DESIGN, CONSTRUCTION, AND EVALUATION OF A VERTICAL HYDROPOINC TOWER

by

Nicholas A. Heredia

BioResource and Agricultural Engineering

BioResource and Agricultural Engineering Department

California Polytechnic State University

San Luis Obispo

2014

TITLE: DESIGN, CONSTRUCTION, AND EVALUATION OF A VERTICAL HYDROPOINC TOWER

AUTHOR: NICHOLAS A. HEREDIA

DATE SUBMITTED: MARCH 21, 2014

Dr. Daniel Howes ______________________________

Senior Project Advisor Signature

____

Date

Dr. Art MacCarley ______________________________

Department Head Signature

____

Date

ACKNOWLEDGEMENTS

I would like to acknowledge Professor Daniel Howes and the entire BioResource and Agricultural Engineering faculty for providing me with the education and skills required to complete this project.

I would also like to acknowledge and thank my parents for their continuous support thought my college career.

ABSTRACT

This project encompasses the design, construction, and evaluation of a vertical hydropoinc tower. The tower was designed to cycle nutrient rich water through two hydropoinc systems, drip and nutrient film technique then return the water back to the reservoir. The tower will grow 5 different plant varieties. Evaluations have been done on the elevation, system type, and crop type to determine the most productive.

The tower contained four troughs where plants were grown. Due to the structure of the tower two of the troughs were elevated 20" higher than the other two troughs. The elevation of the plants did not cause a noticeable difference in growth. The two systems used were Nutrient Film Technique (NFT) and Drip. The NFT system contained a set water level in the troughs to allow the plants to receive water through the roots. The Drip system ran a hose to each of the plants allowing the plants to receive water as it passes by their roots. The two systems grew plants at the same rate and growth was not noticeably different between the two systems. The leafy plants used were romaine lettuce, head lettuce, winterbor kale, swiss chard, and bonnie spinach. The crops that exhibited the largest growth in the 18 days were the romaine lettuce, head lettuce, and winterbor kale.

The idea of growing with a vertical hydropoinc tower is to increase the productivity per acre of land. Keeping this in mind a recommendation for future growing cycles is to use the same wood frame but to modify the troughs by adding an additional hole between the existing holes to increase the amount of plants grown. Another recommendation is to only use the NFT irrigation system because you will not need to purchase emitters and additional hose to run to each plant. Lastly growing a variety of romaine lettuce, head lettuce, and winterbor kale together in the system is recommended because they displayed the largest and quickest growth in the 18 days of growing.

DISCLAIMER STATEMENT

The university makes it clear that the information forwarded herewith is a project resulting from class assignment and has been graded and accepted only as a fulfillment of a course requirement. Acceptance by the university does not imply technical accuracy or reliability. Any use of the information in this report is made by the users at his/her own risk, which may include catastrophic failure of the device or infringement of patent or copyright laws.

Therefore, the recipient and/or user of the information contained in this report agrees to indemnify, defend and save harmless the State its officers, agents and employees from any and all claims and losses accruing or resulting to any person, firm, or corporation who may be injured or damaged as a result of the use of this report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The purpose of this project was to design, install, and maintain a hydropoinc tower containing different types of lettuce varieties. The development and learning of how to properly grow hydroponic greens is important for future project ventures. Once growing quality lettuce on a smaller scale is achieved expansion can be easier. Designing and testing smaller systems will also allow you to test different techniques and decide which works the best.

There have been large shifts toward locally grown fresh and healthy produce. Hydroponic systems can accomplish this by allowing crop production in urban environments not available for conventional farming.

Hydroponic grow towers located in urban environments can help with maximization of crops per acre. Instead of expanding horizontally increasing the acreage of a farm a hydroponic tower can expand upwards and maximize the use of urban land.

This project will be located in building 17A of the crops unit.

Included in this project will be the steps taken to design, construct, and grow lettuce varieties in the hydroponic tower, the challenges I faced during the grow cycle, results, cost analysis, and recommendations for future designs and growth cycles.

LITERATURE REVIEW

History of Hydropoincs

Hydropoincs is the method growing of plants using water and the essential nutrients required without the presence of soil. This form of growing has been shown from the hanging gardens of Babylon, the floating gardens of the Aztecs of Mexico, and in older Chinese cultures (Resh, 1995). In 1929 William Gericke of the University of California Berkley began promoting the growing of plants in a soil less medium and coined the term hydropoincs.

Necessity of Hydropoincs

Hydropoinc farming can be useful because growing can take place in rough environments such as arid deserts and frozen tundra's (Turner). Growing in such environments can be made possible with the use of greenhouses or indoor farming because of the environmental control.

By 2050 the earth's population is predicted to increase to 9.6 billion leading to a decrease in land available for food and produce production (Anonymous, 2013). With this increase in population we will need to develop alternate farming techniques to help feed the planet. Since land is quickly being urbanized and cities are expanding at a rapid rate this helps justify the study and implementation of hydropoinc growing techniques because it does not require soil.

Along with the many uses for hydropoincs on earth we can even begin seeing the usefulness of hydropoincs in future space travel. NASA has already begun experimentation and research with hydropoincs because we have yet to find soil suitable for supporting life in space (Turner). Soil would also be a heavy and unnecessary item to bring to space. Hydropoincs would allow us to grow plants in spaceships and uninhabitable land for long missions through space as well as providing a good source of food for space travel. The plants would also supply oxygen and remove carbon dioxide from the astronaut's environments.

Hydropoinc Success

One of the first and most successful demonstrations of hydroponic farming came from Pan American Airline's hydropoinc farm on Wake Island in the middle of the Pacific Ocean. This island was used for planes to stop and refuel at. The problem with the island was that there was not enough land to grow vegetables in the traditional manner and it was expensive to ship produce to the island. Pan American Airlines decided to establish a hydroponic farm on the island to feed the passengers and crew with fresh vegetables year round (Sandall, 2011).

