Assessment of Fish and Plant Growth in Aquaponics Enhanced with Vermicompost Tea

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Abstract

Rising populations are putting a strain on food production. New methods of food production such as aquaponics are being used to help meet the needs of the rising populations. Aquaponics is the growing of both fish and plants in a closed loop system with the use of non-soil medium. These closed loop systems are simple systems that inherently have issues that natural ecosystems deal with internally. Aspects of terrestrial and aquatic interaction can be added to these closed looped aquaponic systems to help with deficiencies found in the aquaponic systems. Vermicompost tea, which mimics natural terrestrial inputs can add nutrients, minerals and bacteria that aquaponic systems would lack. The hypothesis for thus study is that additions of vermicompost tea will increase fish and plant health. This in turn will help produce a better product for both consumers and producers alike helping alleviate the rising populations strain on food resources. Results for the study show significant increases in fish weights with additions of vermicompost tea, however further testing is required to fully understand the complete ramifications of adding vermicompost tea to an aquaponic systems.

Introduction

Increasing population and rising food costs are requiring people to find more efficient and sustainable methods to produce high quality food. The earth's population is just under eight billion people and is steadily rising (United States Census Bureau, 2016). The increase in earth's population means that more resources are required to sustain the population. Food production is one aspect that has been affected by the increasing population of the earth.

As more people reside on the earth, more room needs to be made to accommodate them. This in turn limits the amount of land available for production of agricultural commodities that are needed to sustain the growing population. Methods of agriculture must change to meet the demand for more food. The change in agricultural production in turn leads to consequences that affect other aspects of the world, for instance the use of chemical fertilizers that build up in water systems and ultimately pollute the water (Ongley, 1996).

Farming today is a simplified system that is unstable (Cox, 1994). Mono-cropping leads to issues with pest control and diseases, which can only be mitigated by diversifying the farming system and allowing biodiversity to control these issues. Some natural ecosystems are not simplified and are able to deal with issues such as pest control and diseases by themselves. Mono-cropping issues must be addressed by the farmer, which costs money and time. By diversifying the system these issues can be mitigated naturally (Cox, 1994). New farming practices used today to meet the needs of the growing population can also be diversified to help mitigate instabilities within them.

Agriculture production systems such as hydroponics and aquaculture are just two of the solutions for the rising population being put into practice. Hydroponics is the application of growing plants in non-soil media, such as lava rock, with additions of essential fertilizers. This allows for production of food that doesn't require vast amounts of land like industrial agriculture requires. Aquaculture is breeding, rearing, and harvesting aquatic animals such as fish. Aquaculture eliminates the need to harvest from natural systems and instead allows for the production of aquatic species under conditions that can be regulated. The combination of these two is called aquaponics.

Aquaponics, for this study, is the combination of growing fish and plants within the same system. Water is pumped from fish tanks through a growing medium for plants and then the water is recycled back through the fish tank. By recycling the water through the growing medium and the fish tank, the plants receive nutrients from the fish excrement through nitrogen fixing bacteria in a continuous cycle. The objective of aquaponics is to exploit the benefits of both hydroponics and aquaculture to produce a system that grows plants faster, allows year around production, creates a smaller environmental footprint, and consumes less water and energy. Instabilities, such as pathogen contamination and fluctuating water quality, occur in simplified aquaponic systems and processes must be diversified to overcome and manage such unstable conditions.

Issue

Aquaponic operations can produce both plants and fish, although they must be managed correctly to optimize plant and fish growth. One element of terrestrial and aquatic interfaces that is missing in an aquaponic system is the exchange of organic matter, which can be a source of nutrients, encourage beneficial microorganisms, and may be an important part of direct or indirect fish and plant health. Because an aquaponic system is closed it cannot receive these beneficial components naturally. I propose that the addition of vermicompost tea, which mimics organic matter, into an aquaponic system will increase plant and fish health.

Methods

To test the influence of adding vermicompost tea to an aquaponic system an experiment was run using three treatment tanks and three control tanks in blocked pairs. Fish and plant weights were measured to determine overall health of the aquaponic system. The fish being used in this study were common goldfish**.** First, each fish in each tank were weighed to set a baseline weight for comparison for the end of the study period. The plant being used for this study was romaine lettuce, *Paris island cos.* At the end of the study, dry weights of each plant in the treatment tanks and control tanks were measured. Comparison of the control tanks versus the treatment tanks for both the fish and plants will determine overall health. Three control and three treatment tanks were chosen randomly. One treatment received 5% vermicompost tea, another received 10% vermicompost tea, and the third received 20% vermicompost tea. Treatment tanks received vermicompost tea weekly for five weeks. Electroconductivity, pH, NH_3/NH_4, nitrite, nitrate and temperature were monitored daily.

