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Small-Scale Lettuce Production with Hydroponics or Aquaponics

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Many vegetables can be grown in water culture using nutrients either provided by chemical fertilizers or produced by aquacultured fish. This publication describes an experimental set-up to grow lettuce (*Lactuca sativa*). A low capital, simple to operate system was developed at the University of Hawai‘i at Mānoa using aquaponics, an integration of fish and vegetable culture. Shallow trays were constructed that can be filled with water. Lettuce plantlets were placed in small "net pots" inserted in holes in styrofoam panels suspended over the trays. The lettuce roots take up nutrients from the water in the trays, which in this case regularly received water from tanks in which fish were grown, plus some supplemental nutrients. The water from the lettuce trays was recycled to the fish tanks when new fish-tank water was added to the trays. The only electrical component in the system is an air pump to aerate the fish tanks, providing the fish with oxygen and preventing denitrification. This publication describes how to construct and operate such a system. We had eight trays in the experimental set-up shown in the photos, but one tray, or any number, can be used.

Tray construction

The lettuce trays are shallow wooden boxes with a plastic liner to make them capable of holding water. They are the size of a standard sheet of plywood. Each tray costs about $84 to construct and is capable of producing 48 heads of lettuce every 5–6 weeks. The bottom of each tray is a ¾-inch thick, 4x8-ft high-density-overlay plywood sheet. The walls of each tray (Photo 1) are made with two 8-ft 2x4s and two 4-ft 2x4s, attached to the plywood with screws. To prevent the screws from splitting the plywood, the long walls were placed ½ inch from the edge of the plywood sheet, and the short walls were placed 1½ inches from the edge.

The walls were connected to the plywood with 2-inch #8 stainless steel screws placed every 16 inches; they were secured to each other at each corner with two 3-inch #10 stainless steel screws.

Each tray should be elevated on six supports consisting of 6x8x16-inch concrete hollow tile blocks, one or two blocks high. To provide a plastic liner two layers thick for each tray, a 20-ft wide roll of 6-mil polyethylene plastic was cut into 6-ft sections that were folded once to make a 6x10-ft liner. The experimental system illustrated in this publication used clear polyethelene, but black material is recommended, because it lasts longer in the sun. To weigh down the plastic, fill the trays with 1 inch of water, and staple the liner in place along the outside bottom of the tray walls. Stainless steel staples can be used, but cheaper staples are fine because the liner will need to be replaced after 2–3 years. If the ground on which the

1. Lettuce tray corner, without plastic liner

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2. Lettuce tray with liner stapled in place, leveled with shims on hollow-tile support

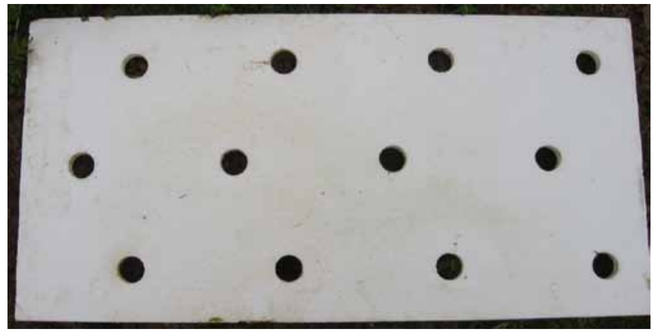
blocks are placed has not been graded level, the trays can be leveled with shims or scrap lumber, using the water height as a guide (see Photo 2).

Tray covers

Four 1-inch thick, 2x4-ft, 2-lb density polystyrene panels are used for each tray. Twelve holes are drilled into each panel with a 2-inch hole-saw drill bit. A cardboard or paper template can be made to guide the placement of the holes, which should be spaced in staggered rows 8 inches apart on-center, with the center of the first hole about 4 inches from the edge of the panel. Holes should be 12 inches apart within the rows (Photo 3). Drill the holes half-way through the polystyrene from one side, then complete the hole from the other side to avoid polystyrene plugs getting stuck in the drill bit.

