Utilizing Food Waste to lower the pH of Allegheny College's Pilot Recirculating Aquaponic System



By
Erin Cavagnaro
Department of Environmental Science
Allegheny College
Meadville, Pennsylvania

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Dr. Thomas Eatmon	**Date**	***Dr. Eric Pallant***	**Date**

Erin Cavagnaro
Pledge

Name: Erin Cavagnaro Date: Spring, 2012
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Thesis Committee: Dr. Thomas Eatmon, Dr. Eric Pallant

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Aquaponics serves as a model of sustainable food production as it doesn't require the use of added fertilizers, conserves water through biological filtration and recirculation, and yields multiple products. Commercially aquaponics is still in its infancy and has yet to demonstrate significant levels of success, particularly in cold weather climates. In the near future Allegheny College plans to offer courses in agriculture in which the products grown will be sold to Parkhurst, the school's dining service. During the winter months, the courses will utilize an aquaponic system as a means of food production. The water used for Allegheny's pilot aquaponic system has a pH of 8.4, making it relatively difficult to grow and sustain plant life as a pH of 7.0 is ideal for plants and fish to thrive in aquaponic systems. Utilizing an experimental research design, orange peel waste was taken from the school's dining hall and added to the system in order to determine if acidic food waste can serve as a low-cost, organic means of pH reduction in aquaponic systems. The first trial revealed that the system's high alkalinity made it difficult to lower the water's pH. Although the experimental system's pH was lowered to 7.6 (compared to the control's pH of 8.4), plant growth in both the experimental and control systems was severely stunted. In a second trial the concentration of orange peel waste was increased, however the desired pH of 7.0 was not reached and plant growth remained inhibited.

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Introduction

Nearly all of the pre-settlement forest, prairie and wetland areas in the United States have been converted to or affected to some extent by agricultural production. Today, over half of the nation's land is in crops, pasture and range (USGS, 2007). Technological advances in farming methods over the past 60 years have dramatically changed the face of agriculture. Small family-owned farms that once produced the majority of the nation's agricultural products have been replaced by large agribusinesses. Support of this intensified agriculture has required larger fields, a reduction in the types and rotations of crops, and a strong reliance on chemical fertilizers to maintain high productivity (USGS, 2007). Substantial environmental and social issues are associated with this type of agricultural production, which include biodiversity loss, erosion, nutrient depletion, and pollution associated with agricultural run-off (Schahczenski & Hill, 2009). By adopting more sustainable farming practices such as conservation tillage, land restoration, land use change, irrigation and water management, and organic production, farmers can begin to alleviate the negative environmental impacts associated with today's agricultural production (Schahczenski & Hill, 2009).

Aquaponics, the integration of hydroponics and aquaculture, serves as a model of sustainable food production. The waste products of one biological system, fish, serve as nutrients for a second biological system, plants, and eliminate the need for nitrogen-based fertilizers (Diver, 2006). Aquaponics is the ideal answer to a fish farmer's problem of disposing of nutrient rich wastewater, and to a hydroponic grower's need for nutrient rich water (Diver, 2006). The integration of fish and plants results in a polyculture that increases biodiversity and yields multiple products (Diver, 2006). The product yield per unit area is larger in aquaponic systems than in traditional agriculture as both plants and fish are produced simultaneously. In addition, water is conserved through biological filtration and recirculation. Aquaponic systems don't require the use of soil or artificial fertilizers and therefore don't involve immense land use which typically leads to erosion and biodiversity loss. Commercially, aquaponics is still in its infancy and has yet to demonstrate significant levels of success, particularly in cold weather climates.

In the near future, Allegheny College's Environmental Science department plans to offer two courses in agriculture in which the products grown will be sold to Parkhust, the school's dining service. During the winter months, the courses will utilize aquaponics as a means of food

production. Allegheny's aquaponic system will therefore serve as a model of a commercial aquaponic system operating in a temperate climate. An issue that is of concern to Allegheny is that currently water used in a pilot aquaponic system has a pH of 8.4, making it relatively difficult to grow and sustain plant life. A pH of 7.0 is ideal for plants and fish to thrive in aquaponic systems. My research aims to address this concern by utilizing acidic food waste to lower the pH of a recirculating aquaponic system in an organic way. The waste was taken from Brooks dining hall so that it wouldn't add to the cost of operating the system and would help to make the production and consumption of food at Allegheny a more closed-loop process. I utilized an experimental research design in order to determine if food waste can effectively lower the pH of a commercial aquaponic system at Allegheny College and consequently improve plant and fish growth.

Literature Review

System Design

In order for aquaponics to be commercially profitable, the optimal fish and plant species must be chosen by the grower. Several warm-water and cold-water fish species are known to adapt to recirculating aquaculture systems including trout, perch, arctic char, bass and tilapia (Diver, 2006). Most commercial aquaponic systems in North America have had the best results with tilapia because this species is tolerant of fluctuating water conditions (such as pH, temperature, oxygen and dissolved solids) and is suitable to local and wholesale markets (Diver, 2006). Tilapia is also a freshwater species that can tolerate crowding (Rakocy et al., 2006). Plants such as lettuce, herbs, specialty greens (spinach, basil and watercress), tomatoes, bell peppers and cucumbers have lower to medium nutritional demands and also adapt well to aquaponic systems (Diver, 2006; Rakocy et al., 2006).

Biofiltration, the process of oxidizing ammonia into nitrate, is important in an aquaponic system because it fixes nitrogen into a form that can be utilized by plants (Hiebert, 2011). Biofilters contain media with large surface areas that allow for the growth of nitrifying bacteria which convert the system's ammonia into nitrate (Hiebert, 2011). Aquaponic systems are generally designed to meet the size requirements for solids removal and biofiltration for the quantity of fish being raised. The key is the ratio of daily feed input to plant growing area. A general guide for raft aquaponics (a system design in which plants are grown in rafts that float on

top of the water) is that a ratio in the range of 60 to 100g of fish feed/m^2 of plant growing area per day should be used (Rakocy et al., 2006). Ratios in this range have been used successfully in the University of the Virgin Islands system for the production of tilapia, lettuce, basil and several other plants (Rakocy et al., 2006). In addition, fish-to-plant ratios are an aspect of the system that can significantly impact its yields. Al-Hafedh et al. (2008) operated an indoor aquaponic system for 13 months and varied fish feed, plant densities, and surface ratios. The team explored optimal ratios that yielded the best quality plants. It was determined that a fish-to-hydroponic-surface ratio of 56g/m^2 was best, and that for the production of marketable lettuce a plant density of 25-30 plants/m^2 was optimal (Al-Hafedh et al., 2008).

