COOPERATIVE EXTENSION
UNIVERSITY OF HAWAI'I AT MĀNOA
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Design of a Small-Scale Off-Grid Hydroponic System for Screenhouse Leafy Vegetable Production

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Introduction

Hydroponics and aeroponics are methods to grow plants without soil. These production systems offer a substantial opportunity to achieve commercial success in crop production, particularly in short-cycle leafy vegetables. These systems are constructed in modular units and can be built with minimal technical expertise and relatively affordable materials.

Producing crops in this manner with a high plant density or a vertical distribution allows for maximization of space, resulting in a small footprint. This characteristic also makes soilless systems ideal for screenhouse or greenhouse production, since a sizable yield can be produced in a relatively small area. Additionally, the relatively low power consumption of outdoor hydroponics allows for operating them off-grid, offering an opportunity to boost vegetable production in rural and marginal areas. Finally, the USDA National Organic Program (NOP) allows hydroponic operations to be certified under NOP regulations which increases the marketability of hydroponically grown commodities.

In this article, we provide an overview of different soilless hydroponic techniques that were evaluated in the Conley Coldframe Series 1100 screenhouse unit (Conley's, Montclair, CA) as part of a Cooperative Extension Field Day event that was held at the Waimanalo Research Station. Lettuce was seeded on December 21, 2018 and transplanted on December 31, 2018. Power for the hydroponic pumps was obtained from an off-grid 12-volt solar panel system. The soilless hydroponic systems constructed included a re-circulating nutrient film technique (NFT) system, vertical aeroponic system, micro-sprinkler tray for seed germination, a DIY 2-inch PVC pipe system and a non-circulating, suspended pot system known as the "Kratky" system, after UH CTAHR Horticulturalist, Dr. Bernie Kratky. We evaluated different organic fertilizer options and used Dr. Kratky's system as a control.

General Hydroponic Principles

In natural systems, the soil provides support, water, oxygen and nutrients to the plants. In a soilless system, each of these functions must be provided by different elements. Supports are typically provided by various growing media such as rockwool blocks, Oasis® cubes, coco coir or peat moss "pods", clay balls, or other inert materials which do not change the characteristics of the hydroponic solution. Plants obtain their nutrition by way of their roots being in contact with a nutrient rich, water-based solution. One of the risks of hydroponics is that there is not enough oxygen dissolved in the solution for the roots to perform respiration. This problem is typically solved by pumping water (circulating systems) and/or installing bubblers in the solution tank to supply oxygen. Nutrients are typically dissolved in solution in a predetermined quantity, but care must be taken to maintain the salt concentration and pH below levels of plant toxicity. Electrical conductivity (EC) and pH can be tested with hand-held meters and generally growers should be cautious when using concentrations above 2 mS/cm[1] (≈1750 ppm) never exceed 3 mS/cm (Kratky, 2010) for adult plants, while lower concentrations are recommended for seedlings and during hot weather. A pH between 5.5 and 6.5 is recommended (Kratky, 2010). Another issue that requires management is algae growing in the solution tank and inside of the NFT channels. It is recommended to shade all elements of the system that are exposed to sunlight. Care should be taken to avoid contamination of the nutrient solution by rain, that in some circumstances can substantially alter the pH and EC of the solution. High temperature of the growing solution is detrimental to plant growth and the solution tank must be large enough to provide a buffer for the solution temperature between day and night.

Nutrient Film Technique (NFT) System

In an NFT system, a shallow layer of nutrient rich solution is circulated past bare plant roots in flat bottomed PVC channels ("gutters") to maximize the surface area exposed to air and allow for oxygen diffusion into the solution. In our trial, we used HydroCycle 4" Pro NFT Lettuce Systems (Aquaponic Place, Waimanalo, Hawaii). We connected two 4-foot lengthwise gutters to obtain an 8-feet-long, 4-inch-wide gutter. Plants were planted with an 8-inch spacing, so an 8-foot gutter held 12 plants. The nutrient solution was held in a 140-gallon tank (Tuff Stuff Products oval tank) and was pumped with a submersible 12V pump (Attwood Tsunami T500 GPH Bilge Pump, Figure 1) into a 1" polyethylene hose. Spaghetti tubing (1/4") fed the solution into the gutters (Figure 1) and the solution was collected at the end of the gutter into 1" PVC pipes. The solution was