Place the panels so they rest on the walls of the tray, with three 4-inch plastic flower pots in the tray under each panel to prevent it from sagging. Place rocks around the perimeter of the panels to keep them from being blown off by wind. Finished trays are shown in Photo 4.

Transplant each lettuce seedling to a 2-inch net pot inserted into one of the holes drilled in the polystyrene panel. Fill the trays with enough potable (drinkable) water to reach the bottom of the net pots, so the lettuce plant roots can take up water and nutrients. Photo 5 shows a developing lettuce plant's roots decending from its net pot. The water should not be higher than the bottom of the net pot; that is, it should not touch the panel. It is important to leave an air space above the surface of the water.



3. Spacing of holes in polystyrene panel

4. Lettuce trays stocked with lettuce sprouts

5. Lettuce plants grow in net pots supported by polystyrene panels. Roots of plants extend down into the water.

6. Lettuce plants under a PVC frame covered with 50% shade cloth

7. Developing Red Sails lettuce

Shade structure construction

Lettuce plants require partial shade to grow well in the warm climates found in Hawai‘i and other Pacific Islands. In our experiment, lettuce grew well under 50% shadecloth. In the eight-tray system we constructed, two rows of four trays each were oriented in two 32-ft rows, with a 2-ft aisle between them. The hollow tiles of the outside supports served as anchors for the shade house. Sections of steel pipe 8 inches long, with an inner diameter of 1¼ inches, were inserted into tile holes and seured in place by filling the hole with cement. The uprights for the shade structure are then put into these pipe pieces. Our shade structure frame was constructed using 1-inch inner diameter PVC pipe for the uprights, sides, and cross-connectors, connected with PVC elbows and Ts and glued together with PVC cement. We used 4-ft pieces for uprights, but in retrospect we should have made it taller, for ease in moving around under the structure. A single-tray or two-tray set-up can do with a lower shade cover, which can be lifted off to tend the system. The structure was covered with 50% green shadecloth secured to the frame with zip ties. It was anchored with ¼-inch thick polypropylene rope tied to hollow tile blocks (Photo 6).