Savidov et al. (2005) tested the commercial feasibility of an aquaponic system by growing tilapia in Alberta, Canada during a two year study. The team tested 12 crops (five greenhouse vegetables and seven herbs) for production yields throughout the study. Yields of tomatoes and mini cucumbers reached 20.7kg $plant^{-1}$ $year^{-1}$ and 33.kg $plant^{-1}$ $year^{-1}$ and exceeded average values of commercial greenhouses in Alberta that used conventional hydroponic technology. During the study, the yield of Genovese basil in the aquaponic systems increased from 13kg m^{-2} $year^{-1}$ to 24 kg m^{-2} $year^{-1}$ as production and harvesting methods were refined. Savidov et al. (2005) clearly demonstrated the technical feasibility of aquaponic technology. When operating a successful aquaponic system, it is important to keep food input relatively constant, ensure good aeration, ensure adequate biofiltration, remove excess solids, control the water's pH, and supplement with calcium, potassium and iron (Rakocy, 2007).

pH & Water Quality

The concentration of hydrogen ions in a solution, or pH, is often referred to as the "master variable" because it controls many other water quality variables, especially the process of nitrification. Nitrification is the aerobic conversion of ammonia into nitrates by bacteria and is one of the most important functions in an aquaponics system because it reduces the toxicity of the water for the fish and allows the resulting nitrate compounds to be taken up by the plants for nourishment (Rakocy et al., 2006). Nitrification is more efficient at pH 7.5 or higher and practically ceases at pH values less than 6.0 (Rakocy, 2007). Since nitrification is an acid producing process that continually decreases pH, an aquaponic system's pH must be measured

daily and typically a base (calcium hydroxide and potassium hydroxide) must be added to neutralize the acid (Rakocy, 2007).

In addition to nitrification, pH also affects nutrient solubility, the ability of nutrients to dissolve in water so they may be taken up by plants. If pH is too high nutrients precipitate out of solution, causing plants to display nutrient deficiencies and growth and production to decrease. If pH is too low, ammonia accumulates to levels that are toxic to fish and a different set of nutrients precipitate out of solution with similar damaging effects on plant growth and production (Rakocy, 2007). Optimal pH for hydroponic plant growth ranges from 5.5 to 6.5 (Islam et al., 1980). Because the pH of a solution affects the solubility of nutrients, especially trace metals, essential nutrients such as iron, manganese, copper, zinc and boron are less available to plants at pH higher than 7.0, while the solubility of phosphorus, calcium and magnesium drastically decreases at pH lower than 6.0 (Rakocy et al., 2006). Generally, tilapia can survive in pH ranging from 5.0 to 10.0, but do best when the pH is between 6.0 and 9.0 (Popma & Masser, 1999). A balance must therefore be found between the optimal pH for nitrification, nutrient solubility, plants and the pH required to sustain healthy fish. Scientific studies show that a pH of 7.0 is the ideal compromise for both plant and fish production in aquaponic systems (Diver, 2006; Nelson, 2009; Rakocy, 2007; Rakocy et al., 2006; Savidov et al., 2005).

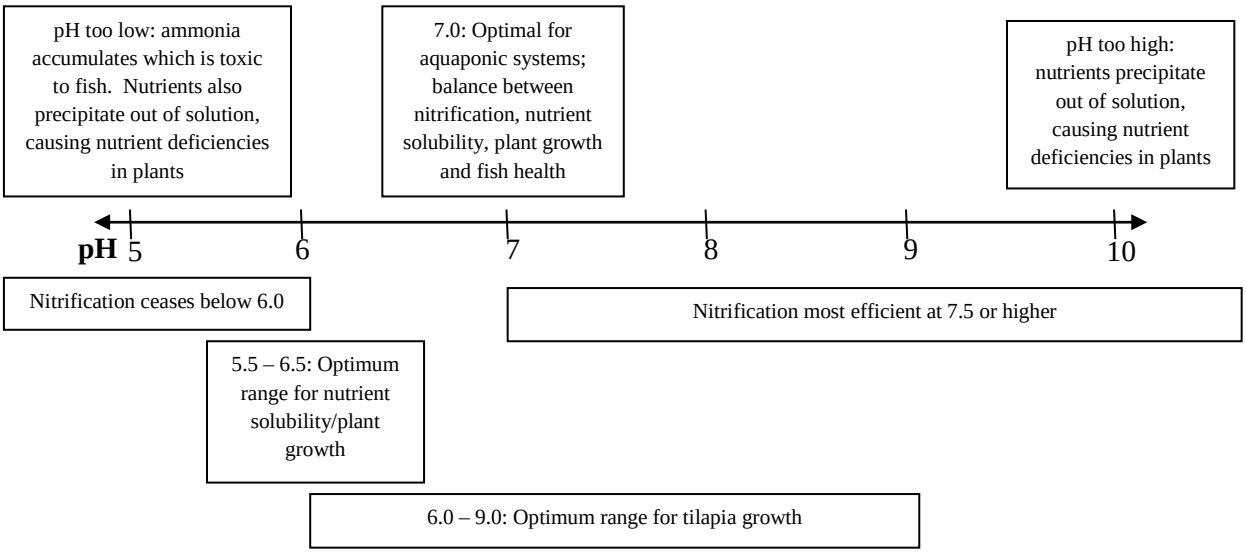


Figure 1. Effect of pH on aquaponic system components.

In order to determine nitrification activity response to pH between 5.5 and 8.5, Tyson et al. (2004) conducted a study using recirculating trickling biofilters containing perlite medium. The team found that total ammonia nitrogen concentration decreased from 5 to 0 mg L^{-1} in 12 (pH 8.5), 20 (pH 7.5) and 20-24 (pH 6.5) days after the introduction of nitrifying bacteria to the perlite biofilters. Nitrite became measureable in the biofilter water at 8 (pH 8.5), 16 (pH 7.5) and 20-24 (pH 6.5) days after the introduction of nitrifying bacteria. In addition, no nitrification occurred in the biofilters maintained at a pH of 5.5. These results indicate that ammonia conversion to nitrate was significantly faster at pH 8.5 than at pH 7.5 and 6.5, and that the reconciling pH for aquaponics would likely be between 6.5 and 7.0 to optimize the production of the fish and plant cash crops. In a later study, Tyson et al. (2007) aimed to determine the nitrification rate response in a perlite trickling biofilter exposed to hydroponic nutrient solution, varying nitrate concentrations, and pH levels optimum for plants (6.5) and nitrification (8.5). No significant difference in nitrification rate was found when recirculating system water contained no nutrient solution versus a complete hydroponic nutrient solution. These results indicate that hydroponic plant nutrient supplementation to concentrations found in plant production systems don't significantly affect nitrification rate.

While the process of nitrification is the main cause of reduced pH in aquaponic systems, research has shown that pH increases in hydroponic systems can also occur because plant roots excrete alkaline compounds and there is no oxidative nitrification to counteract this process as there is in aquaponic systems (Rakocy, 2008). Another source of alkalinity is the process of denitrification in which nitrate ions, the final product of nitrification, are converted to nitrogen gas under anaerobic conditions, producing an alkaline compound in the process (Rakocy, 2008). Therefore, in aquaponic systems with a high pH, either the fish are playing such a minor role that the system is acting as a hydroponic system, or there are large accumulations of anaerobic sludge where denitrification is occurring. It is also important to check the pH of the water before beginning an aquaponic system to determine if your system is starting at a pH that is too far above or below the desired optimal level of 7.0 (Rakocy, 2008). Aquaponics expert Dr. Rakocy of the University of Virgin Islands recommends lowering the pH of a system by adding nitric acid, sulfuric acid, phosphoric acid, or hydrochloric acid at substantially diluted concentrations. He advocates first taking a water sample to determine the amount of dilute acid solution that

must be added in order to obtain the desired pH. The acid must be added to the system slowly so that fish and plants aren't shocked by a rapid change in pH (Nelson, 2009).