In Tokyo Japan an island nation with limited land, hydropoincs has taken ahold and Japan has begun producing rice hydroponically to help feed their nation (Turner). They harvest rice in underground vaults without soil and because of the control they have in the vaults they can harvest 4 times annually instead of the typical once a year harvest (Turner).

Not only has hydropoincs been successful in island situations but it has also taken grasp in more urban environments. The Boston, MA based company Freight Farms has begun growing large quantities of fungi, veggies, and leafy greens in large shipping containers. These containers are sent to customers so they can grow their own produce during the winter months saving money on shipping costs.

Pros

Farming hydroponically has certain advantages. Once you understand the process it's steady, controlled, and reliable. With hydropoincs you can grow inside of climate controlled environments allowing for multiple growing seasons through the year. You can harvest certain crops such as lettuce in as little as three weeks (mphgardener). With certain designs companies have been able to produce continuous year round crop consistent in size and yield (Freight Farms). Hydropoincs is water efficient because the plants take the water they need while recycling the unused back to the reservoir giving you little to no water losses. Since the plants are grown indoors or in greenhouses water is not lost to deep percolation, runoff, and evaporation. Since water flush with nutrients is continuously flowing past the plants it's easy for them to receive their required nutrients. Supplying the plants their required macro and micronutrients gives a high quality taste (mphgardener). This is why it is important to experiment with different types of nutrient levels for different crops to figure out what works and what doesn't.

Cons

Hydropoinc farming has lots of advantages but it still has its disadvantages as well. The main reason hydropoinc farms are not replacing conventional farms is due to their high startup costs. Starting a hydropoinc farm requires costs for system design, water, nutrient, greenhouse, the hydropoinc system, labor, and most importantly the cost of land.

Another drawback to hydropoinc farming is the high amount of technical knowledge required to be successful with hydroponic farming. The absence of nutrient rich soil is not easy to overcome when starting a hydropoinc farm. Ensuring you have all the macro and micronutrients required for the crop is a necessity, without appropriate nutrients your plants won't grow.

Another costly problem that can arise with hydropoinc farming is once disease starts it can quickly spreads thought the system. Disease can destroy large amounts of crops, which is why it is important to keep a clean growing environment.

Lettuce Requirements

Providing plants with their essential nutrients and proper growing conditions in a hydropoinc system is important for plant health and growth.

The temperature lettuce is grown in plays a big factor in the growth rate and quality of it. Lettuce is a crop that grows in cool environments that prefers daytime temperatures ranging from 50-70˚F and nighttime temperatures in the mid 40˚F (Resh, 1995).

Seeds germinate in about a week depending on conditions and can be started in regular seed starting mix that can be purchased from any grow store (mphgardener). Seeds can also be started in a growing medium called rock wool. To start the seeds in rock wool presoaking it with a nutrient solution to lower the pH to 5.2-5.4 from the initial pH of 7.5 is necessary (Brechner). Lettuce seeds require light to germinate so when starting make sure to cover the seeds with something that can allow light to pass through (mphgardener).

Once the plants are placed in the system there are more factors to take into consideration such as relative humidity, carbon dioxide levels, lighting requirements, pH, and electrical conductivity. Relative humidity affects the transpiration of the plants. Transpiration is the amount of water that passes through the root zone and leaves through the plants. If you have higher levels of relative humidity this causes the plants to transpire less and with less transpiration that means less nutrient rich water is going into the plant thus slowing the quality and growth rate of the plant (Cornella). High levels of humidity can also cause certain disease problems. High levels of relative humidity encourage the growth of Botrytis and mildew (Cornella). Carbon dioxide concentrations affect the plants ability to perform photosynthesis and grow (Cornella). Outdoor CO_2 concentration is around 390 ppm and it is important to take this into consideration when growing inside a greenhouse (Cornella). On bright days plants can deplete CO_2 concentrations and slow the rate of photosynthesis. On the other side if you want to speed up the rate of photosynthesis you can increase the levels of CO_2 to 1000-1500 ppm (Cornella). The pH of your nutrient solution is important because it controls the availability of the fertilizer salts (Cornella). The optimal levels of pH are around 5.8 but a range of 5.6-6 is acceptable (Cornella). At higher or lower levels nutrient deficiencies can occur.

There are lots of different nutrient combinations that you can choose from to feed your hydropoinc plants. A popular way most people start with is just to purchase premade nutrient solutions that you mix with your water. For hydropoinc lettuce you need a nutrient solution that contains the basic macronutrients Nitrogen (N), Phosphorous (P), Potassium (K), and micronutrients, Boron (B), Copper (Cu), Iron (Fe), Magnesium (Mg), Molybdenum (Mo), Zinc (Zn), and Chlorine (Cl). Your nutrient solution must contain all of these elements that are naturally derived from the soil. The ratio of fertilizer that hydropoinc lettuce grows well with is 20(N)-18(P)-38(K) (mphgardener). That ratio only takes into account the macronutrients but micronutrients are necessary as well. Hydropoinc fertilizers must be used because they also contain all of the micronutrients necessary. If ordinary soil fertilizer is used your plants will not survive because ordinary soil fertilizer does not contain the required micronutrients (mphgardener). Hydropoinc fertilizers typically do not come at the ratio mentioned above adding Calcium Nitrate ($CaNO_3$) and Epsom salt ($MgSO_4$) will be required to reach the proper ratio. A quality nutrient mix for hydropoinc lettuce can be achieved by mixing 10 grams of 4-18-38 hydropoinc fertilizer, 10 grams of Calcium Nitrate, and 5 grams of Epsom salt in 5 gallons of water (mphgardener).

Besides fulfilling the nutrient requirements for the plants you will also need to supply them with the appropriate amount of water for the entire growing process. To ensure that the plants will have enough water daily checks be done. The pump used must also be able to meet the plants peak evapotranspiration.

<u>Growing Mediums</u>

Once the seeds sprout then you can insert them into your growing medium. You can grow the plants in lots of different mediums. The most popular mediums are hydroton (honeycomb clay pebbles with a ceramic shells), Rockwool (melted balsamic rock spun into fibers), and Perlite (heated silica that has expanded).