1. Electrical conductivity units customarily used in nutrient solutions are mS/cm (milliSiemens/centimeter) and they are equivalent to dS/m (deciSiemens per meter) or mmhos/cm (millimhos per centimeter).

circulated back into the tank by gravity through a sloped 1” pipe (Figure 1). The pump was operated continuously. The gutters were held on plastic (96x24x12”) Uline Plastic Dunnage Rack Tables with 30-inch legs. Two 8-foot gutters were installed on each table. Two pieces of 2x4 wood were stacked under one end of each 8-foot gutter (total thickness: ~3 inches), to provide enough slope to direct excess solution back into the solution tank. The slope obtained was about 3% (3”/96” or 0.03). We built two NFT systems, each system was composed of one tank that served 6 tables and 12 gutters. For demonstrative purposes, one tank was equipped with a 12V bubbler for aerating aquariums (Marine Metal B15 Aeration System Power Bubbles, Figure 1). We planted lettuce seedling using rockwool as a media on December 31, 2018. A total of 144 heads of lettuce could be grown using the two systems. The limitation to the system was the connectors for the 4’ gutters. From some connectors the nutrient solution leaked, reducing the water level in the solution reservoir. Thus, the solution needed to be replenished more frequently.

Figure 1. Load side (top left and right) of the NFT system (note the spaghetti tubing inserted into the gutters and the pieces of wood to provide slope) and discharge side (bottom left) of the NFT system. The pump (red) is visible in the center and the bubbler on the left (bottom right).

DIY 2” PVC gutter

A 2” PVC pipe was tested to replace imported NFT commercial gutters with affordable and easily accessible materials. A gutter was made using a 4 foot 2” PVC pipe (schedule 40) drilling holes with a 2-inch hole saw to accommodate 2-inch net pots. For this system to be effective the volume of solution needs to be sufficient to allow the media to come in contact with the nutrient solution, as the 2” pipe is rounded and not flat bottomed.