Additional Water Quality Components

Alkalinity is a measure of the buffering capacity of water, or the capacity of water to neutralize acids. It refers to the ability of water to resist change in pH. If water has sufficient buffering capacity, it can absorb and neutralize added acid without significantly changing the pH (Addy et al., 2004). Water with good buffering capacity contains compounds such as carbonates, bicarbonates, and hydroxides, which combine with H^+ ions from the water and consequently raise the water's pH (Addy et al., 2004). However water's buffering ability is limited; once the buffering capacity is used up pH changes more rapidly as acids are added (Viladomat & Jones, 2011). Buffering can have both beneficial and harmful effects in aquaponic systems. Nitrification produces nitrate (an acid) that without buffering would cause a system's pH to decrease over time (Viladomat & Jones, 2011). However if the water in the system had sufficient buffering, the system's pH would stay stable. In contrast, hard tap water often has a large buffering capacity (Viladomat & Jones, 2011). If the pH of the water is too high for the fish, the buffering capacity makes it difficult to lower the pH to a more desired value.

Dissolved oxygen (DO) can significantly impact nitrification since the process can only occur under aerobic conditions at DO levels of 1.0 mg/L or more (Rakocy et al., 2006). Maintaining high DO levels is extremely important for optimal plant growth. If DO is deficient, root respiration decreases which reduces water absorption, decreases nutrient uptake, and causes a loss of cell tissue from roots, resulting in reduced plant growth (Rakocy et al., 2006). Low DO levels also correspond with high concentrations of carbon dioxide, a condition that promotes the development of plant root pathogens (Rakocy et al., 2006). Therefore root respiration, root growth and transpiration are greatest at saturated DO levels. The University of Virgin Island's commercial-scale aquaponic system maintains DO levels near 6 to 7 mg/L (80%) saturation using an aeration system in order to sustain optimal DO for nitrification and plant growth, in addition to fish health (Rakocy et al., 2006). When DO is low, in order to maintain the same oxygen supply to tissues, fish must allocate more energy to breathing which consequently increases their total energy expenditure (Kramer, 1987). If energy allocation to breathing is held

constant as oxygen availability continues to decline, the oxygen allocated to other processes must decline, resulting in changes to both breathing and other activity levels (Kramer, 1987).

Water temperature impacts the rate of nitrification, as the process reaches a maximum rate at temperatures between 30-35°C (86-95°F) and ceases to occur at temperatures of 40°C (104°F) and higher (Zhu & Chen, 2002). At temperatures below 20°C (68°F) nitrification proceeds at a slower rate, and stops at temperatures below 10°C (50°F) (Zhu & Chen, 2002). Water temperature regulates DO concentrations within an aquaponic system. Cold water has a higher capacity for DO than warm water because at lower temperatures the gas molecules are moving slower and are more compact, while at higher temperatures DO and other gases in the water move faster and spread farther (Rakocy et al., 2006). In addition, at warmer temperatures the metabolic rates of fish increase, resulting in a greater consumption of DO from the water (Rakocy et al., 2006). Water temperature also plays an important role in aquaponic plant production. The ideal water temperature for most hydroponic crops is about 24°C (75°F), however most crops will grow sufficiently in water temperatures as low as 18°C (65°F) (Rakocy et al., 2006). The recommended water temperature for maintaining healthy tilapia is 28-30°C (82-86°F) (Baras et al., 2000). Tilapia growth rate will decrease dramatically in water colder than 20°C (68°F), while the fish will start to die in temperatures around 10°C (50°F) (Baras et al., 2000).

Dissolved nutrients in the system are measured collectively as total dissolved solids (TDS), which are inferred from conductivity. Conductivity is a measure of the ability of water to conduct an electrical current, and increases with the concentration of ions in water (Kimmel & Argent, 2009). In an aquaponic system, levels of TDS ranging from 200 to 400 ppm are sufficient because nutrients are being continuously generated but typically aren't accumulating (Rakocy et al., 2006). If dissolved nutrients build up too rapidly they can approach phytotoxic levels and poison the plants. Phytotoxicity occurs at TDS concentrations above 2,000 ppm (Rakocy et al., 2006). Aquaponic systems have variable environmental conditions such as daily feed input, solids retention, mineralization, water exchange, nutrient input from source water or supplementation, and variable nutrient uptake by different plant species, making it very difficult to predict each system's optimal level of TDS or conductivity (Rakocy et al., 2006). Ions that typically increase conductivity are nitrate (NO_3^-), phosphate (PO_4^-), sulfate (SO_4^{-2}), potassium (K^+), calcium (Ca^{+2}), and magnesium (Mg^{+2}) (Diver, 2006). Total dissolved solids play an

importation role in osmotic regulation; the relationship of water to dissolved solids in an organism's cells and the external environment (Kimmel & Argent, 2009). If TDS levels are too high, they can be toxic to aquatic life. Toxicity of TDS to fish depends on the combinations and concentrations of the ions in solution, which may have additive or synergistic properties, and is not predictable from TDS concentrations alone (Kimmel & Argent, 2009).

Acidic Foods

Numerous foods are known to contain different acids that could potentially lower the pH of water in an aquaponic system. Citric acid ($C_6H_8O_7$) is an organic acid considered to have high water solubility, and occurs naturally in several varieties of berries and citrus fruits (Oxford, 2005; IFIC & USFDA, 2010). Berries containing high amounts of citric acid include strawberries, raspberries and cranberries, while lemons, limes and oranges make up the citrus fruits with the highest citrus acid levels (IFIC & USDA, 2010). Grapes and bananas contain high levels of organic tartaric acid ($C_4H_6O_6$) which is also known to be highly soluble in water (Malmary et al., 1992). Oxalic acid ($H_2C_2O_4$) is a relatively strong organic acid that is considered to be slightly soluble in water. Citric acid can be found in fruits such apples, pears and bananas, in addition to leafy green vegetables like spinach and Swiss chard. Soy beans and lentils also contain high amounts of oxalic acid. Phosphoric acid (H_3PO_4) is an inorganic, water-soluble acid that is a widely-used additive in the food industry. Phosphoric acid is typically added to soft drinks, baking powders and processed dairy products such as cheese and creamers (USFDA, 2010). Caffeic acid ($C_9H_8O_4$) is an organic acid that occurs naturally in all plants because it is a key intermediate in the biosynthesis of lignin (Kondamudi et al., 2008). Coffee contains high amounts of caffeic acid, and although much of the acid is removed during the brewing process, coffee grounds do still contain some caffeic acid as well (Kondamudi et al., 2008). Tannic acid ($C_{76}H_{52}O_{46}$) is a relatively weak organic acid found in black and green teas (Graham, 1992).