Hydroton is popular because it’s light, holds moisture, stays put, can be sterilized and reused. The main drawback of hydroton is that it’s expensive and filling multiple cups can be costly.

Rockwool also has its advantages because it maintains a reservoir of nutrients in the root zone along with a high percentage of pore space. Rockwool is preferable when you are turning your irrigation system on and off or watering a few times a day.

Perlite is similar to hydroton in the sense that it’s reusable, and light. The advantages perlite has over hydroton is that it’s inexpensive. Perlite is used when you are growing plants with larger root zones because of its cheaper cost. The drawback of using perlite is that pieces of it tend to be pulled with the water and can clog pumps, filters, and emitters. An effective way to combat the flow of perlite is to place paint strainers on the buckets before you insert the perlite. The paint strainers act as a filter and keep the perlite from traveling through your system.

Types of Hydropoinc Lettuce Systems

There are lots of different hydropoinc systems that can be chosen depending on what you are growing. The most popular are water culture, drip system, and nutrient film technique (NFT) (Resh, 1995).

One of the simplest hydropoinc systems to grow with is the water culture system. The only requirements required with the water culture system is a water reservoir to supply nutrients to the plants, a Styrofoam platform to float the plants on top of the nutrient solution with, and preferably an air pump with air stones attached to supply the roots with oxygen. Water culture systems are the systems of choice to grow leafy lettuce with because they are fast growing water-loving plants. These are very inexpensive systems, which can be utilized in areas with little to no electricity.

Another widely used hydropoinc system is the drip system. In this system a dripper is ran to every plant placed in a growing medium. After the water passes through the plants cup it's placed back in the water reservoir and recycled through the system again.

The system that people generally relate to hydropoincs is the nutrient film technique (NFT). This system places plants in long plastic grow trays. Plants are then supported in smaller plastic net cups filled with a growing medium. A water level is set in the tube depending on the maturity of the plants. When the plants are younger the water level is set higher allowing the roots to reach it the water. Once the plant roots mature the water level is lowered to promote root growth. In this system the nutrient solution is pumped past the plant roots allowing the plants to meet their water and nutrient requirements. The drawback of this system is that it is susceptible to power outages and pump failures. Once a failure occurs the plants roots dry out very rapidly.

DESIGN AND CONSTRUCTION

Site Location

Site location is essential to growing successfully. The ideal location to produce hydropoincs is a greenhouse that has been positioned for full exposure to the sun. The site should be for the most part level and be located near a large population (Resh, 1995). The system will be set up in greenhouse 17A of the crops unit. This greenhouse is ideal because it is cooled with an evaporative cooler and is located with full exposure of the sun.

Available Space

A well-designed layout can improve the ease of maintenance and cleaning. The space needs to be able to accommodate the nutrient rich reservoir and the troughs that the water will be ran through.

For this design space was limited. The tower needed to be designed to fit onto a 74” wide steel bench. The tower design took up 46” x 6’ in space. The length of the design comes from the 6’ length of the troughs selected for use.

This design was smaller than what was originally anticipated. The height of the design was limited by the greenhouse lighting and gave a max height available of 7’. The original system that was designed stood on the ground and rose up 6’. This would allow for more troughs to be positioned on the tower allowing for more plants per area.

Reservoirs and Pumps

A reservoir in a hydropoinc system is important as it functions as the source of the nutrient solution that is used to feed the plants. For the NFT system it is important to supply enough water to fill the trough to ensure the plants roots can absorb water. The maintained water level in the reservoir is critical to system maintenance. If the water level drops too low and the pump runs dry the pump can burnout and leave the plants un-irrigated. Reservoirs need regular cleaning and refreshing of water to remove algae and harmful pathogens that can develop in the water.

The pump selected will need to be able to overcome the tower height and supply each plant with water. The other requirement of the pump is reliability. If the pump goes out and the plants are left without water continuously running to them they will dry out and die.

DESIGN AND CONSTRUCTION PROCEDURE

Construction Procedure

The outline of the procedure taken for the project was as follows. Once the building location was determined the tower construction began.

Prior to tower construction it was important to measure the allowable dimensions and design based off of them.

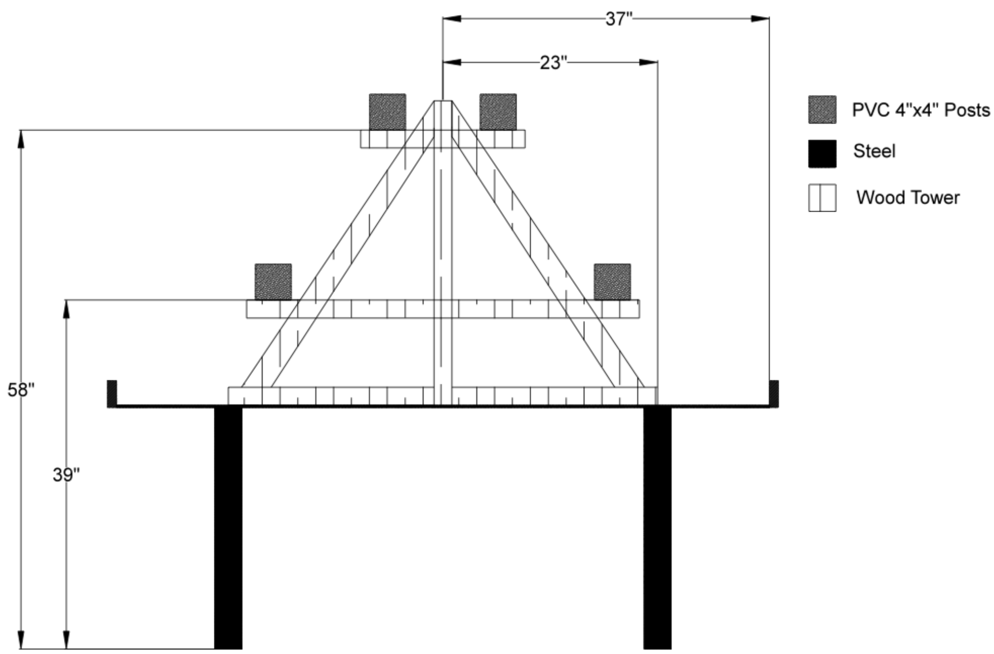

FIGURE 1: ALLOWABLE DIMENSIONS

The tower was constructed using 2”x4” pieces of wood. A skill saw was used to cut the wood and a power drill was used to screw the wood together. Once the wood frame was put together the horizontal supports were put on for the 4”x4” PVC square pipes to rest on. One side of the horizontal supports was 1” lower than the other to ensure proper drainage.