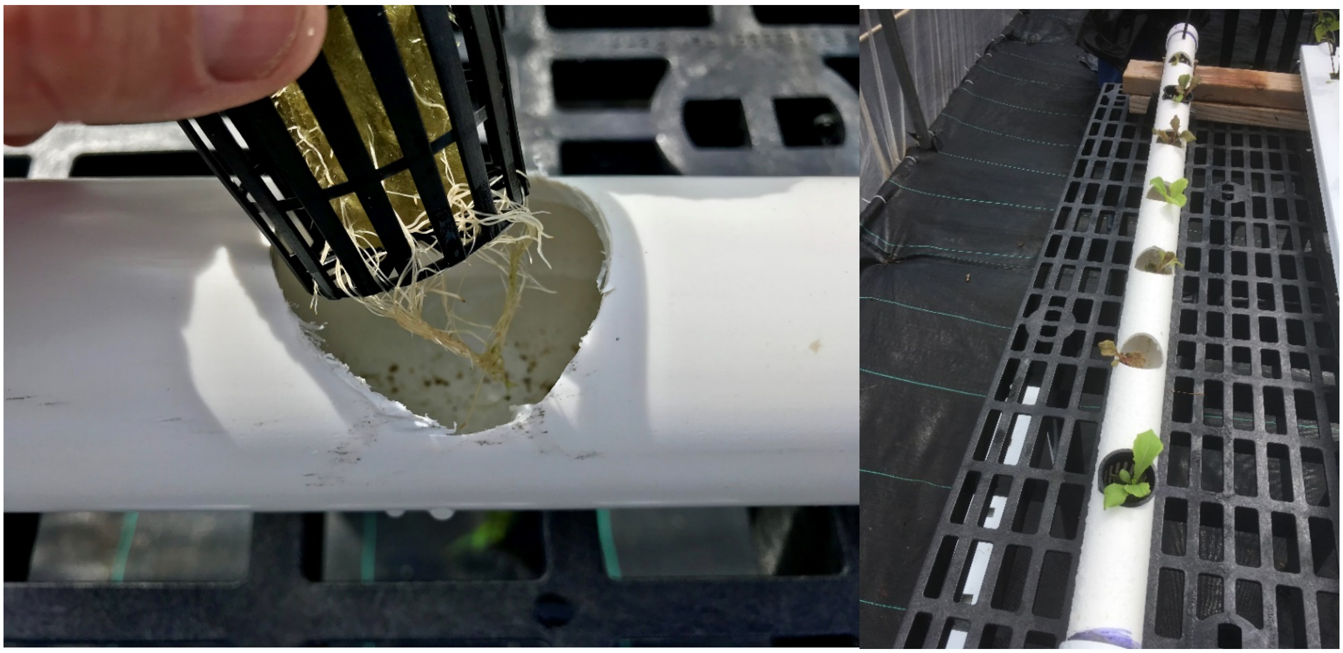


Figure 2. The DIY gutter and 2” net pot

Vertical Aeroponics System

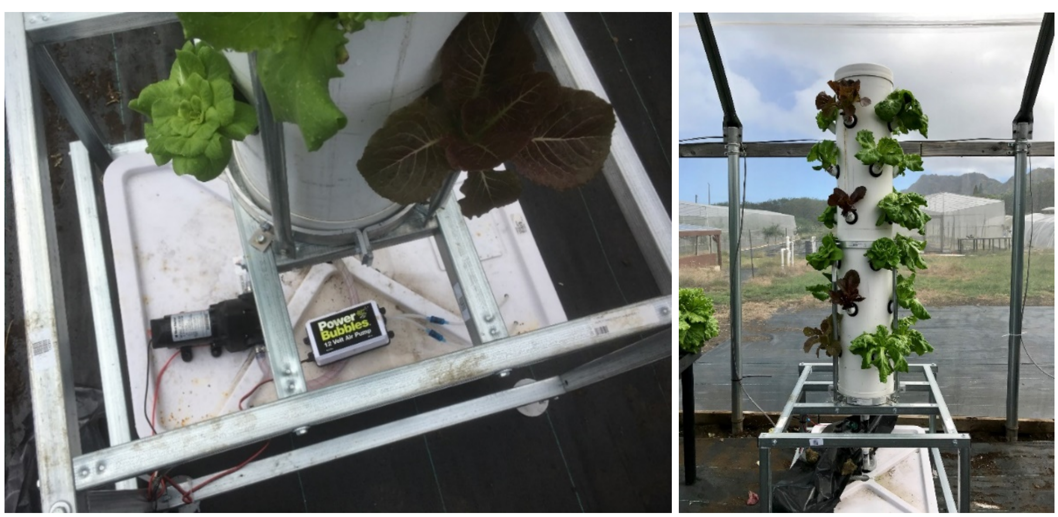


Figure 3. The aeroponic vertical system, note the 12V pump and bubbler.

Aeroponics differs from hydroponics in that the roots are in contact with the nutrient solution in the form of mist. Sprayers or misters are used to obtain the mist and they require larger pressures (15 to 25 psi) than drippers to operate properly. Due to the growing interest in vertical towers, a HydroCycle 4'8" Vertical Micro Aeroponic System (FarmTek, Dyersville, IA) was purchased for this project. The pump and bubbler were replaced to be compatible with 12V units (Figure 3). We switched the pump to a West Marine, 3 gallons per minute (GPM), Freshwater System Pump and used a Marine Metal B15 Aeration System Power Bubbles.

The aeroponic system housed 24 plants seeded in rockwool blocks. We operated the vertical system through a timer (JVR 12V Timer Switch Programmable Digital 12 Volt), programmed to power the system for 5 minutes every hour. With the aid of the timer, minimal hydroponic solution was utilized.

Estimated Cost / Head of Lettuce Using a Vertical System

Vertical Tower:

20 gallons of water	
4 ounces	Hydrogarden 8-15-36
3.33 ounces	Calcium Nitrate
1.6 ounces	Magnesium Sulfate

Estimated cost:

$0.76	Hydrogarden 8-15-36		
$0.11	Calcium Nitrate		
$0.07	Magnesium Sulfate	$0.12	Rockwool per head x 24 each
$0.94	**Total cost for solution**	**$2.88**	**Total cost per head of lettuce**
$3.82	**Total Cost for 24 heads**		
$0.16	**Total Cost / head of lettuce**		

Total cost per head does not reflect the cost of the vertical aeroponics system, shipping, seeds, water and farm labor.