Methods 1.1 - Aquaponic Systems Construction

Six replicate aquaponic systems were pre-built with an ebb and flow media bed on top of four 56.8L aquaria (Figure 1). The media beds were constructed using a 34.1L black plastic meson mixing trays filled with 9.5mm lava rock (Figure 1, #1). Bell siphons (Figure 1, #2-5) were constructed and installed in the media beds to regulate the filling and draining intervals of the beds. Materials used for the bell siphons included a perforated 10.16cm wide by 20.32cm tall PVC pipe (Figure 1, #2) preventing gravel from entering the bell siphon. A capped 5.08cm wide by 15.24cm tall PVC pipe with 6.35mm holes drilled along the bottom opening (Figure 1 #3), was used for the bell and placed over a drain pipe, a 1.91cm wide by 10.16cm tall PVC pipe inside the media bed (Figure 1, #4). The drainpipe (Figure 1, #5) was connected through the bottom of the media bed with 1.91cm PVC male and female adaptors, including 1.91cm PVC with two ninety-degree fittings to create a siphon inside the bell.

Water was pumped from the aquarium using an 80 gallon per hour submersible pump via a 1.27cm tube (Figure 1, #7). Together, the bell siphon mechanism and a water pump allowed water to be pumped from the aquarium continuously, automatically filling and emptying the media bed, returning the water back to the aquarium. Aeration to all four systems was achieved using a 45.0 L/min air pump delivering air to each replicate aquaponic system via a 6.35mm air tube attached to a 5.08cm cylindrical air stone submerged in each system.

Methods 1.2 - System Preparation

System preparation was performed prior to hypothesis testing. System preparation is necessary to keep water quality factors such as pH, EC, and temperature similar between all tanks to acquire accurate results.

Four of the six aquaponic systems used for the experiment were preset and had goldfish and romaine lettuce already growing in the system. Two more identical systems where constructed and dechlorinated water was added and allowed to cycle for three days. During this time the romaine lettuce was removed from the four preexisting aquaponic systems. Preparation of an aquaponic system usually involves a phase called “cycling,” which is necessary to colonize the aquaponic system with nitrogen fixing bacteria, *Nitrosomonas eutropha* and *Nitrobacter winogradskyi*. The four existing aquaponic systems were used to colonize the two new aquaponic systems.

To colonize the two new aquaponic systems, five gallons of water were removed from each of the four preexisting systems. A water quality test was performed for each separate aquaponic system. A water quality test was used to measure levels of pH, EC, NH_3/NH_4, NO_2

and NO_3. Based on these measurements, water from the preexisting aquaponic systems was then dispersed between the two new aquaponic systems to colonize them with *Nitrosomonas eutropha* and *Nitrobacter winogradskyi.* Water was exchanged between the four existing systems as well to make the aquaponic systems similar in water quality. Dechlorinated water was added to all six aquaponic systems. Each tank was marked to hold 41.8 liters of water in the whole system. This level was maintained throughout the experiment.

Methods 1.3 - Fish Dispersal

Eighty goldfish were dispersed between the six aquaponic systems. The goldfish in the existing tanks were removed and placed in a five-gallon bucket with an aeration stone. The fish were then randomly picked out of the five-gallon buckets and weighed and then dispersed evenly throughout the six aquaponic systems. Fish dispersal occurred as follows: with closed eyes, a net was submerged into the 5-gallon bucket and whichever fish was caught went into the first aquaponic tank. Again the net was submerged and a second fish was removed, was placed in the second aquaponic tank. The same procedure was used for the remaining fish until there were 13 fish in each tank.

Each tank was numbered starting with tank one and ending with tank six. Tank one and two were pair block one, tank three and four were pair block two and tank five and six were pair block three. At first the weights of the goldfish in each pair block were significantly different. To average the weights between the paired blocks, a goldfish was taken from the aquaponic system with a higher weight in goldfish. The fish was weighed and subtracted from its original tank and then the goldfish was added to the aquaponic system with the lower total fish weight in that pair block.

Once all the fish where dispersed in the six aquaponic systems, water changes were done every day for a week. This was done to bring pH and EC to levels that are appropriate for an aquaponic system (Table 1). Water changes were performed every day for a week so that levels of pH and EC could be monitored and brought within these ideal aquaponic ranges.

Methods 1.4 - Seed Sprouting

A week prior to hypothesis testing seeds were planted for the six different aquaponic systems. For this experiment romaine lettuce (*Parris island cos*) seeds were going to be used. A similar aquaponic system was built as described in Methods 1.1. This aquaponic system was used to start seed growth. Instead of media being placed in the media beds, water was allowed to flow freely through this area and trays filled with individual sponges were set in the media tray. Each sponge received one romaine lettuce seed. A grow light was placed over the aquaponic system and the seeds germinated within four days. 144 seeds were planted and of those 103 sprouted. Romaine lettuce was not to be distributed into the aquaponic systems until the cotyledon appeared. A cotyledon is the first leaves to appear from a germinating seed.

Once the cotyledons sprouted 54 of the 103 seedlings were randomly chosen to be used in the experiment. A total of eight lettuces went into each of the aquaponic systems. Each lettuce was numbered starting at one through 54. A random number generator with these constraints will be used to designate which romaine lettuce will go into the first aquaponic system and so on until all the romaine lettuce has been dispersed between the six aquaponic systems. The media beds were broken into quadrants of eight and each numbered one through eight. A random number generator was used to designate where the lettuce was placed. This was done for all six of the aquaponic systems (Figure 3).