FIGURE 2: TOWER FRAME

After the tower was constructed the next step was to drill 3” diameter holes in the 4” x 4” x 72” PVC square pipes for the cups containing the plants to sit into. This was done using a power drill and a 3” diameter hole saw.

FIGURE 3: HOLESAW USED

The first step of this procedure is to drill slowly until the hole saw bit went into the material. Once this happened it is important to stop drilling because if the 3” diameter saw catches on the PVC the torque generated by the hole saw and the drill can damage your wrist. The next step is to reverse the drill and cut out the larger 3” hole by spinning the drill backwards. The holes were put on 1’ spacing to ensure that all the plants will receive direct sunlight.

FIGURE 4: HOLESAW CUTS

The next holes to be cut were the drainage holes. These were 1-1/16” holes placed at the end of the pipe to allow for the drainage device to fit through and screw together. The drainage system is shown in Figure 5. The drainage device will be sealed with silicon to the PVC trough.

The top part of the drainage device is shown in Figure 5 and will be included for the NFT system and removed for the drip system. The NFT system will need the riser to increase the water level height allowing the plants to remove water through their roots.

FIGURE 5: DRAINAGE SYSTEM

2-5/8” holes were also drilled directly above the drainage system. These holes are needed to make adjustments to the NFT system water level if needed.

The last holes cut into the 4” x 4” PVC pipe were the two holes for each of the NFT drippers to go into the trough with. This is where the water will be entering the NFT system.

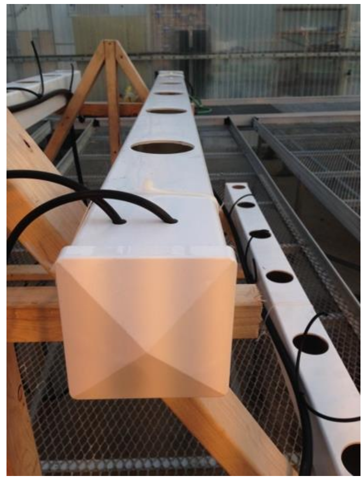

FIGURE 6: NFT DRIP HOLES

After the holes were cut out of the PVC and the tower was constructed the next step was to seal the drainage system and to seal the ends of the 4” x 4” PVC square tubing using silicon. The silicon was left to dry for 24 hours to ensure appropriate curing.

FIGURE 7: SILICON SEALANT

After the silicon was dry the next step was to set up the irrigation system. Water is run continuously through the system to ensure the plants can receive water at their convenience. The manifold hoses are 1/2" diameter and the smaller supply hoses ran off of the manifold are 1/4". The NFT system uses 2 smaller 1/4" hoses ran into the 4" x 4" tubing. The drip systems have a 1/4" hose going into each of the cups.

FIGURE 8: NFT AND DRIP TROUGHS

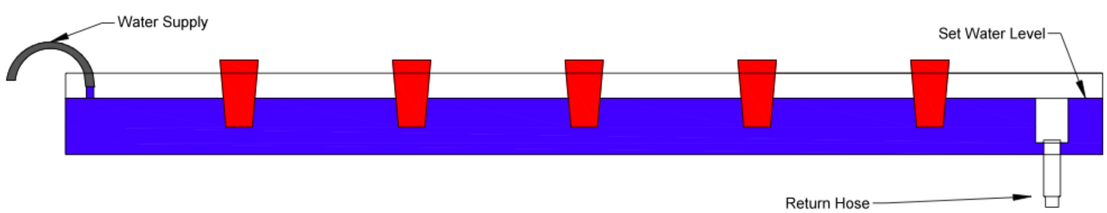

FIGURE 9: NFT CUTAWAY VIEW

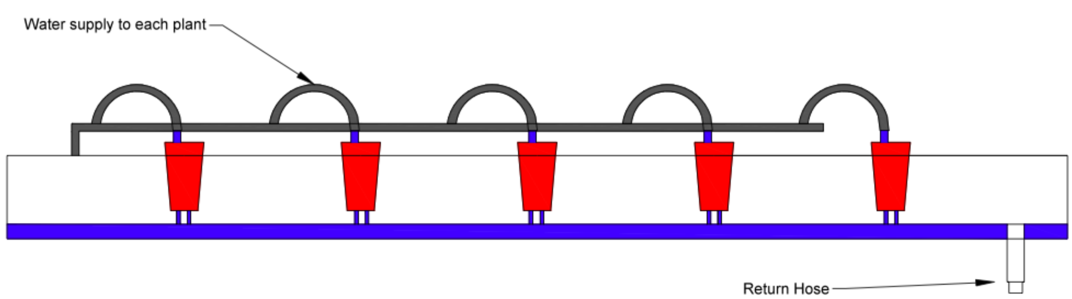

FIGURE 10: DRIP CUTAWAY VIEW

Emitters were not used to ensure clogging would not be a factor. The pump was sized based on pumping height requirements. Since the maximum height of the system was 58" a pump that could pump at least 7' was selected and throttled to the appropriate flow. Since water is continuously ran past the plants the only pump requirement was to provide continuous flow.

The last step was the construction of the cups that will hold the hydroton. Red cups were selected because they are inexpensive. To allow for drainage and root growth multiple holes were placed all over the cups using a soldering iron.