Expenses:	$1301, total cost of vertical system with shipping
Assumptions	Harvest every 5 weeks
	10 harvest a year
	Market price: $2.00 / head of lettuce.
	Total cost for 24 heads: $3.82
	Total profit: $44.18 / cycle
	Profit per year at 10 harvest: $441.80

Conclusion:

At $2.00 a head of lettuce, it would take you 2.9 years to pay off the unit.
Find an alternative to rockwool or cheaper vertical system

The shipping cost of these vertical systems into Hawaii are quite expensive. Ako and Baker (2009) found that construction of a static 4’x8’ hydroponic bed using polyethylene lined wooden boxes constructed from home improvement store products cost $84. A 4’x8’ bed can hold 48 heads of lettuce, double the amount of lettuce than the vertical system purchased. Uyeda, Cox and Radovich (2011) calculated that a return on investment could be seen as early as the 6^{th} harvest using Dr. Kratky’s synthetic solution and the static hydroponic boxes used by Ako and Baker.

Germination Area Using Micro-Sprinkler System

We built a seed germination station within the screenhouse system powered by the solar panel system. The system consisted of a tank made up of an HDX 27-gallon Tough Storage Tote and a 12 V pump (Attwood Tsunami T800 GPH Bilge Pump). The solar powered 12V pump pushed the solution into a ½” polyethylene hose. The hose was installed around the border of a Botanicare (4’x2’) tub where the seedling trays were placed (Figure 4). Nine Rainbird XS-360 micro-sprinklers (2 gph) were inserted into the poly tube and sprayed the solution onto the seedling trays. The system was operated on a timer (JVR 12V Timer Switch Programmable Digital 12 Volt) and was programmed to turn on 5 minutes every hour. Excess solution was gravity fed back into the solution tank.

Figure 4. The germination station

Lettuce Varieties

The lettuce varieties evaluated in the trial were obtained from Osborne Seed Company, Johnny’s Select Seeds, Wild Garden Seed and Glenn Teves (Molokai Extension Agent). Manoa Leopard hybrids were developed by Glenn Teves for heat tolerance and screened on Oahu in 2018. Sugano and Spinelli made selections in 2018 and germinated select lines of Manoa Leopard for the 2019 hydroponic lettuce variety trial. Forty varieties of lettuce were evaluated using the NFT hydroponic system.

Figure 5. Dr. Spinelli harvesting Manoa Leopard seeds at the Waimanalo Research Station

Fertilizer Solution

The NFT and the vertical hydroponics systems followed the Hydro-Gardens Chem-Gro 8-15-36 manufacturer's lettuce recommendations. We mixed Chem-Gro 8-15-36, calcium nitrate and magnesium sulfate. A diluted Miracle Gro water soluble seedling formula was used to provide nutrition to the seedling for the first two weeks after planting. After transplant, we used a low dosage of Chem-Gro 8-15-36, calcium nitrate and magnesium sulfate keeping the EC below 1.0 mS/cm. As plants started to mature, care was taken to keep the electrical conductivity of the solution below the recommended Chem-Gro 8-15-36 thresholds (1350 ppm for seedlings and 1575 ppm for mature plants, equivalent to about 2 and 2.6 mS/cm in EC units respectively). Initial seedlings used for this trial showed signs of lower leaf margin burn commonly associated with salt injury. Many of these seedlings died. Some varieties showed strange lower leaf discoloration (Figure 7). Unfortunately, we couldn't ascertain the cause of the damage. The concentrations of potassium and nitrate measured in the nutrient solution were adequate (K>1200 ppm, NO_3>225 ppm) and the pH and EC were within the recommended ranges (pH=6.2 and EC=1.1 mS/cm). Other varieties showed some evidence of calcium deficiency-related tipburn (Figure 7). Calcium related tipburn may have been the result of low calcium in solution, but more often is caused by water stress or low transpiration in periods of rapid plant growth in susceptible varieties (Turini et al., 2010). We lowered the EC to 1.1-1.5 mS/cm to get the crop to harvest. The pH and conductivity were monitored with hand-held meters, and "pH down" was used to keep pH in the targeted pH range of 6.4-6.7. The incoming water pH levels at Waimanalo Research Station averaged 7.0.

Figure 6. Measuring EC with a hand-held meter

Figure 7. Example of leaf discoloration (cause unknown) (left), and example of burned leaf tips related to calcium deficiency (right).