Methods 1.5 - Brewing Vermicompost Tea

Brewing vermicompost tea is made with approximately 7.6 liters of de-chlorinated tap water, for every 0.5 kg of fresh vermicompost inside a fine nylon mesh bag and submerged following Ingham (2005). A custom brewer was constructed from a 22.7L plastic carboy container (Figure 2, #1) with four 2.54cm PVC pipes (Figure 2, #3) along the outside connecting to both top, and bottom of the carboy using PVC connecters. These pipes were used as airlifts driven by a 45 L/min air pump (Figure 2, #2) and one 1.27cm by 10.16cm air stone inside the bottom of each pipe (Figure #4) to circulate, and aerate the vermicompost tea. The compost tea was brewed (aerated and left to grow bacteria and fungi) for 80 hours before application into the aquaponic systems, as recommended by The Compost Tea Brewing Manual (Ingham, 2005). Content of the compost tea consisted of vermicompost, kelp extract, humic acid and molasses.

Methods 1.6 - Experimental Procedures

Once equilibrium was achieved in the six aquaponic systems the goldfish were randomly distributed between the tanks. A few days before hypothesis testing the eight Romaine lettuce seedlings were planted in the six media beds. Each aquarium was maintained with 41.8 liters of water at all times with dechlorinated water was added as necessary to maintain this level. The goldfish were fed a pelleted fish food and the amount was based on the mean weight of fish in all the tanks multiplied by 1.5 percent. For this experiment the fish will be fed 2.76g of food once daily. This amount should allow growth without damaging water quality. Pelleted fish food for the experiment consists of EWOS bass floating 4mm fish feed.

Vermicompost tea will be added to three of the six tanks with different percentages going into each of the three tanks. The amount of vermicompost tea being added to the test tanks in varying percentages: 5%, 10% and 20%. Tank one and two were pair block one with tank two receiving 5% vermicompost tea, tank three and four were pair block two with tank four receiving 10% vermicompost tea and tanks five and six were pair block three with tank six receiving 20% vermicompost tea. Aquaponic systems that received vermicompost tea received tea every week for five weeks. The aquaponic system that was designated to receive 5% compost tea received 2.09 liters of tea per week. This is based on the volume of the tank which is 41.8 liters. The 10% vermicompost tea aquaponic system received 4.18 liters and the 20% vermicompost tea aquaponic system received 8.36 liters of vermicompost tea.

Vermicompost tea was made in fifty-gallon batches and prepared four days prior to adding to the aquaponic systems. The tea was at its greatest potency four to five days after brewing. To make a fifty-gallon batch of tea, fifteen pounds of vermicompost tea, 250g kelp extract, 500 ml humic acid and 500 ml molasses was needed.

Methods 1.7 - Testing of Water

Aquarium water was monitored to determine temperature, EC, pH, NH_3/NH_4, nitrite, and nitrate levels. Testing as performed before and after vermicompost tea was added to test tanks to monitor overall water quality and aquaponic system performance. Water quality was also gathered for controls at the same time. NH_3/NH_4, nitrite, and nitrate where determined by using API fresh water master test kit. pH is determined using a Eutech Ecotestr pH1 digital meter and EC is determined with HM COM-100 digital meter.

Methods 1.8 - Statistical Analysis

At the end of the experiment the romaine lettuce plant quality was measured. This includes stalk length, number of leaves (both healthy and unhealthy leaves) and dry weight. Dry weights were measured by drying the plants in an oven at 140 degrees Fahrenheit for 24 hours following methods from (U.S. EPA,1994). Once dried, the plant weights were recorded. Each aquaponic system had the goldfish removed and placed in individual five-gallon bucket with aeration stone and the goldfish were re-weighed and recorded for each individual aquaponic system. The experiment was run as a 3x6 paired T-test with three treatment levels and six replications.

Results

Upon completion of the five-week experiment data concerning plant and fish health were compiled. Raw data are available in appendix 1. Data collected for plant health were separated into three categories with the first being good/bad leaf count (Figure 5, Figure 6) and the second category being stalk length (Figure 7). Dry weight of the plant was the final category for plant health (Figure 8). Statistical analysis of plant health was calculated and p-Values were determined.

The only significant change between the control and test tanks was plant stalk length ($p<0.05$), which were longer in controls than in treatments (Figure 7). All other aspects of plant health did not differ between treatment and controls ($p>0.05$).

The difference in fish weight gain was taken from beginning fish weights and ending fish weights and a p-Value was calculated for the difference in weight gain. Overall, there was significant fish weight gain between control and treatment groups shown ($p<0.05$, Figure 4).

Discussion

The 17% increase in fish weight between and treatments and controls reflects the influence of vermicompost tea on fish conversion rations and fish health. In contrast, there were no significant difference in plant health between treatment and controls. The increase in fish weights has significant impact for food production, especially in the field of aquaponics. Increased fish weights in aquaponics translates to more profit for the farmer. If the addition of vermicompost tea, which is relatively inexpensive and easy to make, can increase fish conversion ratios by 10% then that is profit that the aquaponic farmer did not have before. This also leads to a benefit for the consumer. The consumer receives a larger fish than they would have had if there had been no additions of vermicompost tea. Overall, the farmer receives more profit and consumer spends less money; however, further testing is needed to understand the significance of the weight gain of fish. This test was run using the common goldfish and may respond differently to vermicompost tea than other fish. It would be more beneficial to run this test using fish such as tilapia and bass. These fish are food production fish and would probably have a higher conversion ratio because they are raised to have more meat on them. Longer studies are also needed to determine whether fish increase in size indefinitely with additions of vermicompost tea or if they only grow in size during certain stages. These questions and others will require further testing to resolve, however this experiment showed that there was a significant increase of fish weights from additions of vermicompost tea.