FIGURE 11: DRAINAGE HOLES

The reservoir selected was 25 gallons. Holes were cut out of the top and sides of the reservoir to allow for water to be pumped out and drain back into the reservoir without exposing the water to direct sunlight and promote algae growth.

<u>Nutrient Selection</u>

The nutrient solution that was used for this project was MaxiGro purchased from General Hydropoincs in San Luis Obispo. The nutrient contents are shown in Table 1 and contain all primary, secondary, and micronutrients. As instructed on the back of the bag one teaspoon of nutrient solution was added with every gallon of water added. For simplicity five teaspoons were mixed in a five-gallon bucket with water from the greenhouse. Once the bucket was filled it was dumped into the reservoir. Ten gallons were added initially and the pump was turned on. Once the NFT troughs were filled to the selected level and the water was draining from each hose another five gallons was added to the reservoir.

TABLE 1: MAXIGROW NUTRIENT CONTENTS

Maxigrow Nutrient Content:					
10	N	5	P	14	K
Total Nitrogen (N)=	10%				
		1.50%	Ammoniacal Nitrogen		
		8.50%	Nitrate Nitrogen		
Available Phosphate (P2O5)=	5%				
Soluble Potash (K20)=	14%				
Calcium (Ca)=	2%				
Magnesium (Mg)=	2%				
		2%	Water Soluble Magnesium (Mg)		
Sulfur (S)=	3%				
		3%	Combined Sulfur (S)		
Iron (Fe)=	0.12%				
		0.12%	Chelated Iron (Fe)		
Manganese (Mn)=	0.05%				
		0.05%	Chelated Manganese (Mn)		
Usage: 1-2 teaspoons per gallon freshwater					

Plant Selection

The plant selection included Bonnie Spinach, Swiss Chard, Head Lettuce, Winterbor Kale, and Romaine Lettuce. These leafy lettuces were all selected to determine which one grew the best with each system, which one grew the best with the provided nutrients, and whether or not you could grow different types of leafy greens together using one hydropoinc system.

FIGURE 12: BONNIE SPINACH

FIGURE 13: SWISS CHARD

FIGURE 14: WINTERBOR KALE

FIGURE 15: HEAD LETTUCE

FIGURE 16: ROMAINE LETTUCE

Transplantation

Before the plants were placed in the hydropoinc system transplantation from the soil to the hydroton needed to take place.

FIGURE 17: PRE TRANSPLANTED PLANT

This was done by grabbing as much of the soil around the stem of the young plant and removing it from the square container it came in. When doing this it is important to not damage the roots of the system. Once the plant is removed from the container the next step is to remove the soil around its roots. Rinsing the roots of the plant in a water bath and lightly rubbing the roots to take off excess soil takes care of this. After the soil is removed from the roots the hydroton is filled in ¼ way of the red cup. The plant roots were placed on top of the hydroton and more hydroton was added around the plant filling the cup ¾ full.

It is important to presoak the hydroton for at least one hour before plant transplantation. When hydroton is soaked in water it tends to raise the pH of the water (mphgardener). To combat this adding a half-liter of vinegar to a 5 gallon bucket will lower the hydroton appropriately (mphgardener).

Temperature

Temperature measuring stickers were placed inside the water of the reservoir and on the outside of the lower NFT trough. These were checked and recorded when I checked the water level and shown in Table 2. Nothing was done in attempt to cool the water because the temperature was never excessively hot. The lower temperatures were due to a combination of the swamp cooler in the greenhouse and the wintertime climate.

TABLE 2: TEMPERATURE RECORDINGS

	A	B	C	D	E
1	Daily Temperature Recordings:				
2		Date:	Time taken:	Outside Trough (˚F):	Inside Reservoir (˚F):
3	Transplant	20-Feb			
4		21-Feb	2:00 PM	82	77
5		22-Feb			
6		23-Feb			
7		24-Feb	12:00 PM	65	62
8		25-Feb	9:30 AM	58	55
9		26-Feb			
10		27-Feb	9:30 AM	57	55
11		28-Feb			
12		1-Mar	1:00 PM	59	57
13		2-Mar			
14		3-Mar			
15		4-Mar	11:00 AM	63	63
16		5-Mar	12:30 PM	72	68
17		6-Mar			
18		7-Mar			
19		8-Mar	3:00 PM	83	79
20		9-Mar			
21	Harvest	10-Mar	4:30 PM	75	73

PROBLEMS

Leaks

One of the first problems was that multiple leaks occurred in the system. Five minutes after the system was turned on the silicon seal on the lower NFT system began leaking. Water began to drip out and if the silicon was not fixed the reservoir would deplete at a rapid rate. This is a critical problem because if the water was depleted the pump could end up pumping dry and damage could occur if it is not turned off.

To fix this problem the water going to the NFT system was rerouted to another trough. To ensure that the plants would not die they were placed in a water bath to keep the hydroton and roots soaked.

FIGURE 18: WATER BATH

Once the plants were placed in the water bath the leaky end of the trough was pulled off, silicon was removed, and a thicker coat of silicon was applied. The end stop was put back on and duct tape was taped over the end stop to ensure a good leak free seal was made. The trough was left to dry for 24 hours then put back in place and held the water without a problem.

The next leak that occurred was on the lower portion of the drains.

FIGURE 19: LEAK LOCATION

FIGURE 20: LEAK FIXED WITH SILICONE

The hose purchased came wound in a circle, which put a permanent bend in the hose. This caused a moment to be applied to the seal when the hose was ran to the reservoir. This moment generated force on the silicon seal and ended up rupturing the seal on the inside.

To fix this the plants were removed and placed into another water bath. Silicon was applied to the outside of the drainage hole as shown in Figure 20. After the silicon was dried the drainage system was connected back up and the leaking stopped.

<u>Clogging</u>

Another problem that arose with the system occurred with the connector that connected the hoses to the drainage devices and connected the hose to the pump. The adaptor began to get clogged with the nutrient solution. This was first noticed after the first hour of pumping. The pump would run fine for the first 10 minutes but then it would begin to slow down and water would not reach the top of the tower. I first thought that the pump was fatiguing but the next day I noticed that all the troughs were overflowing.