Static hydroponic “Kratky” systems

Eight polyethylene-lined wooden tanks were prepared to grow lettuce heads in a non-circulating static hydroponic system (originally proposed by B. Kratky, for more information about the “Kratky” system, visit: *https://www.ctahr.hawaii.edu/oc/freepubs/pdf/vc-1.pdf*). Three organic fertilizer solutions were tested in comparison with Dr. Kratky’s recommended solution (Figure 8). They were Biomin N (1% of N), Allganic (mined Sodium Nitrate, 15% of N), and ChemWise Pre-Empt organic fertilizer (0.27% of N). For a 6-gallon tank, the Kratky solution applies 1.2 oz of 8-15-36 (8% N) and 1 oz of calcium nitrate (15% N), that equals a total of 0.25 oz of N per tank. To match the same quantity of N per tank, we applied 600 mL of Biomin (density 42 oz/liter) and 1.66 oz of Allganic. For the Pre-Empt fertilizer, we applied 10 oz of product, following the label instructions. Since Pre-Empt has extremely low in N content, it would have required a very large application of material (6 pounds) to match Kratky’s applied N.

The seedlings for the organic system were grown in coco coir using a seedling formation developed by Sugano, Uyeda and Silva (2017) for the Wounded Warriors (W2) Project. The seedling media was specifically formulated to address the W2 project’s interest in using Pre-Empt in organic hydroponic systems. Overall, the Pre-Empt fertilizer did comparatively well against Dr. Kratky’s synthetic solution. However, the cost of importing Pre-Empt into Hawaii is a concern. More work is needed to find alternative commercial organic solutions for hydroponic growers.

Figure 8. Organic seedlings grown in coco coir and the evaluation of organic nutrient solutions (from left to right): “Kratky” system (left), Biomin Booster, Pre-Empt, and Allganic.

Solar Panel System-Off Grid Power Source

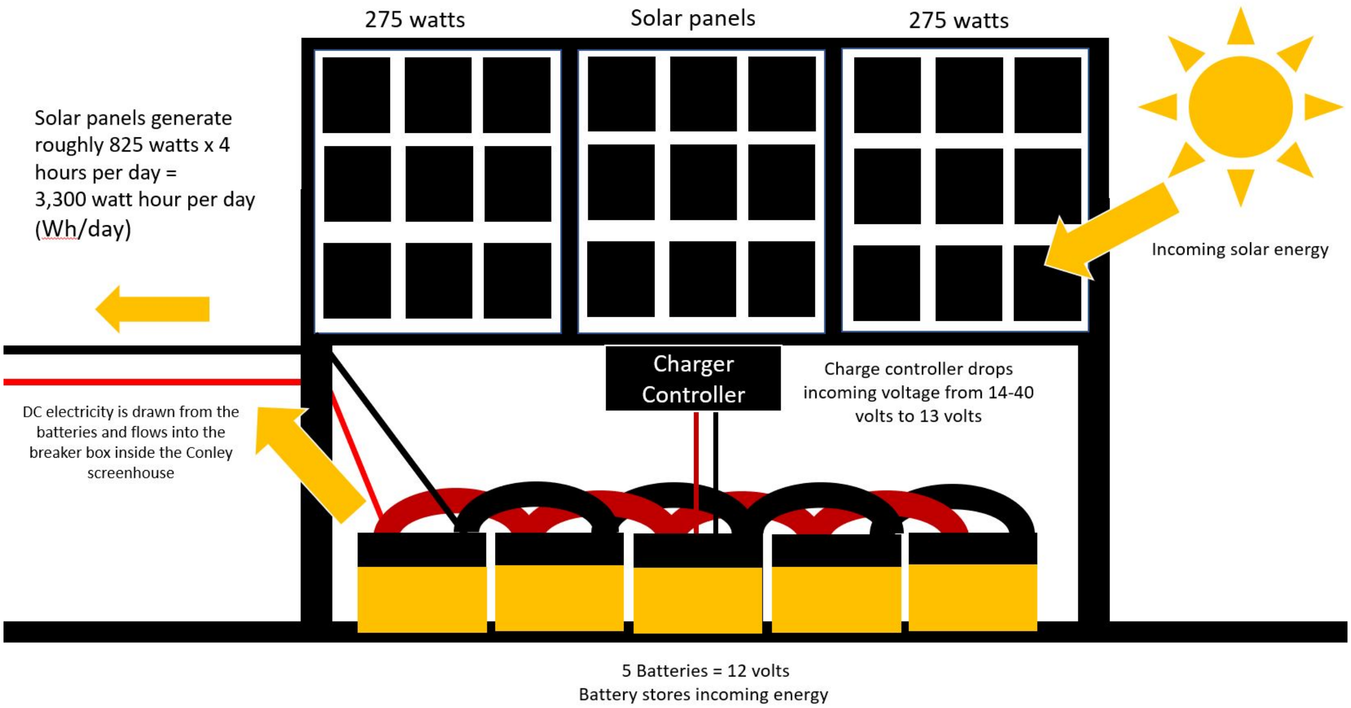
The Conley Coldframe Series 1100 screenhouse unit (Conley’s, Montclair, CA) was installed at the Waimanalo Research Station as a pest management tool due to its effectiveness in managing agricultural pest such as birds, Chinese rose beetle, fruit flies, and *Lepidoptera pests* (Sugano, et al., 2018). The screenhouse system eliminated the need for any pesticide (insecticides, fungicides, rodenticides, molluscicides, etc.) applications during this trial period. However, the location of the screenhouse system did not allow for electrical access to power the NFT system.

