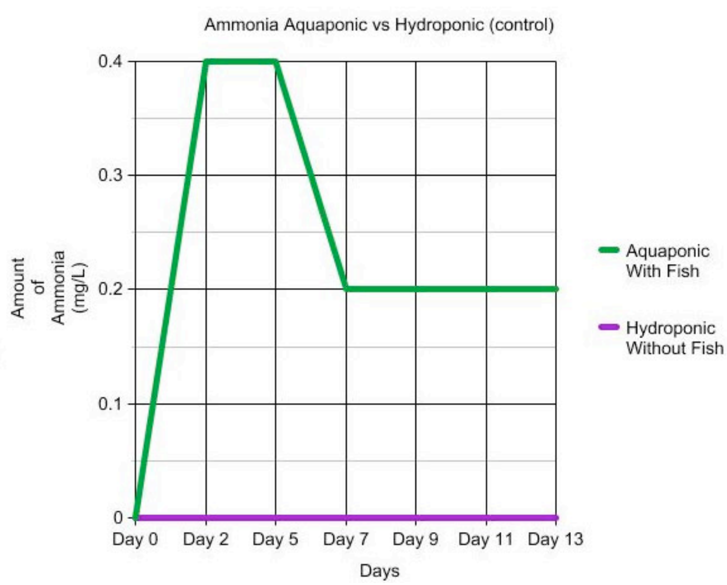
Table 2: A comparison of Water Quality of Aquaponic growth medium with goldfish vs. no fish

With Fish- Water Quality								
	Day 0	**Day 2**	**Day 5**	**Day 7**	**Day 9**	**Day 11**	**Day 13**	**T=test**
pH	7.27	7.07	7.51	7.79	7.81	7.57	7.75	0.091500196
Nitrate mg/L	3	5	10	20	10	5	5	**0.004672502**
Ammonia mg/L	0	0.4	0.4	0.2	0.2	0.2	0.2	**0.002329607**
Salinity ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	#DIV/0!
Phosphate mg/L	0.5	0.5	2	1	6	2	2	0.462428412
Temperature °C	24	24	24	24	25	24	24	0.177958842

Without Fish- Water Quality								
	Day 0	**Day 2**	**Day 5**	**Day 7**	**Day 9**	**Day 11**	**Day 13**	
pH	7.12	7.46	7.7	7.78	7.8	7.75	7.86	
Nitrate mg/L	0	0	0	0	0	0	0	
Ammonia mg/L	0	0	0	0	0	0	0	
Salinity ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
Phosphate mg/L	1	1	1	1	3	0.25	0.1	
Temperature °C	24	24	24	24	24	24	24	



Graph 4: Aquaponic medium showed a dramatic increase and decrease of nitrate, where T-test confirmed this change at 0.000467. The increase of nitrate was due to the conversion of ammonia to nitrate by bacteria and the decrease of nitrate display's the plant's consumption of nitrate.



Graph 5: Aquaponic medium showed changes in Ammonia due to increase of fish waste. T-test confirmed this change at 0.00232. Ammonia was converted to nitrate by bacteria.

Discussion and Conclusion

In the experiment to explore the growth of aquaponics compared to traditional gardening and hydroponic gardening, the quantitative data that was taken showed a correlation between measurements of plant height and water quality. Observations found that the traditional and hydroponic gardening grew an exceeding rate more than the aquaponics.

In **Graph 1**, traditional gardening showed a higher growth rate of the peas (*Pisum sativum*) with a difference of 11 centimeters between aquaponic gardening. Although growing at a faster rate than aquaponic gardening, traditional gardening's height varied from Day 2 to Day 11 but then increased rapidly the growth rate from Day 11 to Day 13. Aquaponic peas grew instead at a steady pace and a constant slope from Day 2 to Day 7 but on Day 7 increased rapidly. In addition, aquaponic peas had an overall healthier appearance, vibrancy in color, and much more effective in growth than hydroponic medium with T-test= 0.01464103 confirming the growth.

In **Graph 2**, hydroponic gardening of beans (*Phaseolus vulgaris*) was much more successful than aquaponic gardening and traditional gardening of with a difference of 2 centimeters between hydroponics and aquaponics. Hydroponics beans grew at a constant rate between the days of Day 2 to Day 7 but the growth rate lessened after Day 7. Although aquaponics growth rate was discrete from Day 2 to Day 7, the growth rate of the beans was much better after Day 7, which correlated to the increase of nitrates (**Graph 4)** and decrease of ammonia (**Graph 5)** Day 7**.** This confirmed that nitrates contributed to the plant growth.

In **Graph 3**, measurements taken for the height of tomatoes (*Solanum lycopersicum*) for traditional, hydroponic, and aquaponic had no significance differences in growth. However, aquaponic tomatoes looked much healthier.

Thus from this experiment, results confirmed that there was no difference in plant growth between traditional, aquaponic, and hydroponic growth of plants. However, it was found that there was a correlation of the increase of nitrates with the plant growth in aquaponic medium. Thus, the hypothesis, If aquaponics were used to grow tomatoes (*Solanum lycopersicum*), beans (*Phaseolus vulgaris*), and peas (*Pisum sativum*), then the nitrate converted from fish waste will enhance plant growth in the aquaponic system was supported as shown on Day 7 from **Graphs 1-5**. Overall, growing plants in an aquaponic medium does show success in plant growth, healthier appearance, and a viable alternative to growing food (Figure 8 & 9).

Future Research

Future research suggestions include for the experiment to be continued and held for a longer time to observe the changes in growth and rate. In addition, the amount of nitrates should be further researched by setting up different amount of fish in each aquaponic system to see if the amount of ammonia waste by the fish, has a direct relationship to the amount of nitrates produced and growth of the plants.

With the knowledge gained and abundance of data gained, it is the hope that with the loss of the land on Oahu, the aquaponic gardening will be successful in growing produce and promote healthy living.

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