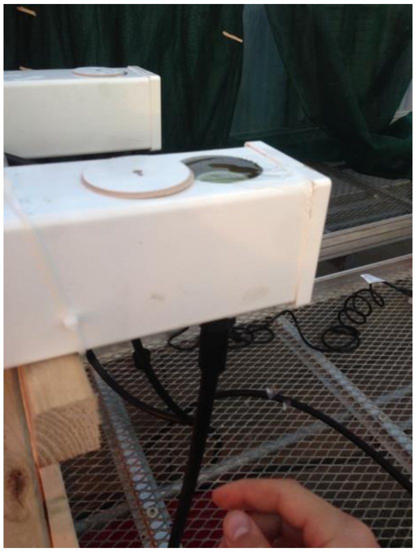

FIGURE 21: OVERFLOW FROM CLOGGING

FIGURE 22: CLOGGED MESH FILTER

The lower part of the drainage system was removed as shown in Figure 22 and the mesh filter was clogging. This was happening to all of the drains and to combat it slits were cut in all of the mesh filters including the one connecting the pump to the hose.

FIGURE 23: MESH FILTER SLIT

The only problem that arose from slits being cut was that the pump flow was to fast. Water was shooting out and over the edges of the cups. To combat this the pump was throttled down to an acceptable level.

RESULTS

The Design and Installation of the Systems

The tower and two systems were designed and constructed with a lot of work, time, and effort, but after the installation was complete the system was capable of producing high quality leafy lettuce a rapid pace.

From my personal experience the construction of this project can be done by anyone with reasonable tool experience and the right set of tools as well as the time commitment to see the project through.

The design and construction phases of the project took the most time. The repairs that needed to be done took up a good amount of time as well.

Maintenance

Other than the problems mentioned earlier the only maintenance that needed to be done was adding water when the water level in the reservoir dropped to low. This was done by mixing up 5 gallons of water with nutrient mix and dumping it into the reservoir.

An important thing to note is that algae did not become an issue through the 18 days of growth. This lack of growth could have been due to the weekly reservoir water change outs.

Plant Production

In the beginning of the project the pump was shut off the second and third days after transplantation happened. This happened because the pump was tied to the lights and someone unknowingly turned the lights off which turned the pump off. Once I realized the water was turned back on and a new outlet for the pump was used.

Once the water was continuously flowing, the plants grew at a rapid rate and turned out really well. Figure 24 shows the plants after 18 days of growth.

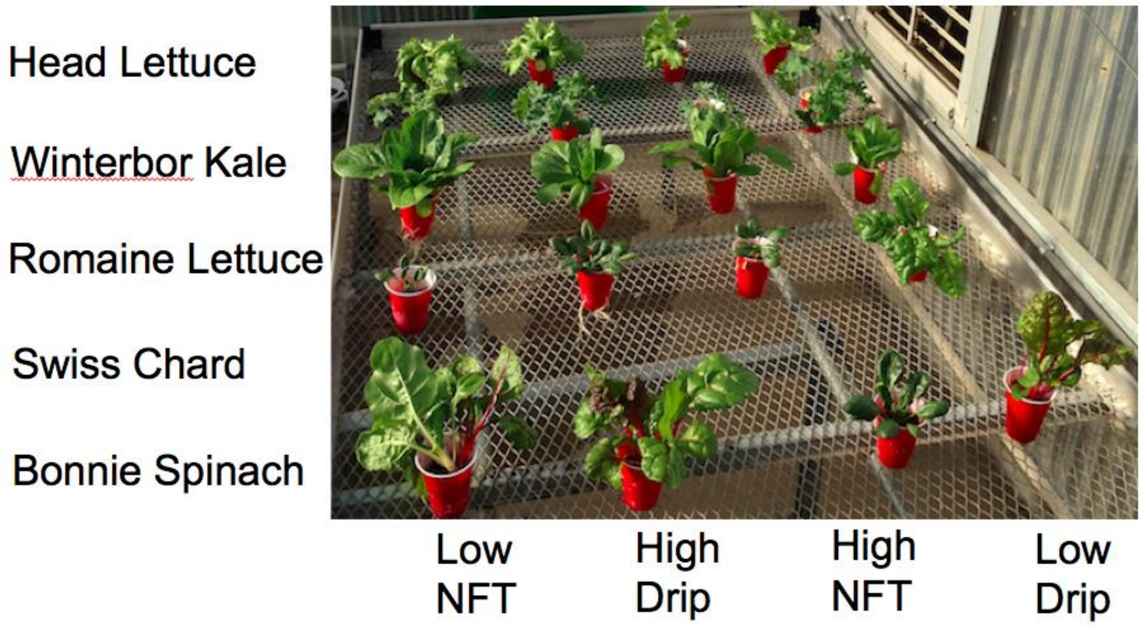

FIGURE 24: COMPARISON OF PLANTS AND SYSTEMS

As shown in Figure 24 most of the plants grew well. The plants on the left side of the picture were facing the west and grew a little better than the east facing plants. My theory on why this happened is because there is another greenhouse located to the east of the greenhouse used which could have blocked some of the sun in the early part of the day. The west facing and left side plants in the picture grew better because they had more exposure to the sun than the east facing plants.

System differences between the NFT and drip are hard to tell. Each system grew the plants well. All the plant water requirements were met and they all grew well except for the Swiss Chard.

The only Swiss Chard that grew well was in the low drip system, which is opposite of what would be expected to have happened because this plant received the least amount of light. But both the Swiss Chard’s grown with the drip grew better than the ones grown with NFT. This could possibly have happened because Swiss Chard roots do not like complete submergence in water.

DISCUSSION

System Pump Sizing

This system was largely over designed. The reason for this was to ensure appropriate supply of water to the plants. Table 2 shows the pump sizing calculations to appropriately supply the plants with their peak water requirements for a NFT system.