The hydroponic systems required an off-grid power source. A solar powered system was designed by Jensen Uyeda (Oahu Extension Agent) and powered by a bank of 3 solar panels, 12V, 275 watt each (Chaori SunPerfect model CRM275S156P-72), total 1125 watt, and by 5 deep cycle RV batteries (Interstate SRM-4D 12V battery, 195 Amp hour) for a total storage capacity of 975 amp hour (Figure 9). The pumps and bubblers were wired to an electrical panel, housed in a plastic outdoor enclosure (BUD Industries NBF-32426 Plastic Outdoor NEMA Economy Box) with marine 12V circuit breakers (VETOMILE Waterproof 3PIN 8 Gang Marine Boat Rocker Switch Panel with Circuit Breaker Overload Protection) and a volt meter to monitor battery voltage (WATERWICH 2 3 4 Hole Marine Illuminated Toggle Rocker Switch Panel Waterproof Ignition Rocker Switch 12V-24V Volt Meter).

The solar panel system was sized based on daily power demand, using a fraction of daily full power production of about 0.17, i.e. assuming that the panels will produce at their full capacity for one-sixth of 24 hours. The batteries were sized in order to have a theoretical storage capacity to power the demand for 6 days without recharge (refer to Figure 11 for calculations of the electrical system). Solar panels used in this trial were donated to CTAHR by Ili'ili Farms (Waianae, Oahu).

Figure 9. Solar panels, battery bank and electrical panel.

This publication does not serve as an endorsement or recommendation of this off-grid power system. New solar technology is constantly being developed. Before installing any electrical systems, consult professional advice from a licensed electrical contractor. Always read and follow safety instruction manuals and use precautions when working with electricity. Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the University of Hawaii and does not imply its approval to the exclusion of other products that may also be suitable or that may inadvertently not have been listed.