Acid Rain in Crawford County, Pennsylvania

Rainwater is another naturally available resource that could be used to lower the pH of water in an aquaponic system. Acidic precipitation is primarily the result of anthropogenic emissions from fossil fuel burning, automotive exhaust, agriculture, and other activities that

produce sulfur oxide (SOx) and nitrogen oxide (NOx) gases (US EPA, 2007). These pollutants enter the atmosphere, where they are chemically changed and returned to the earth as either wet deposition (rain, sleet, snow) or dry deposition attached to dust particles (US EPA, 2007). Pennsylvania receives rainfall with an average pH of approximately 4.2 (French Creek Watershed Conservation Plan, 2002). The average acidic precipitation in the French Creek Watershed of Crawford County is around 4.3 (French Creek Watershed Conservation Plan, 2002).

System Design

The recirculating raft system was constructed in Allegheny College's greenhouse located in Meadville, Pennsylvania (Figure 2). In a recirculating system, fish are held in rearing tanks with biofilters on which the process of nitrification occurs. Pumps then push the nitrate-rich water from the rearing tanks up to the grow trays where the plants remove the nutrients. Due to gravity, the water falls back down to rearing tanks where the process begins again. Raft systems consist of polystyrene floating sheets (or rafts) and netpots for plant support that float in the system's grow tray. Each grow tray in Allegheny's pilot system measured 85cm x 75cm x 15cm and held 25 gallons of water and 30 Romaine lettuce plants. Both 55 gallon rearing tanks were stocked with 25 tilapia fish purchased from Raup Fisheries in Norrisville, PA. Sun System 2" 400W metal halide lights were used as supplemental lighting on a 16-hour-light, 8-hour-dark cycle.

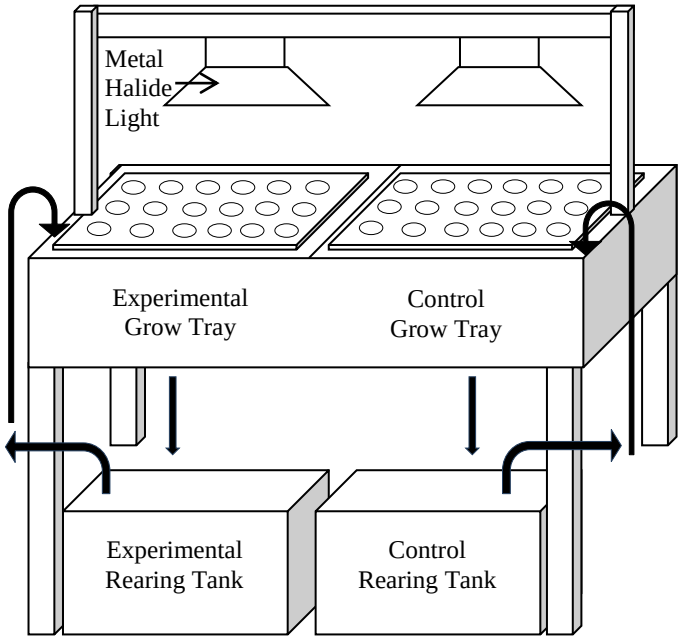


Figure 2. Allegheny's experimental recirculating raft system. Arrows indicate the flow of water through PVC piping.

Experiment 1 - Food waste and rainwater effect on water pH

Methods, Results and Discussion

The purpose of this experiment was to test locally available substances known to be acidic to determine if they effectively lower water pH and could potentially be utilized in Allegheny's aquaponic system. Water samples were collected from each of the experimental and control rearing tanks and a standard Gran titration was performed to measure alkalinity (Wetzel and Likens 1979). The titration revealed the alkalinity of the system's water to be 120 mg/L. Treated water typically has an alkalinity ranging from 100-150 mg/L, while untreated water's alkalinity usually ranges from 60-80 mg/L (Mechenrich & Andrews, 2004). A higher alkalinity is desirable in treated water because water with low alkalinity tends to be corrosive (Mechenrich & Andrews, 2004). Initial pH levels of both rearing tanks were measured using a handheld pH meter and were determined to be 8.2. Four 250mL Erlenmeyer flasks were filled with 200mL of water from the rearing tanks for each of the five foods (coffee grounds, orange peels, lemon peels, banana peels, and spinach) and rainwater. The effect of coffee grounds on the water was determined first by gradually increasing the amount of coffee grounds added to the flasks; 2.5g were added to flask 1, 5.0g to flask 2, 7.5g to flask 3, and 10.0g to flask 4. Using an Orion 410A+ tabletop pH meter, pH was recorded after one hour of the food being added and then again after 24 hours. This process was then repeated for orange peels, lemon peels, spinach, bananas and rainwater (Table 1). Coffee grounds, orange peels and lemon peels lowered the water pH a notable amount without having to add an impractical quantity of the food waste. Therefore these three foods were used in the second half of the experiment in order to test the food's reliability in lowering the water pH. A mass determined in the previous trial (7.5g for coffee grounds, 0.5g for orange peels, and 0.5g for lemon peels) was added to four flasks and pH was measured after one hour and then again after 24 hours (Table 2). Despite their success in lowering pH, coffee grounds were eventually rejected as a suitable food waste for Allegheny's system because they would have stained the equipment as well as detract from the system's aesthetic appeal. Orange and lemon peels remained viable options, but ultimately orange peels were selected as the ideal waste because they were readily available from Allegheny's dining hall, while lemon peels were not.

Table 1. *Food Waste and Rainwater Effect on Water pH*. Highlighted lines indicate the concentration that was used in the second portion of the experiment in order to test the food's reliability in lowering water pH. It is important to note that the concentration for rainwater is in mL/100mL.

Food Type	Concentration (g/100mL)	pH After 1 hour	pH After 24 hours	Reduction in pH (from 8.2)
Coffee	1.25	8.23	8.11	0.09
	2.50	8.15	7.27	0.93
	3.75	7.97	7.12	1.08
	5.00	7.75	7.07	1.13
Oranges	1.25	7.52	6.26	2.44
	2.50	7.14	5.71	2.49
	3.75	7.02	5.69	2.51
	5.00	6.91	5.63	2.57
Lemons	1.25	7.43	6.98	2.58
	2.50	7.09	5.60	2.60
	3.75	6.98	5.58	2.62
	5.00	6.90	5.58	2.62
Bananas	1.25	8.18	7.95	0.25
	2.50	8.18	7.91	0.29
	3.75	8.17	7.87	0.33
	5.00	8.16	7.82	0.38
Spinach	1.25	7.83	7.52	0.68
	2.50	7.80	7.50	0.7
	3.75	7.67	7.42	0.78
	5.00	7.66	7.41	0.79
Rainwater	5	8.19	8.01	0.19
	10	8.19	8.0	0.20
	15	8.19	8.0	0.20
	20	8.19	7.98	0.22

Table 2. *Food Waste Reliability in Lowering Water pH.*

Food Type	pH After 1 hour	pH After 24 hours	Difference (from 8.2)
Coffee (3.75 g/100mL)	7.57	7.22	0.98
	7.57	7.21	0.99
	7.65	7.26	0.94
	7.63	7.22	0.98
Average	7.61	7.23	0.97
Std. Dev.	0.04	0.02	0.02
Oranges (2.5 g/100mL)	7.75	6.81	1.39
	7.67	6.54	1.66
	7.67	6.64	1.56
	7.71	6.70	1.50
Average	7.70	6.67	1.53
Std. Dev.	0.04	0.11	0.11
Lemons (2.5 g/100mL)	7.66	6.61	1.59
	7.67	6.53	1.67
	7.65	6.52	1.68
	7.67	6.65	1.55
Average	7.66	6.58	1.62
Std. Dev.	0.01	0.06	0.06

Experiment 2 – Utilization of orange peel food waste

Methods

The purpose of this experiment was to determine if adding orange peels to the experimental system would lower the water pH and therefore cause better plant growth when compared to the control plants grown under unaltered conditions. Data collected in the first experiment was utilized to calculate the amount of orange peel food waste added to the system. On Wednesday November 20th 836g of orange peels were added to the growth tray of the experimental system. The food waste was put into two mid-sized Tupperware containers with holes in the lid so that the waste would remain contained but still able to come in contact with the water. Lettuce plants were left to mature in the system for four weeks while additional orange peels were added as needed throughout the trial. Water lost through evaporation and transpiration was replaced as needed. Buckets were filled with water and left for a minimum of 24 hours to allow for the evaporation of chlorine before being added to the rearing tanks. The water added to the experimental tank was lowered to 7.0 using orange peels before being added to the tank.