There was a significant difference between stalk lengths between control and treatment tanks, however the significance was attributed to the control tanks. Addition of vermicompost tea to test tanks did not increase plant stalk length. There is even the possibility that the addition of vermicompost tea suppressed plant stalk length, however more testing would need to be done to determine this.

Conclusion

Aquaponic systems are simple systems that are less diverse and generally have fewer issues as compared to a natural system that regulates internally. By adding another aspect to aquaponics, such as additions of vermicompost tea that mimics natural inputs of organic materials, nutrients, bacteria and other organisms, the system becomes more diverse. Aquaponic systems are limited in there inputs which in turn limits the growth of the fish and plants. Although aquaponics is already used in agriculture to produce food in a more sustainable way, there are aspects that cost money and require specific knowledge. However, aquaponic systems are a great resource for meeting the food consumption needs of the rising human population. By adding vermicompost tea to the system, the hypothesis that plant and fish health would be increased thus supplying a better food source, was found to be partly true with increased weight of fish in treatment tanks and no significant increase in plant health in treatment tanks. More research is required to fully understand all that is happening within these aquaponic systems. By making a simple system even more like a natural system, food that is being produced for human consumption can be produced with better results with minimal costs to those running the aquaponic systems.

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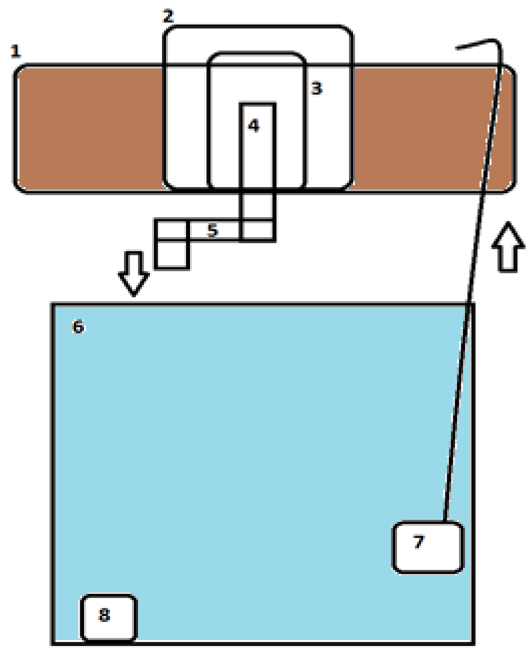
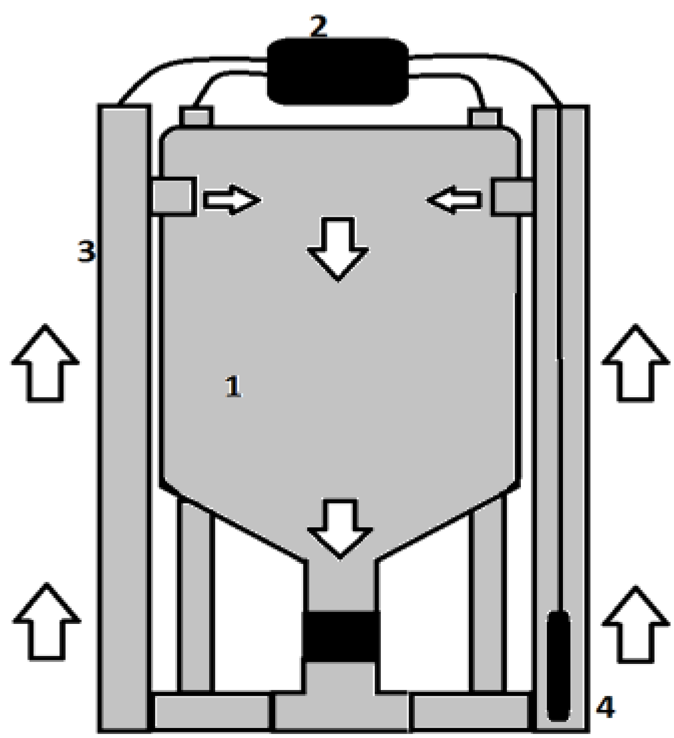
Figure 1: Aquaponic System Diagram



1. 34.1 L meson tray
   63.5cm(L) X 45.72cm(W) X 15.24cm(H)
2. Perforated 20.32cm tall, 10.16cm pvc gravel guard
3. 15.24cm tall, 5.08cm pvc gravel guard
4. 10.16cm tall, 19.05mm diameter pvc standpipe
5. 19.05mm diameter pvc drainpipe
6. 56.78L aquarium (filled with 37.85L)
7. Total Pond 70-GPH Fountain Pump (Model # MD11060) with 12.7mm black irrigation line
8. 31.75mm x 50.8mm air stone connected with 6.35mm line

Figure 2: Vermicompost Tea Brewer



1. 6-gallon plastic carboy
2. 45 liter/minute air pump
3. (4) 1 inch pvc airlifts
4. (4) air stones inside each airlift
5. (2) Sock teabags are placed inside suspending from the carboy wall.