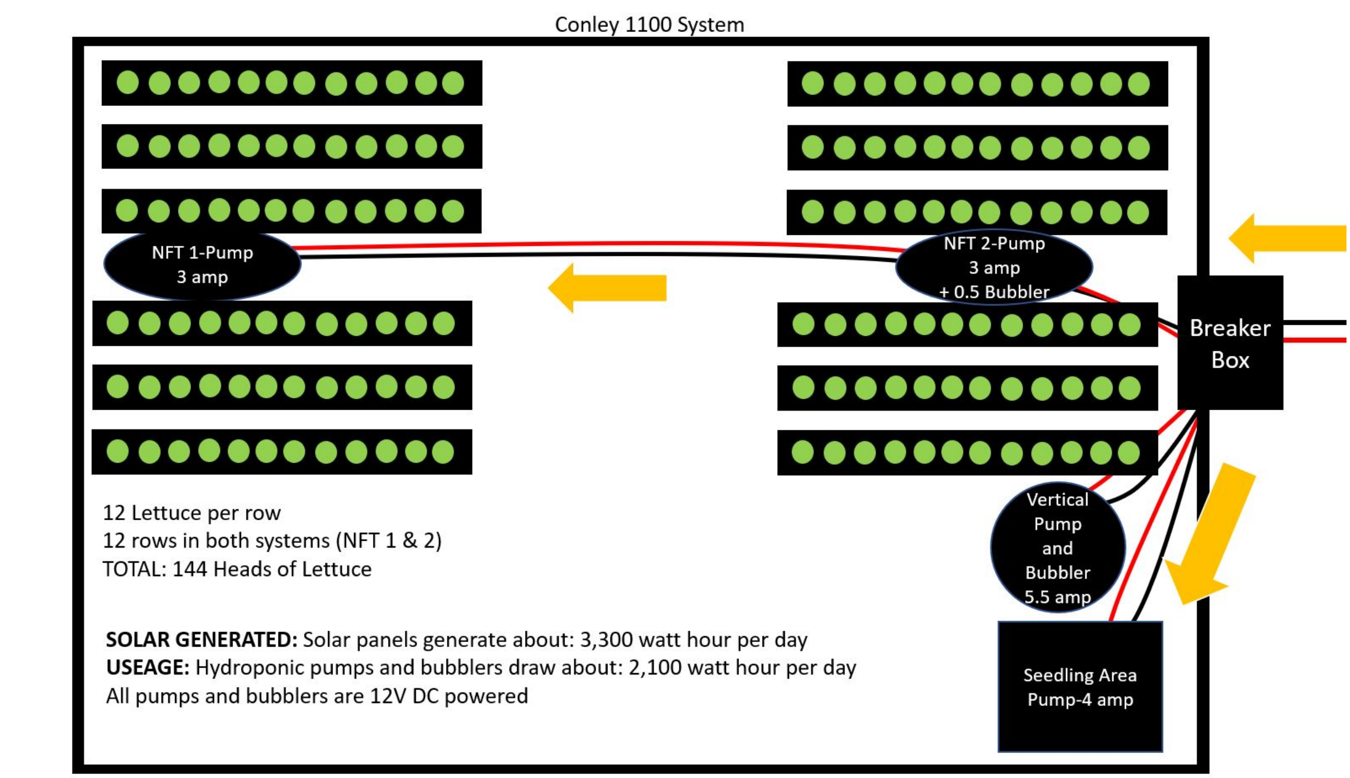


Figure 10. Illustration of the solar powered electrical system and NFT electrical requirements

Power Demand

Item	Load		Duty cycle		Hourly power requirement	Daily power requirement
	amp	watts			watt hour	watt hour
NFT1	3	36	24h	100%	36	864
NFT2	3	36	24h	100%	36	864
NFT bubbler	0.5	6	24h	100%	6	144
Vertical pump	5	60	5 min every hour	8%	5	120
Vertical bubbler	0.5	6	5 min every hour	8%	1	12
Seedling pump	4	48	5 min every hour	8%	4	96
					88	**2100**

Power Supply

Power	Number of panels	Total	Daily fraction of power production hours			Daily power production
watts		watts				watt hour
275	3	825		0.17		**3300**

Storage Capacity

Capacity	Number of batteries	Total capacity			Capacity of running on storage	
Amp hour		Amp hour	Watt Hour		Days	
195	5	975	11700		**6**	

Figure 11. Summary of power demand, supply and storage capacity calculations.

Summary

Hydroponics is an alternative form of crop production in which crops are grown without soil. There are many types of hydroponics systems on the market. For the field day, we evaluated and demonstrated hydroponic systems available locally including the NFT system, the CTAHR tested non-circulating “Kratky” system and a vertical aeroponic system which is gaining in popularity and interest.

Economics should always be considered for commercial hydroponic operations given the large upfront cost to purchase recirculating equipment and supplies, including hydroponic gutters, pumps, solar panels, batteries, etc. However, once the initial investment is made, the operational costs are limited to seed, fertilizer and growing media. Our estimated costs were $0.22/lettuce head in the conventional recirculating NFT system, $0.16 / head for the vertical system, and $0.07/head in the conventional “Kratky” non-circulating hydroponic system (appendix 1 & 2). We estimate that a commercial hydroponically grown crop can be produced in 5-6 weeks (depending on the growing conditions) and production can be year-round in Hawaii.

We were able to grow lettuce without pesticides, bird and rodent damage and threats from slugs or snails which can harbor the rat lung worm disease (*Angiostrongyliasis*) by integrating this project with our protected agriculture system. This project demonstrated that the combination of a hydroponic system with a screenhouse produced marketable yields while advancing environmental conservation, integrated pest management and food safety.