	A	B	C	D	E	F	G	H
1	**Sizing for NFT system**							
2								
3	Future DU=	100%	assume 100 b/c water is being recycled through system					
4	Peak Etc (zone 6 in june)=	8.00	in	San Luis Obispo Area				
5	Weeks in June	4.33	weeks					
6	in/wk=	1.85	in/wk					
7								
8	Gross in/wk=	1.85	in/wk					
9								
10	**Pump Sizing based on 24hr, 7day/wk cycle**							
11	Operational Hrs:							
12	Days per week=	7.00						
13	Hrs/Day	24.00	use 24 to choose smallest pump required for non stop watering					
14	Hrs/week=	168.00	hr/wk					
15								
16	Plant Spacing=	11.50	in	x	12	in		
17	Plant Spacing=	0.96	ft^2					
18								
19	Field Size=	46.00	in	x	60	in		
20	Field Size=	19.17	ft^2					
21								
22	IE=	0.95	Large because only losses occur through evaporation					
23								
24	GPM gross = [in*spacing]/[hrs*96.3]							
25	GPM (Net)=	0.00						
26	GPH=	0.13						
27								
28	GPM (Gross)=	0.00	<- Assuming an IE of 95%					
29	GPH=	0.14						
30	GPH * 2=	0.28	GPH					
31	Double for factor of saftey							
32								
33								
34	**Pump Sizing For 16hr, 6 day/wk cycle**							
35	Operational Hrs:							
36	Days per week=	6.00						
37	Hrs/Day	16.00	using 16 hrs to avoid watering during peak hours					
38	Hrs/week=	96.00	hr/wk					
39								
40	Plant Spacing=	11.50	in	x	12	in		
41	Plant Spacing=	0.96	ft^2					
42								
43	Field Size=	46.00	in	x	60	in		
44	Field Size=	19.17	ft^2					
45								
46	IE=	0.95	Large because only losses occur through evaporation					
47								
48	GPM gross = [in*spacing]/[hrs*96.3]							
49	GPM (gross)=	0.00						
50	GPH=	0.23						
51								
52	GPM (Net)=	0.00	<- Assuming an IE of 95%					
53	GPH=	0.24						
54	GPH * 2=	0.48	GPH					
55	Double for factor of saftey							
56								
57								

TABLE 3: PUMP SIZING

As shown from the table you see that for nonstop watering similar to what took place, a pump would only be needed to supply 0.28 Gallons per Hour. If you chose to only run the pump 6 days a week at for 16 hours per day to avoid peak energy costs you would only need a pump that could pump around 0.48 Gallon Per Hour.

The problem arises using the drip system is that the plants are grown in hydroton. Using hydroton as a growing medium requires that water be continuously flowing past the roots to avoid root zone drying. Hydroton's water holding properties are not similar to soil because they have a much lower available water holding capacity, which cannot keep up with the plants water demand needed when the pump is turned off. Continuous pumping requirements are a huge drawback of the drip system.

The other drawback for a drip is the need for filtering. During the project emitters were placed on the ends of all the drip hoses going to each plant. The problem with this was that since the water was not filtered the emitters were clogging up with the nutrient solution.

Since the NFT system did not use emitters it was possible to run the system without filtering the water. This property of NFT is advantageous in the fact that filters will not need to be bought leading to lower startup costs and maintenance will be kept to a minimum because filters will not need to be back flushed or changed.

Plant Spacing

The 1ft plant spacing chosen was too large. The idea and purpose of vertical growing is to produce as many crops as possible in a smaller space. With this idea in mind and since overlap did not occur between the plants a smaller spacing should be used. Since the largest romaine lettuce grew to a max size of 1ft in diameter upon harvest, a recommended spacing would be to have 1/2ft of space on each side of the plants to prevent overlapping.

RECOMMENDATIONS

Plant Selection

My recommendation for plant selection would be to grown Kale, Romaine Lettuce, and Leafy Lettuce. This is because all three plants grew the best overall in both systems.

System Selection

The next recommendation is to use only NFT systems because they require fewer hoses to setup resulting in a lower startup cost. They also hold a set water level in the trough if the water is shut off helping keep the root zone from drying out and killing the plants. By holding of the set water level the pump will not be required to run the whole time in fear of the root zone drying. This can give you cost savings in the long run.

Drainage System

A new drainage system is recommended because the use of silicon sealant is not sturdy. Any type of horizontal force on the drainage system can break the seal thus creating a leak. A system that utilized some form of O-ring sealant that can be tightened down is recommended. This will allow for a tighter seal to be made to prevent leaks.

Filtration

Filtration will be needed when using the drip system. When using drip with emitters to control and have uniform flow going to each plant a filtration system must be used. The nutrient mix used did not completely dissolve in the water even after pre mixing the nutrients was done. This non-dissolved mix can cause problems when using emitters because they will clog easily with nutrients consequently blocking the flow of water going to each plant. To combat this a filtration system must be additionally purchased and installed. For a system of this size a simple mesh irrigation filter can be purchased and installed for under $100. This does drive up the systems starting cost but can save you headaches from clogged filters in the long run.

Other Crops

Other crop varieties can be grown using a system similar to this as long as the crops root zone can fit into the red cups used. This limits the plant selection to smaller plant varieties. Larger plants such as tomatoes can be grown hydroponically but different growing methods must be used. A good example of the alternative methods to use for larger plants is the dutch bucket method. This employs the use of larger 5 gallon buckets filled with perlite as the growing medium. The larger bucket allows for a larger area for the roots to fit into.

COST ANALYSIS

System Cost

The material list and total cost of the system is shown in Table 3.