Table 1: Somerville, et. al 2014 (FAO Fisheries and Aquaculture Technical Paper No. 589 Small-scale aquaponic food production Integrated fish and plant farming.)

Ideal parameters for aquaponics as a compromise between all three organisms

	Temp (°C)	pH	Ammonia (mg/litre)	Nitrite (mg/litre)	Nitrate (mg/litre)	DO (mg/litre)
Aquaponics	18–30	6–7	< 1	< 1	5–150	> 5

Figure 3: Plant placement

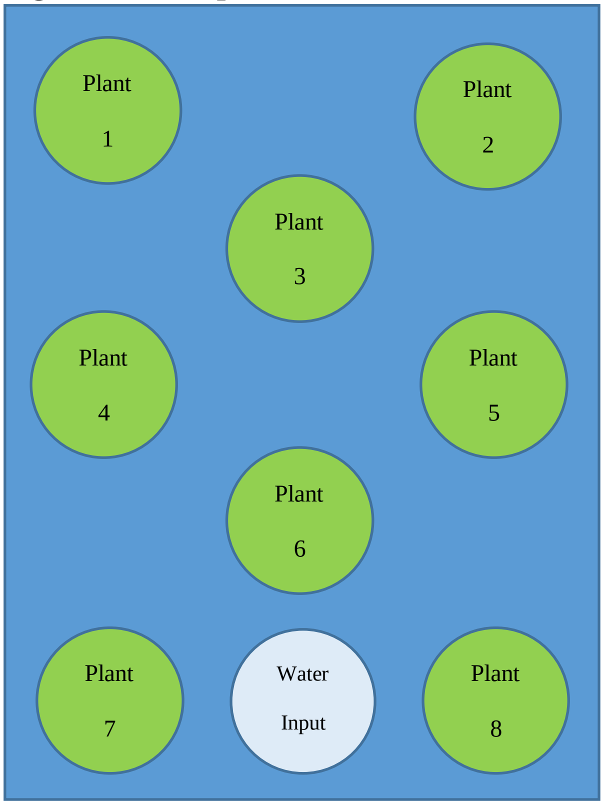


Figure 4: System Final Fish Weight Gains

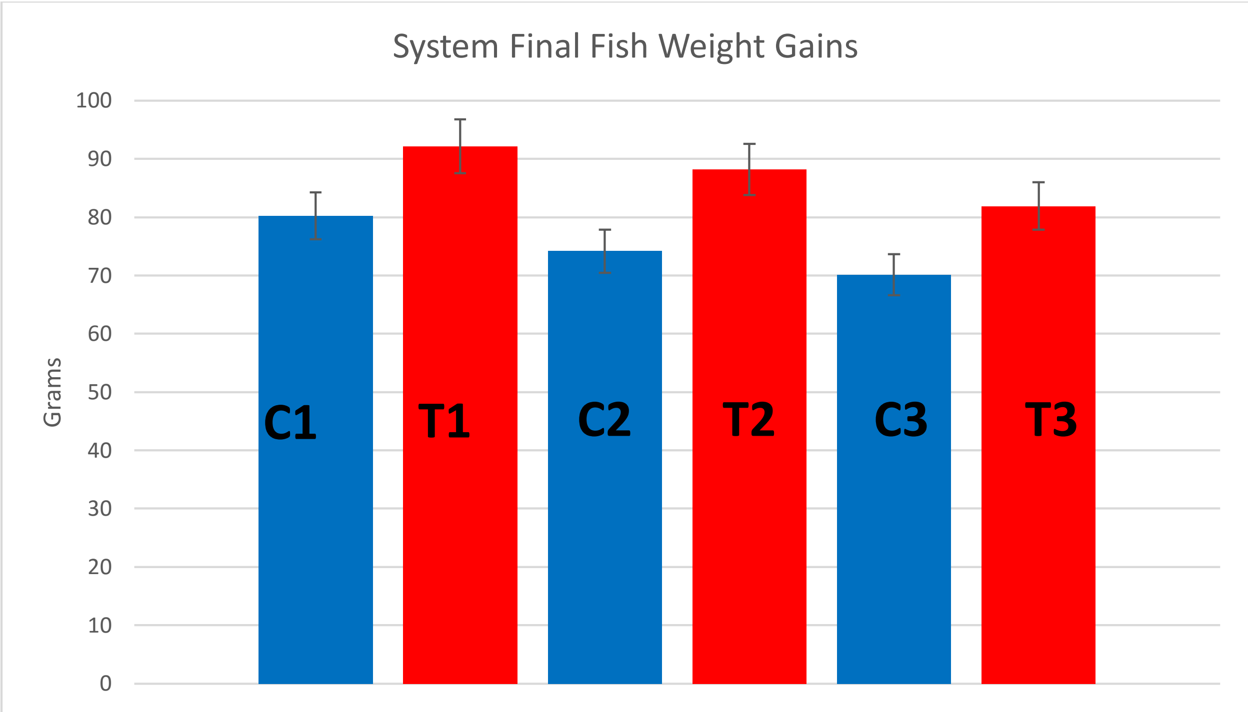