Lettuce preparation

Sixty rockwool cubes (30 for each system) were placed in a bucket of miracle grow solution to soak overnight. In addition, 120 Romaine lettuce seeds (60 per system) were placed in lukewarm water overnight and allowed to germinate. The next day the sprouted seeds were planted in the rockwool cubes using tweezers (2 seedlings per rockwool cube). The lettuce was allowed to mature for seven days while rockwool cubes were kept moist by pouring miracle grow solution over them daily. Once large enough to be placed in the system, the lettuce were put in netpots and set into the holes of the polystyrene rafts.

Water Quality Measurements

Initial readings of each system's nitrates, total dissolved solids (TDS), conductivity, dissolved oxygen (DO), temperature, pH and ammonia were recorded when the lettuce seedlings were first added to the system on November 16th. Air temperature and humidity were also recorded at this time. Water quality was monitored three days per week (Mondays, Wednesdays and Fridays) at approximately 11am (Appendix A). Nitrate readings were taken from each

rearing tank using a Cardy Twin Nitrate meter. Total dissolved solids levels were also taken in each rearing tank using a TDS meter. Conductivity and temperature were measured in each rearing tank with a YSI Model 85 Dissolved Oxygen and Conductivity meter. The YSI Dissolved Oxygen and Conductivity meter was also used to measure DO levels in each of the rearing tanks and grow trays. A handheld pH meter was used to record the pH in each rearing tank. Ammonia was measured at the rearing tanks using an ammonia test kit. The greenhouse's air temperature and humidity were recorded using a Taylor Indoor/Outdoor Thermometer-Hydrometer with Remote Sense.

Lettuce and Fish Mass

Both rafts containing lettuce plants were weighed three times per week (Mondays, Wednesdays and Fridays) using a hanging scale (Appendix B). Two chains were inserted into the rafts using hooks to allow the raft to hang from the scale and the mass to be read. An initial mass of the rafts containing only netpots and rockwool cubes was recorded so that it could be subtracted from the raft measurements and the lettuce mass could be determined. Fish mass was measured first at the start of the four week trial and then again at its conclusion to quantify growth (Appendix B). A bucket filled with water was hung from the scale. The scale was tared, fish were added to the bucket, and their mass recorded.

Results & Discussion

The orange peels added to the experimental system gradually lowered the water's pH to around 7.6 as compared to the control tank's pH of 8.4 (Figure 3). Orange peels were continually added to the experimental system in order to keep the pH down; however the desired pH of 7.0 was never reached. This is likely due to the water's high alkalinity. Due to its high buffering capacity, the water was likely able to neutralize much of the acid from the orange peels, causing the decrease in pH to be less than what was desired.

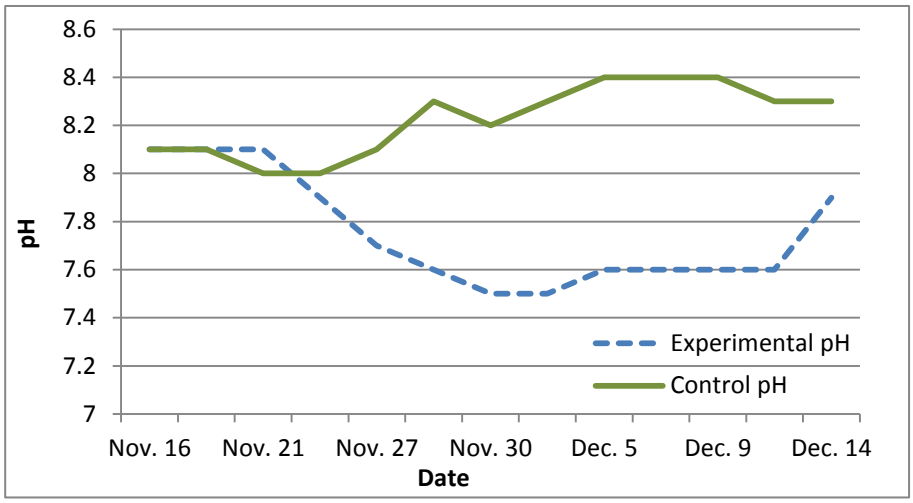


Figure 3. Experiment 2 pH over time.

Experimental and control plant growth were fairly close throughout the four week period. However in the last week the experimental plants did show more growth than the control plants; their mass was 0.96kg compared to the control's mass of 0.85kg (Figure 4). This increased growth in the last week could be due to the decrease in the experimental system's pH, as the lower pH wasn't actually achieved until mid-way through the trial period. Regardless, growth of both the experimental and control lettuce was substantially stunted when compared to an outdoor study conducted by Allegheny College that utilized a similar system design. Romaine lettuce plants in Allegheny's outdoor study reached full maturity in four weeks and appeared healthy. Experimental and control lettuce plants in this study both displayed yellowing of the leaves which can be indicative of nutrient deficiencies, specifically because of too little iron, magnesium, and/or nitrate (GreenCoast Hydroponics, 2006). Plant mass was quantified by measuring rafts and subtracting the empty raft mass due to convenience and the following of standard practice in commercial aquaponic systems. However, for statistical analysis, it would

be more beneficial to measure each lettuce plant individually so as to determine statistical significance between experimental and control plant growth. The fact that raft mass was measured rather than individual plant mass is not significant cause for concern in this experiment because neither the experimental nor control plants reached maturity within the four week period.