	A	B	C	D	E
1	Materials List				
2					
3		Item:	Price Each:	Quantity:	Total Price:
4		4"x4"x56" pvc troughs	$15.00	4	$60.00
5		2"x4"x8' wood frame	$8.00	4	$32.00
6		50' of 1/2" drip hose	$6.75	1	$6.75
7		50' of 1/4" drip hose	$4.27	1	$4.27
8		Drip hose taps for 1/2" hose to 1/4" hose (Pack of 10)	$2.00	1	$2.00
9		1/2" end hose clamps	$1.67	2	$3.34
10		330 GPH pump	$50.00	1	$50.00
11		1/2" hose adapter	$1.75	5	$8.75
12		0-15 gph emitters (pack of 10)	$5.00	1	$5.00
13		1/2" T	$4.49	2	$8.98
14		20 pack of red cups	$5.00	1	$5.00
15		saudering iron	$20.00	1	$20.00
16		25 gallon reservoir	$9.00	1	$9.00
17		Maxigrow nutrient solution mix	$15.00	1	$15.00
18		Bag of hydroton	$20.00	1	$20.00
19		Silicone Sealant	$10.00	1	$10.00
20		Caulking Gun	$4.00	1	$4.00
21		4x 1/2" PVC risers	$1.75	4	$7.00
22		5 gal Home Depot Bucket to mix nutrients with	$2.78	1	$2.78
23					
24				Total=	$273.87
25			Total with 7.5% sales tax=		$293.04

TABLE 4: MATERIAL LIST AND PRICING

As shown in Table 3 the subtotal of the system is $273.87 and adding the 7.5% sales tax in San Luis Obispo gives a total system cost of $293.04.

The cost of this project was higher than originally anticipated. One purpose of this project was to design the system to be cost effective. Some cost cutting measures that can be taken are purchasing a cheaper pump and only using the NFT system.

The pump purchased supplied 300 gallons per hour. This is vastly oversized and a less expensive pump that only pumped around 1gallon per hour could suffice.

Only running the NFT system allows for you to do away with emitters and a filter. The NFT system does not require emitters because water is supplied directly into the troughs from the hoses instead of emitters running to each plant. Because of this there is no need for a filter to prevent emitter clogging. This also allows you to do away with purchasing emitters lowering the startup costs.

REFERENCES

Anonymous. 2013. World Population projected to reach 9.6 billion by 2050. Retrieved from <http://www.un.org/apps/news/story.asp?NewsID=45165#.Usw09mRDtho>

Sheperd, S. 2012. Lecompton couple’s hydropoinc lettuce growing in popularity. Daily Journal World. 9/10/2012 <http://ezproxy.lib.calpoly.edu/login?url=http://search.proquest.com/docview/1038866063?accountid=10362>

Resh, M. Howard Ph.D. 1995. Hydroponic Food Production: a definitive guidebook of soilless food- growing methods – Fifth Edition. Chapter 2, pp.52-58, Chapter 3, pp.59-121, Chapter 6, pp.155-238. Woodbridge Press Publishing Company, Post Office Box 209, Santa Barbara, California 93102.

Sandall, B. Singh, A. 2011. Using STEM to Investigate Issues In Food Production. Carson Dellosa Publishing LLC.

Jensen, M. (n.d.) Hydropoincs Worldwide – A Technical Overview. University of Arizona School of Agriculture <http://ag.arizona.edu/ceac/sites/ag.arizona.edu.ceac/files/Merle%20overview.pdf>

History of Hydropoincs. (n.d.) Retrieved from < http://www.rain.org/global-garden/hydroponics-history.html>

Turner, B. (n.d.) How Hydropoincs Works. Retrieved from <http://home.howstuffworks.com/lawn-garden/professional-landscaping/alternative-methods/hydroponics7.htm>

Brechner, M. Both, A.J. (n.d.) Hydropoinc Lettuce Handbook. Cornell Enviornment Agriculture. <http://www.cornellcea.com/attachments/Cornell%20CEA%20Lettuce%20Handbook%20.pdf>

Anonymous. (n.d.) Basic Hydropoinc Systems and How They Work. <http://manatee.ifas.ufl.edu/sustainability/hydroponics/Basic%20Hydroponic%20Systems%20and%20How%20They%20Work.pdf>

Bobby. [mphgardener]. (2012, April 24). Hydropoinc Fertilizer : What I use and How to Mix It. Retrieved from <http://www.youtube.com/watch?v=vYv9iu2NI3M>

ITRC. (1999). ETc Table for Irrigation District Water Balances. California Polytechnic State University San Luis Obispo Irrigation Training and Research Center. <http://itrc.org/etdata/wbdata/dmdrywb6.pdf>

APPENDICES

Appendix A:
How Project Meets Requirements for the BRAE Major

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

Major Design Experience

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes fundamental elements as outlined below. This project addresses these issues as follows.

Establishment of Objectives and Criteria   Project objectives and criteria are established to meet the needs and requirements of supplying hydroponically grown leafy lettuce with their required water and nutrient needs.

Synthesis and Analysis   This project incorporates plant water requirement calculations.

Construction, Testing, and Evaluation   The hydropoinc vertical farm was designed, constructed, tested, and evaluated.

Incorporation of Applicable Engineering Standards

Capstone Design Experience

The BRAE senior project is an engineering design project based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge/ skills from these key courses.

- BRAE 129 Lab Skills/Safety
- BRAE 133 Engineering Graphics
- BRAE 151 AutoCAD
- BRAE 414 Irrigation Engineering
- BRAE 331 Irrigation Scheduling
- ENGL 149 Technical Writing

Design Parameters and Constraints

This project addresses a significant number of the categories of constraints listed below.

Physical   The tower base needed to fit on the top of the 74” steel growing beds where the project would take place. The low hanging lights in the greenhouse also limited the tower height to under 4ft.

Economic   The vertical farm needed to be a cost effective means of producing lettuce in the long run.

Environmental The benefit of hydropoinc farming is the ability to grow organically.

Sustainability The vertical tower can grow lettuce in as little as 18 days. The only thing that needs to be done between growth cycles is the cleaning of the troughs and hydroton before they are recycled. Once the system is set up there is very little waste.

Manufacturability The system can be scaled up and pumps can be sized appropriately.

Health and Safety The hydropoinc system does not use pesticides that can be harmful for humans to consume.

Ethical N/A

Social N/A

Political N/A

Aesthetic N/A

Other N/A