Figure 5: Average Number of Good Quality Leaves

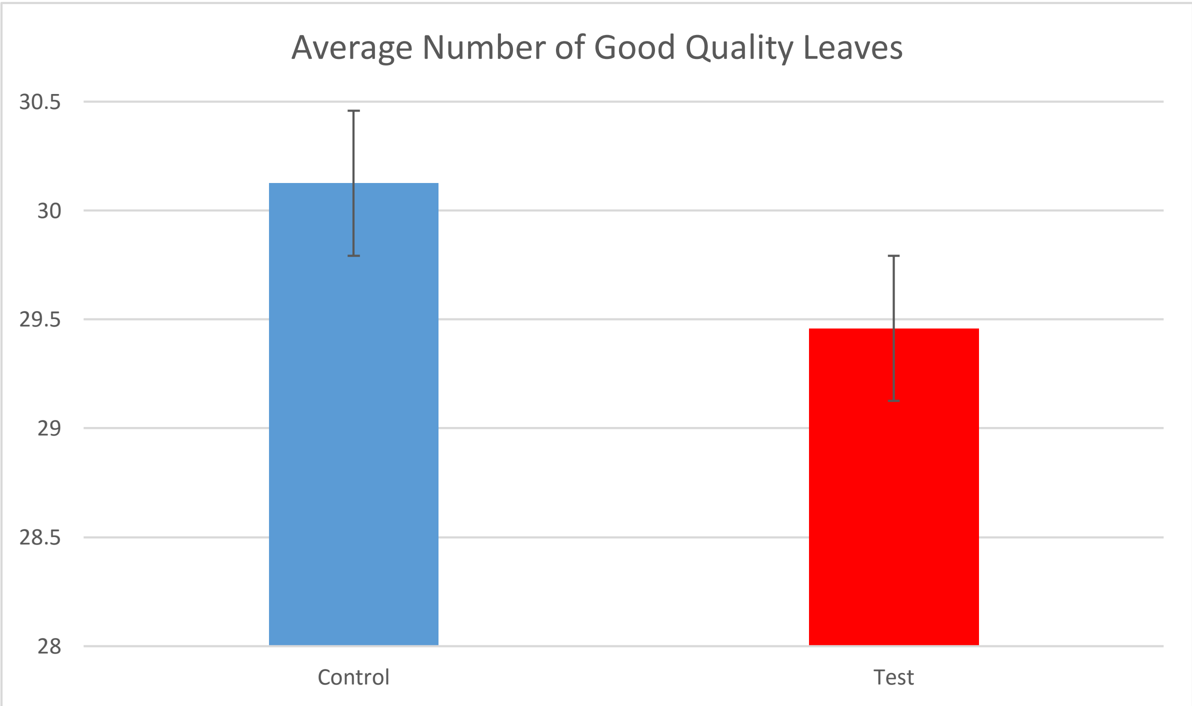


Figure 6: Average Number of Bad Quality Leaves

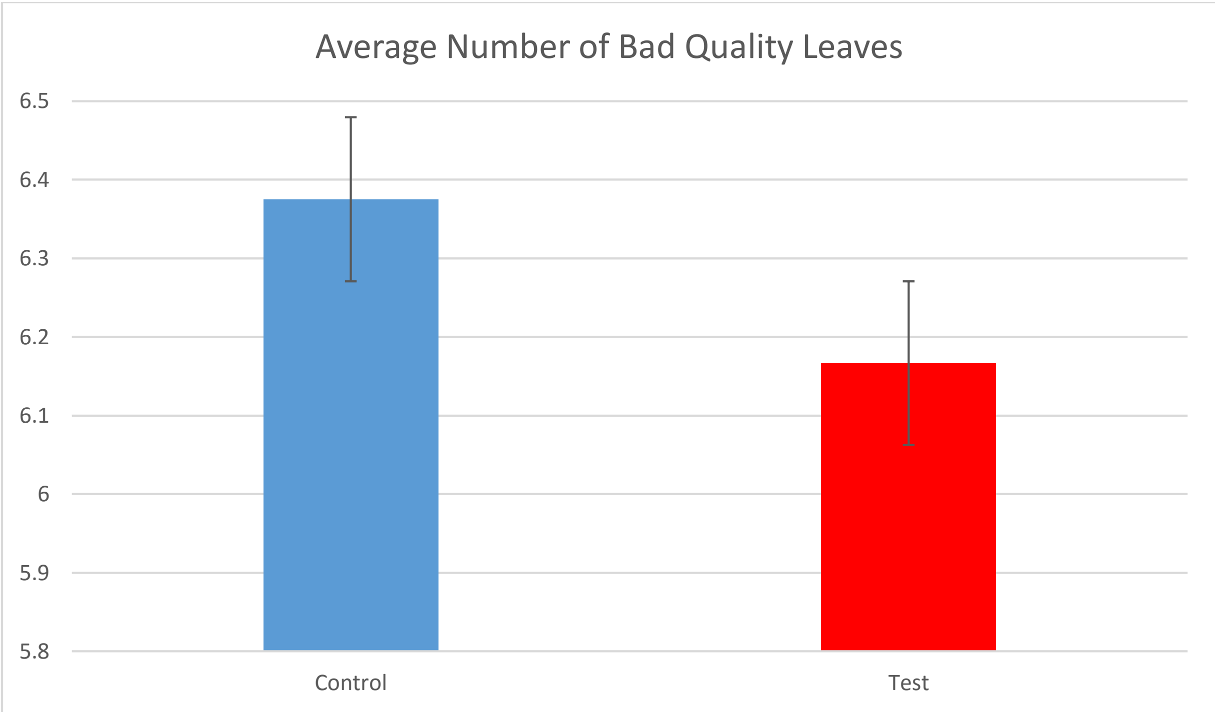
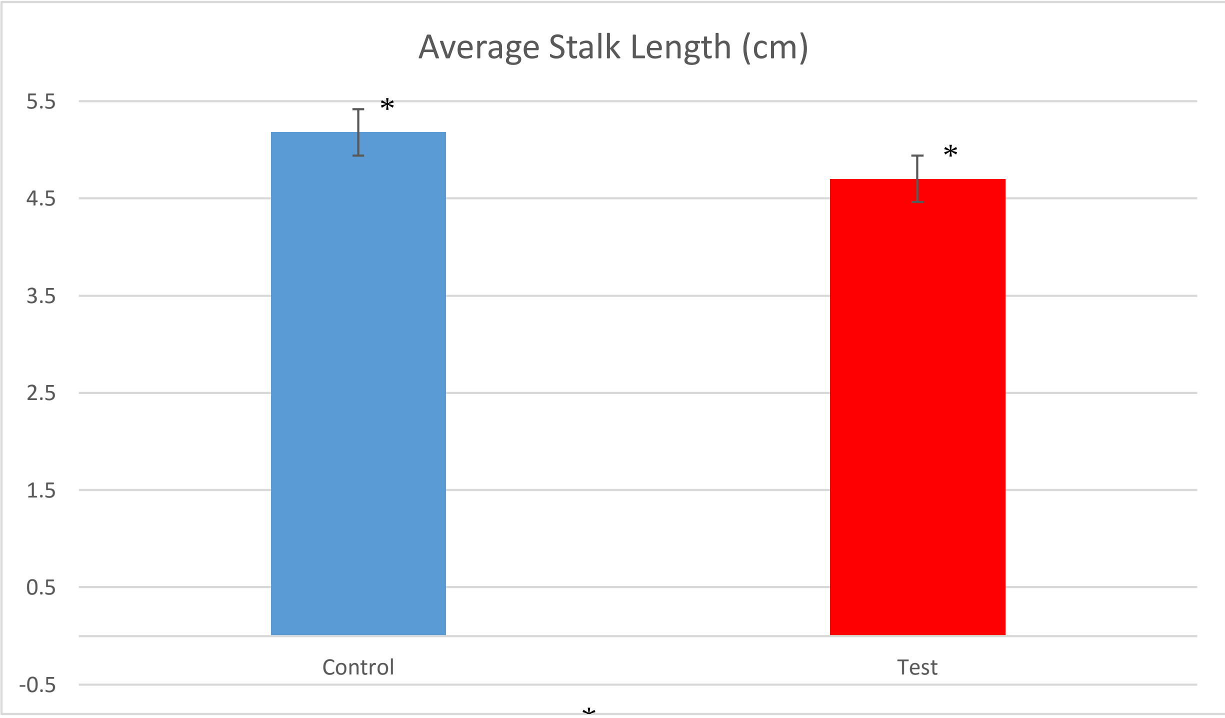
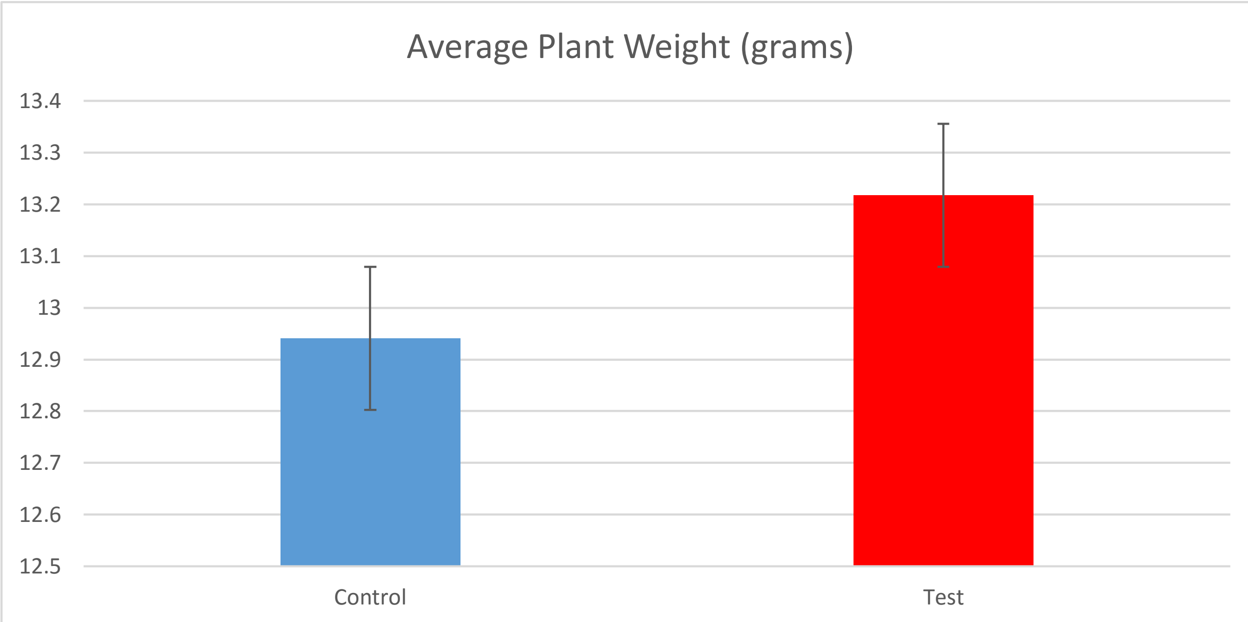