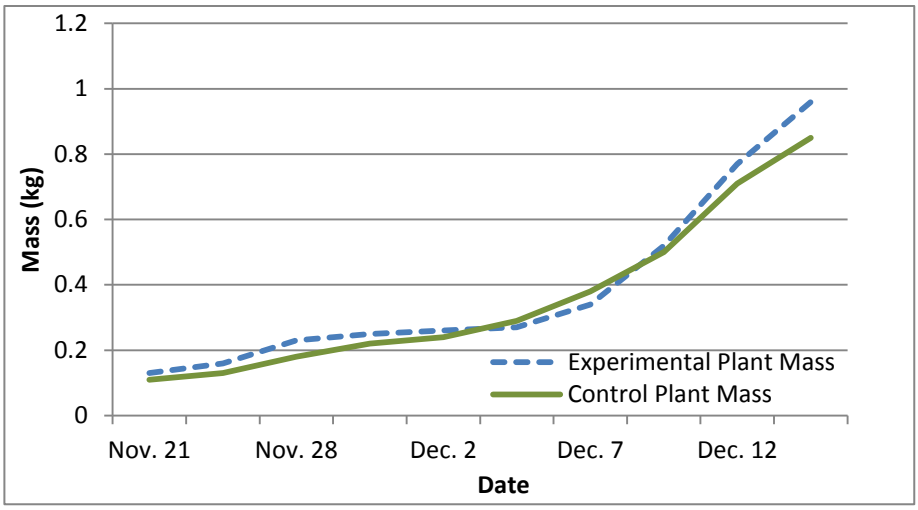


Figure 4. Experiment 2 plant growth over time.

Experiment 3 – Utilization of orange peel food waste and pH Down product

Methods

After collecting the results of experiment 2, which showed that the lettuce didn't grow as well as expected in either the experimental or control system, a third experiment was conducted in which the concentration of orange peels added to the experimental system was doubled from 836g to 1,672g (enough to fill four mid-sized Tupperware containers). In addition, instead of leaving the control system untouched, pH Down (a product used to lower the pH of aquariums) was used to achieve the desired pH of 7.0. The reasoning behind the addition of the pH Down product was to test whether a factor other than pH was stunting lettuce growth throughout the second experiment. If it was found that the lettuce in the control system still didn't grow as well as expected at a pH of 7, it could be concluded that a factor other than pH is impeding plant growth in Allegheny's aquaponic system.

The methods from experiment 2 involving lettuce preparation, water quality, and plant and fish mass were once again utilized in this experiment. On Wednesday February 15th the polystyrene rafts containing romaine lettuce seedlings were added to the systems. In addition,

1,672g of orange peels in Tupperware containers were added to the grow tray of the experimental system. One week prior to this date, the pH down product was gradually added to the control system (so as not to harm the fish) until a pH of 7.0 was achieved. The lettuce was again left to mature in the system for four weeks while additional orange peels and pH down were added as needed throughout the trial. Water lost through evaporation and transpiration was added after sitting for a minimum of 24 hours to allow for the evaporation of chlorine. The water added to both the experimental and control rearing tanks was lowered to 7.0, using orange peels and pH Down respectively, before being added to the tanks. Two tablespoons of chelated liquid iron were added once per week to both the experimental and control system grow trays to aid with the greening of leaves.

Results & Discussion

The increased concentration of orange peels added to the experimental system gradually lowered the water's pH to 7.5 (Figure 5). Although this is still higher than the desired pH of 7.0, the increased concentration appears to have kept the experimental system's pH more stable than in experiment 2 (Figure 3). The addition of pH Down to the control system eventually reduced the pH to 7.0 after extensive amounts of the product were used to overcome the water's strong buffer (Figure 5). However in the last few days of the trial, the pH did begin to climb back up to 7.1 (Figure 3), suggesting that the water's buffering capacity may have never been fully saturated. In other words, the buffering capacity of the water had not yet been overcome by the pH Down product.

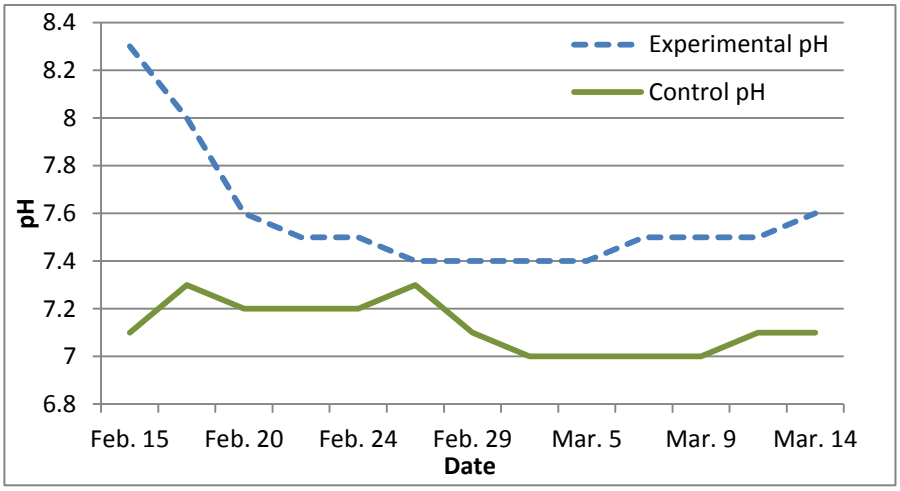


Figure 5. Experiment 3 pH over time.

Control plant growth was larger than experimental plant growth throughout the four week period, with the control plant growth reaching 2.09kg compared to the experimental plant growth of only 0.84kg (Figure 6).

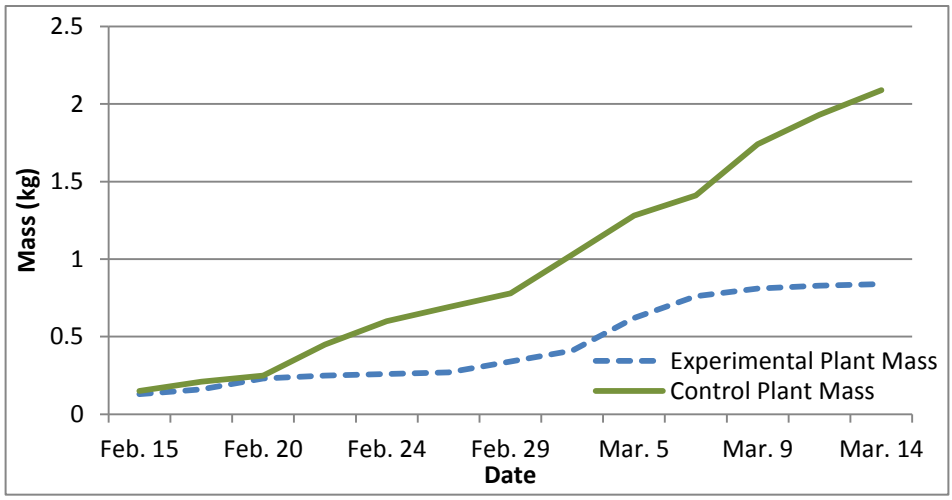


Figure 6. Experiment 3 plant growth over time.

Using a paired t-test, it was determined that the growth of the control plants was significantly larger than the growth of the experimental plants ($P < 0.01$; Table 3; Appendix E).

Table 3. *Statistical Analysis of Experimental and Control Plant Growth.*

	Experimental Plants	Control Plants
Average Mass (g)	59.8	103.8
Median Mass (g)	60.4	92.3
Std. Dev.	9.2	31.5
P-value	2.82E-08	

The experimental plants also displayed yellowing of the leaves, even with the addition of chelated liquid iron, while the control plants displayed healthy green leaves. It is likely that the higher pH made it difficult for the experimental plants to absorb the necessary nutrients, as a pH ranging from 5.5 to 6.5 is optimum for nutrient solubility and subsequently plant growth (Figure 1; Rakocy, 2007). If pH is too high nutrients precipitate out of solution, causing nutrient deficiencies in plants (Figure 1; Rakocy, 2007).