While we followed manufacturer’s recommendations for the hydroponic solutions used in this project, custom mixes can be developed for specific crops or needs. Future work includes the evaluation of organic fertilizers in recirculating systems to lower cost and heighten effectiveness. Lastly, a more in-depth cost of production study is necessary for hydroponically grown crops under different cultivation systems (indoor, outdoors, etc.) in Hawaii.

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APPENDIX 1

UH CTAHR Hydroponic NFT Recirculating Fertilzer Schedule
Seedling Started 12/21/18
Transplanted 12/31/18

Estimated Fertilizer Cost As of February 2019			
Hydrogardens 8-15-36	$76	25 lbs	$3.04 / lb.
Calcium Nitrate	$26.50	50 pounds	$0.53/ lb
Magnesium Sulfate	$34.71	50 pounds	$0.69/ lb
Rockwool (120)	$14.40		

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	
100 gallons of water	Christmas	New Years	INITIAL	RECHARGE	RECHARGE	RECHARGE	Field Day	
Amount of Fertilizer								
Rockwool								
Miracle Gro Start Up Solution	X	X						
Hydrogarden 8-15-36			0.5 lbs	0.25 lbs.	0.25 lbs.	0.25 lbs.	0.25 lbs.	
Calcium Nitrate			0.5 lbs	0.25 lbs.	0.25 lbs.	0.25 lbs.	0.25 lbs.	
Magnesium Sulfate			0.3 lbs.	0.15 lbs	0.15 lbs	0.15 lbs	0.15 lbs	
Cost								
Hydrogarden 8-15-36			1.52	0.76	0.76	0.76	0.76	
Calcium Nitrate			0.265	0.1325	0.1325	0.1325	0.1325	
Magnesium Sulfate			0.207	0.1035	0.1035	0.1035	0.1035	TOTAL
Estimated Cost / Week	$0.50	$0.50	1.992	$1.00	$1.00	$1.00	$1.00	**$6.98**
Measures								
Measured Ph	6.5	6.5	6.5	7	7	6.4	6.4	
Targeted pH	6.4-6.7	6.4-6.7	6.4-6.7	6.4-6.7	6.4-6.7	6.4-6.7	6.4-6.7	
Measured Ec (PPM)	500 ppm	500 ppm	1000 ppm	1300 ppm	1500 ppm	1000-1100	1100	
Hydrogarden recommendation	1350 ppm	1350 ppm	1350 ppm	1350 ppm	1575 ppm	1575 ppm	1575 ppm	

Total cost of solution	$6.98	6 rows of lettuce, 72 heads of lettuce
Cost per head of lettuce/ solution	**$0.10**	
Rockwool/ head	**$0.12**	
Average cost/ head of lettuce	**$0.22**	

APPENDIX 2

UH CTAHR Static Organic Hydroponic Trial
Seedling Started 12/21/18
Transplanted 1/7/19
DR. Kratly's Hydrogarden Solution/ box of 10 heads

Estimated Fertilizer Cost As of February 2019			
Hydrogardens 8-15-36	$76	25 lbs	$3.04 / lb.
Calcium Nitrate	$26.50	50 pounds	$0.53/ lb
Magnesium Sulfate	$34.71	50 pounds	$0.69/ lb

Hydrogarden 8-15-36	1.2 ounces	6 tsp	$0.23
Calcium nitrate	1.0 ounces	6 tsp	$0.03
Magnesium Sulfate	0.5 ounces	3 tsp	$0.02
Total Cost of Fertilizer / 6 Gallon Box			$0.28

Sunshine Mix- OMRI	$55/ 3.8 cubic feet	
Fills 65@ 1 gallon pots	$0.85/ gallon	
Total cost of seeding media	$2.53/ 3 gallon	
Osmocote	$2.00/ lb	
	$0.50/ 72 tray	
Total Cost Media and Osmocote / 72 tray		$3.03
Total Cost / seedling		$0.04
Total Cost / 10 seedlings		**$0.42**

Total Cost / 10 seedlings	$0.42
Total Cost of Soluable Fertilizer / 6 Gallon Box	$0.28
Total Cost/ Box (10 heads)	$0.70
Total cost / head	**$0.07**