Figure 7: Average Stalk Length (cm)



*= p<0.02

Figure 8: Average Plant Weight (grams)



Appendix 1

Table 2: Beginning Fish Weights (grams)						
Tank	1	2	3	4	5	6
Fish #						
1	10.91	9.96	12.91	7.98	10.67	20.33
2	7.19	14.61	14.39	16.81	7.83	13.72
3	15.31	15.31	8.22	25.38	12.09	10.56
4	16.93	10.22	11.23	21.41	10.03	7.75
5	6.67	12.37	9.74	13.03	15.27	8.29
6	17.51	15.61	16.54	25.09	6.02	16.56
7	15.96	34.5	17.61	16.42	16.74	21.68
8	25.1	14.72	16.66	10.4	15.93	8.04
9	8.1	13.25	11.44	13.2	12.2	20.39
10	10.62	21.57	12.56	16.34	13.12	15.48
11	13.87	16.28	14.98	9.75	24.25	14.02
12	15.86	8.95	7.2	15.9	10.33	16.77
13	11.64		15.06		11.83	
14	9.59		19.18		12.56	
Total Tank Weight	185.26	187.35	187.72	191.71	178.87	173.59

Table 3: End Fish Weights (grams)						
Tank	1	2	3	4	5	6
Fish #						
1	7.37	15.39	29.15	24.35	16.79	23.71
2	12.79	55.78	14.86	21.4	30.77	25.2
3	9.83	17.4	22.2	24.47	10.35	24.31
4	19.12	24.15	12.19	19.45	13.39	31.36
5	25.53	23.21	27.04	28.64	22.65	30.73
6	24.16	24.5	20.27	36.75	24.62	37.59
7	46.44	28.9	9.89	10.95	22.83	24.37
8	21.41	23.7	20.26	15.24	16.27	18.66
9	25.56	18.6	16.64	35.02	14.69	19.86
10	15.77	12.82	14.73	11.48	15.08	10.02
11	14.98	22.56	19.5	33.56	16.35	9.72
12	13.42	12.47	24.83	18.55	9.32	
13	14.26		19.02		13.85	
14	14.87		11.36		4.56	
					17.49	
Total Tank Weight	265.5	279.5	261.9	279.9	249	255.5

Table 4: Plant Data for p-Value Calculations							
Good Leaf Quality		Bad Leaf Quality		Stalk Length (cm)		Plant Weight (g)	
Control	Test	Control	Test	Control	Test	Control	Test
16	21	6	4	3.8	1.9	5.6	7.8
27	31	4	5	4.7	4.5	15.89	14.12
14	16	4	3	5.9	6.1	6.44	5.49
41	47	4	4	5.4	5.4	15.06	29.51
41	27	5	6	5.3	4.3	23.39	7.88
33	30	5	4	5.8	4.7	17.28	12.34
30	33	1	5	4.1	5	9.79	13.54
33	30	5	3	5.5	4.6	17.01	12.36
23	24	5	4	5.1	4.4	9.01	9.92
33	30	4	5	5.5	4.7	10.95	13.77
26	20	3	2	5.2	3.4	10.36	6.75
35	40	3	2	4.3	4.7	13.91	15.03
41	35	21	11	7.3	5.5	27.64	22.16
43	38	5	8	6.7	6.3	15.82	18.67
22	26	4	6	4.2	5.1	7.66	12.29
27	29	5	3	7.1	3.5	10.83	11.58
19	20	9	3	4.2	4.4	4.61	7.66
33	34	3	3	4.2	4.9	11.42	12.43
24	21	3	3	4.1	3.9	11.23	6.34
40	42	12	17	5.8	6.1	18.15	22.64
31	32	17	22	5.4	5.3	14.03	18.74
35	26	19	18	5.4	6	17.68	20.36
26	28	2	3	4.4	3.3	6.98	8.06
30	27	4	4	4.9	4.8	9.84	7.79
p-Value	0.26	p-Value	0.38	p-Value	0.019	p-Value	0.40
Mean 30.13	Mean 29.46	Mean 6.38	Mean 6.17	Mean 5.18	Mean 4.70	Mean 12.94	Mean 13.22
SD 8.05	SD 7.50	SD 5.37	SD 5.39	SD 0.95	SD 1.02	SD 5.59	SD 6.12

Table 5: Fish Weight Gain p-Value Calculations			
Control	Weight Gain	Treatment	Weight Gain
Tank 1	80.25	Tank 2	92.13
Tank 3	74.22	Tank 4	88.15
Tank 5	70.14	Tank 6	81.94
	p-Value	0.0015	