Despite the pH being held more consistently around 7.5, experimental plant growth was actually slightly lower in this experiment than in experiment 2 (0.84kg in experiment 3 versus 0.98 kg in experiment 2). Performing a paired t-test would show whether the growth of the

experimental plants in experiments 2 and 3 were statistically significant. However performing a paired t-test comparing experimental plant growth between the two experiments was not possible because only raft mass, and not the individual mass of each lettuce plant, was recorded during experiment 2. Still, this is not an issue of significant concern because neither of the experimental plants in experiments 2 and 3 reached maturity within the four week trial. Additionally, because both of the experimental plants in experiments 2 and 3 were grown at pHs around 7.5 and the growth of both plants were stunted, whether or not the growth of these two groups is statistically significant wouldn't be especially useful data.

Conclusion

The objective of this study was to determine if orange peel waste could be used to lower the pH of a recirculating aquaponic system in order to permit better plant growth. The stunted growth of both the experimental and control lettuce plants in experiment 2 suggested that the concentration of orange peels added to the experimental system wasn't enough to overcome the water's high alkalinity. The increased concentration of orange peels added to the experimental system in experiment 3 still wasn't enough to saturate the water's buffering capacity. However in experiment 3 there was a statistically significant difference between the mass of experimental plants grown at a pH of 7.5 and the control plants grown at a pH of 7.0 ($P < 0.01$; Table 3; Appendix E). This indicates that pH was the factor affecting plant growth throughout the two experiments, and it is therefore important that Allegheny takes measures to control it. While this study attempted to control the College's pilot system pH through the addition of acidic orange peel food waste, it can be concluded that the water's high buffering capacity makes the utilization of orange peel waste intended to lower system pH impractical. It is likely that if the concentration of orange peels were continually increased, one would eventually find a concentration that would successfully lower the system's pH to 7.0. However, the large amount of orange peels that would be required to lower the pH to 7.0 would likely occupy too large an area of the system, causing the grow trays to be completely filled with Tupperware containers, or possibly not even having enough space for all of the Tupperware containers to fit in the system. It is also likely that the amount of orange peel waste needed to achieve the desired pH would be greater than what the school would produce. Adding orange peel waste to Allegheny's aquaponic systems therefore isn't a practical solution for pH reduction. Other acidic food wastes

could be investigated to determine if they are viable, effecitve options. However because such a large amount of orange peels would be needed to reduce the system's pH to 7.0, and because it was extremely difficult to lower the water of the control system's pH with the pH Down product in experiment 3, it unlikely that other available food wastes would be practical for pH reduction.

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Appendix A: Experiment Two Water Quality Data

Experimental System Water Quality

Date	DO_{Tank} (mg/L)	DO_{Raft} (mg/L)	Water Temp. (°C)	Conductivity (µs)	TDS (ppm)	NO_3^- (ppm)	pH	Ammonia (ppm)	Air Temp. (°C)	Humidity (%)
Nov. 16	8.26	8.34	18.1	685	550	41	8.1	1	20.3	34
Nov. 18	8.02	8.32	18.5	621	620	34	8.1	1	18.8	30
Nov. 21	8.15	8.21	20	661	660	42	8.1	1	22.1	36
Nov. 23	7.91	7.99	20.2	668	650	40	7.9	1	21.3	38
Nov. 27	7.34	7.46	20.3	691	650	41	7.7	0.5	19.1	57
Nov. 28	4.66	2.58	20.1	646	670	35	7.6	0.5	20.1	55
Nov. 30	5.48	4.55	19.9	697	660	32	7.5	1	20.2	40
Dec. 2	7.32	7.46	19.4	694	630	41	7.5	0.5	20.9	38
Dec. 5	8.86	9.28	20.7	710	660	42	7.6	0.5	20.7	55
Dec. 7	8.56	8.55	19.7	700	640	75	7.6	0.5	21.1	39
Dec. 9	7.11	7.20	19.5	699	640	72	7.6		23.6	34
Dec. 12	8.32	8.1	18.7	651	650	51	7.6		23.3	26
Dec. 14	8.23	8.37	19.9	688	650	61	7.9		21.4	37

Experimental System Central Tendency and Acceptable Limits

	Mean	Minimum	Maximum	Accepted Range
DO_{Tank} (mg/L)	7.56	4.66	8.86	6 - 8
DO_{Raft} (mg/L)	7.42	2.58	9.28	6 - 8
NO_3^- (ppm)	47	32	75	20 - 300
TDS (ppm)	641	550	670	200 - 2000
Conductivity (µs)	678	621	710	varies by system
Ammonia (ppm)	0.8	0.5	1.0	0 - 1
Water Temp. (°C)	19.6	18.1	20.7	18 - 28

Control System Water Quality

Date	DO_{Tank} (mg/L)	DO_{Raft} (mg/L)	Water Temp. (°C)	Conductivity (µs)	TDS (ppm)	NO_3^- (ppm)	pH	Ammonia (ppm)
Nov. 16	8.34	8.41	17.8	648	530	28	8.1	1
Nov. 18	8.22	8.39	18	585	600	22	8.1	1
Nov. 21	8.3	8.39	19.8	628	600	28	8	1
Nov. 23	8.31	8.36	20	641	600	28	8	1
Nov. 27	8.24	8.2	20.1	645	620	30	8.1	0.5
Nov. 28	8.52	8.57	20.1	691	640	26	8.3	0.5
Nov. 30	8.37	8.48	20	651	620	23	8.2	1
Dec. 2	8.16	8.2	19.2	651	630	30	8.3	0.5
Dec. 5	9.69	9.82	20.6	671	630	30	8.4	0.5
Dec. 7	8.9	8.9	19.8	659	640	68	8.4	0.5
Dec. 9	8.81	8.92	18.5	630	610	65	8.4	
Dec. 12	8.94	9.14	18	626	640	61	8.3	
Dec. 14	8.91	8.99	19.7	692	630	67	8.3	

Control System Central Tendency and Accepted Limits

	Mean	Minimum	Maximum	Accepted Range
DO_{Tank} (mg/L)	8.59	8.16	9.69	6 - 8
DO_{Raft} (mg/L)	8.67	8.20	9.82	6 - 8
NO_3^- (ppm)	39	22	68	20 - 300
TDS (ppm)	615	530	640	200 - 2000
Conductivity (µs)	648	585	692	varies by system
Ammonia (ppm)	0.75	0.5	1	0 - 1
Water Temp. (°C)	19.4	17.8	20.6	18 - 28

Appendix B: Experiment Two Plant and Fish Growth

Plant Growth

		Experimental		Control	
Date	**Empty Raft Mass (kg)**	**Full Raft Mass (kg)**	**Plant Mass (kg)**	**Full Raft Mass (kg)**	**Plant Mass (kg)**
Nov. 21	1.58	1.71	0.13	1.69	0.11
Nov. 23	1.58	1.74	0.16	1.71	0.13
Nov. 28	1.58	1.81	0.23	1.76	0.18
Nov. 30	1.58	1.83	0.25	1.80	0.22
Dec. 2	1.58	1.84	0.26	1.82	0.24
Dec. 5	1.58	1.85	0.27	1.87	0.29
Dec. 7	1.58	1.92	0.34	1.96	0.38
Dec. 9	1.58	2.10	0.52	2.08	0.5
Dec. 12	1.58	2.35	0.77	2.29	0.71
Dec. 14	1.58	2.54	0.96	2.43	0.85

Fish Growth

	Experimental		Control	
Date	**Mass (kg)**	**Number of Fish**	**Mass (kg)**	**Number of Fish**
Nov. 16	0.24	25	0.25	25
Dec. 14	0.26	25	0.27	25
Growth	**0.02**		**0.02**	

Appendix C: Experiment Three Water Quality Data

Experimental System Water Quality

Date	DO_{Tank} (mg/L)	DO_{Raft} (mg/L)	Water Temp. (°C)	Conductivity (µs)	TDS (ppm)	NO_3^- (ppm)	pH	Ammonia (ppm)	Air Temp. (°C)	Humidity (%)
Feb. 15	8.12	8.23	18.8	786	680	56	8.3	0.5	19.3	34
Feb. 17	8.03	8.15	19.1	769	690	53	7.4	0.5	21.2	42
Feb. 20	8.08	8.11	19.7	792	690	51	7.6	0.5	21.9	46
Feb. 22	8.14	8.21	18.8	802	720	54	7.5	0.5	19.5	49
Feb. 24	8.13	8.25	20.9	817	750	51	7.5	0.5	22.7	40
Feb. 27	8.22	8.28	19.2	810	740	47	7.4	0.5	20.3	38
Feb. 29	8.17	8.29	19.5	831	760	46	7.4	0.5	20.7	32
Mar. 2	8.24	8.36	19.7	822	750	49	7.4	0.5	21.4	40
Mar. 5	8.27	8.39	20.3	806	760	53	7.4	0.5	22.0	30
Mar. 7	8.26	8.35	20.7	794	740	57	7.5	0.5	22.1	25
Mar. 9	8.06	8.16	21.6	787	760	53	7.5	0.5	24.1	33
Mar. 12	8.21	8.29	21.5	854	730	50	7.5	0.5	24.9	36
Mar. 14	7.98	8.12	22.6	879	720	47	7.6	0.5	25.4	42

Experimental System Central Tendency and Acceptable Limits

	Mean	Minimum	Maximum	Accepted Range
DO_{Tank} (mg/L)	8.15	7.98	8.27	6 - 8
DO_{Raft} (mg/L)	8.25	8.11	8.39	6 - 8
NO_3^- (ppm)	51	46	57	20 - 300
TDS (ppm)	730	769	760	200 - 2000
Conductivity (µs)	811	769	879	varies by system
Ammonia (ppm)	0.5	0.5	0.5	0 - 1
Water Temp. (°C)	20.2	18.8	22.6	18 - 28

Control System Water Quality

Date	DO_{Tank} (mg/L)	DO_{Raft} (mg/L)	Water Temp. (°C)	Conductivity (µs)	TDS (ppm)	NO_3^- (ppm)	pH	Ammonia (ppm)
Feb. 15	8.26	8.35	18.3	803	710	31	7.1	0.5
Feb. 17	8.20	8.39	18.8	787	720	36	7.3	0.5
Feb. 20	8.26	8.38	19.3	794	740	38	7.0	0.5
Feb. 22	8.37	8.43	18.6	799	730	41	7.2	0.5
Feb. 24	8.33	8.46	20.5	791	730	44	7.0	0.5
Feb. 27	8.44	8.52	18.9	812	720	39	7.4	0.5
Feb. 29	8.37	8.50	19.2	808	740	45	7.1	0.5
Mar. 2	8.41	8.57	19.3	813	750	41	7.0	0.5
Mar. 5	8.48	8.59	20.0	822	760	43	7.3	0.5
Mar. 7	8.47	8.52	20.0	806	780	38	7.1	0.5
Mar. 9	8.38	8.47	21.2	847	790	40	7.0	0.5
Mar. 12	8.45	8.59	21.0	862	790	37	7.0	0.5
Mar. 14	8.43	8.56	22.4	993	800	34	7.1	0.5

Control System Central Tendency and Accepted Limits

	Mean	Minimum	Maximum	Accepted Range
DO_{Tank} (mg/L)	8.37	8.20	8.48	6 - 8
DO_{Raft} (mg/L)	8.49	8.35	8.59	6 - 8
NO_3^- (ppm)	39	31	45	20 - 300
TDS (ppm)	751	710	800	200 - 2000
Conductivity (µs)	826	787	993	varies by system
Ammonia (ppm)	0.5	0.5	0.5	0 - 1
Water Temp. (°C)	19.8	18.3	22.4	18 - 28

Appendix D: Experiment Three Plant and Fish Growth

Plant Growth

		Experimental		Control	
Date	**Empty Raft Mass (kg)**	**Full Raft Mass (kg)**	**Plant Mass (kg)**	**Full Raft Mass (kg)**	**Plant Mass (kg)**
Feb. 15	1.58	1.71	0.13	1.73	0.15
Feb. 17	1.58	1.74	0.16	1.79	0.21
Feb. 20	1.58	1.81	0.23	1.83	0.25
Feb. 22	1.58	1.83	0.25	2.03	0.45
Feb. 24	1.58	1.84	0.26	2.18	0.6
Feb. 27	1.58	1.85	0.27	2.27	0.69
Feb. 29	1.58	1.92	0.34	2.36	0.78
Mar. 2	1.58	1.99	0.41	2.61	1.03
Mar. 5	1.58	2.20	0.62	2.86	1.28
Mar. 7	1.58	2.34	0.76	2.99	1.41
Mar. 9	1.58	2.39	0.81	3.32	1.74
Mar. 12	1.58	2.41	0.83	3.51	1.93
Mar. 14	1.58	2.42	0.84	3.67	2.09

Fish Growth

	Experimental		Control	
Date	**Mass (kg)**	**Number of Fish**	**Mass (kg)**	**Number of Fish**
Feb. 15	0.27	25	0.28	25
Mar. 14	0.28	25	0.29	25
Growth	**0.01**		**0.01**	

Appendix E: Experiment Three Paired t-test Results of Experimental and Control Plant Mass

Plant Number	Experimental Plant Mass (g)	Control Plant Mass (g)
1	58.8	89.5
2	67.9	87.6
3	64.3	106.3
4	61.1	100.4
5	72.1	139.6
6	61.9	111.7
7	58.8	108.4
8	66.6	184.5
9	50.8	103.1
10	47.8	90.4
11	45.7	185.8
12	70.0	85.2
13	74.6	101.3
14	62.5	89.7
15	65.7	118.0
16	52.9	81.8
17	43.5	94.7
18	67.9	87.7
19	52.0	184.9
20	62.5	89.5
21	46.3	87.0
22	59.6	102.3
23	59.1	98.1
24	76.9	92.3
25	52.8	63.3
26	45.9	78.8
27	69.1	84.5
28	66.8	85.2
29	54.6	78.2
30	54.3	
Average Mass (g)	59.8	103.8
Median Mass (g)	60.35	92.3
Std. Dev.	9.2	31.5
P-value	2.82E-08	