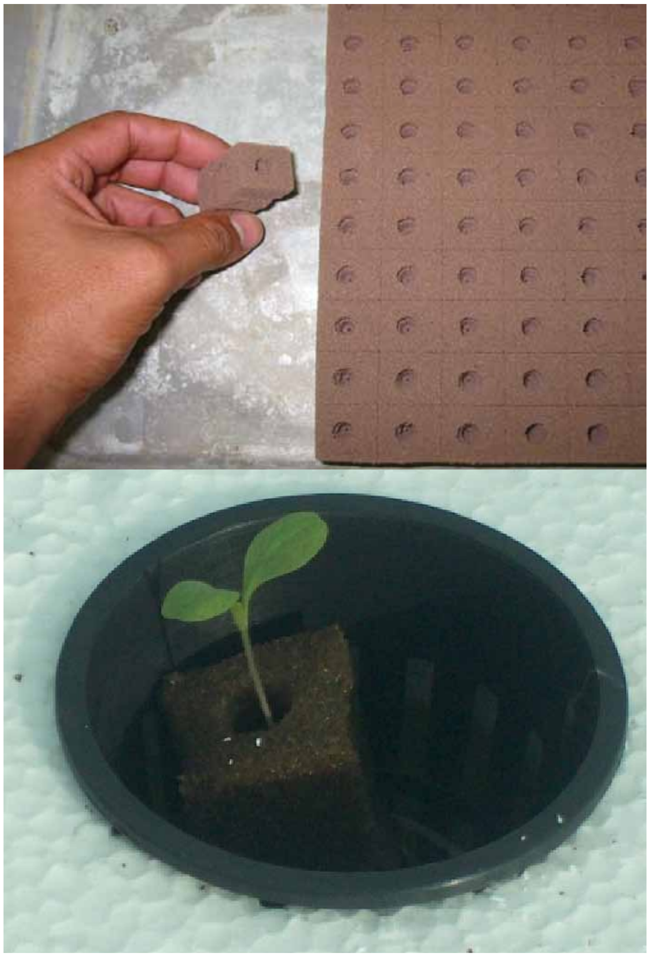
Lettuce type

We used the leaf lettuce cultivar Red Sails and found that it grew well in our system (Photo 7). This was chosen because it demands a premium price in Hawai‘i grocery stores. Its variable leaf shape and attractive colors are appealing to consumers. Chefs favor leaf lettuces like Red Sails for salads because its texture holds dressing well. This variety is also heat-tolerant, a useful trait in the Pacific Islands. Other leaf lettuces are expected to do well, but we did not test any others.

Sprouting lettuce

We used water-absorbing, foam plant-propagation cubes, Oasis Horticubes, to sprout lettuce plants before stocking the trays. This product comes in sheets of 276 pre-scored cubes, each of which serves as a medium for one lettuce plant (Photo 8). Before placing a seed in each hole, we placed the cube sheets in metal baking pans filled with ½ inch of tap water to saturate them. Then the pans were covered, and the seeds were allowed to germinate indoors overnight. The next day, we removed the covers and moved the pans to the growing site, under the shade structure. Water was added to the pans daily for the first week. For the second week, water should be replaced with either half-strength hydroponic nutrient solution or fish water. About 2 weeks after germination, the sheets of cubes were broken apart, and one cube was dropped into each net pot. About 10 percent more lettuce seeds than needed should be sprouted. Heads should be ready to harvest 5–6 weeks after the cubes are placed in the trays, depending on the amount of sunlight they receive.

If mosquitoes become a problem, add 231 μL Prentox® Pyronyl™ Crop Spray (6% pyrethrins) per tray. This equates to about 5 drops from an eye-dropper. Pyrethrins



8. Above, lettuce seeds are sprouted in foam Oasis cubes. Below, one cube is transferred to each net pot 2 weeks after sprouting.

are approved for use on crops for human consumption. Some people have had success with guppies or other small freshwater fish that eat mosquito larvae.

Growing lettuce hydroponically

Lettuce can be grown using commercial hydroponic fertilizers. Three fertilizers are commonly used: Chem-Gro, magnesium sulfate, and calcium nitrate. When the trays we constructed were filled with tap water up to the bottom of the net pots, they held about 61 gallons of water. To do hydroponic cultivation, while filling each tray dissolve 180 g of Chem-Gro, 108 g of magnesium sulfate, and 180 g of calcium nitrate in the water. No additional water or nutrient additions are necessary for the full grow-out period. After each harvest, trays may be refilled with water and fertilizer and new lettuce plants stocked. After three harvests, tray water should be replaced with fresh water. The cost of the fertilizers was less than 2 cents per head of lettuce produced.

9. A cattle watering pan with a biofilter that will be submerged; a 6-inch ruler is shown for size reference.

Growing lettuce aquaponically

In an aquaponics system, fish feed passes through fish and provides nutrients for plant growth. The amount of fish water required to grow lettuce was determined for our set-up. The following relates to one lettuce tray. More lettuce trays would require proportionate increases in set-up size. Other vegetables may require larger amounts.

For each lettuce tray, we had an 85-gallon plastic cattle watering trough (Photo 9) as a fish tank. A 50-watt air pump was sufficient to aerate at least three such tanks. A 2.6-gallon submerged biofilter was placed in each tank adjacent to the air stone(s). The biofilter serves as a "home" for a bacterial colony to develop in; the bacteria will help convert ammonia and nitrite to the nitrate that will nourish the lettuce. To make this biofilter, a cylinder 10x10 inches is made from extruded plastic netting and filled with a PVC biofilter medium.

The fish tank must be shaded to prevent microalgae from growing. An 8x10-ft blue tarp will work. The tank should be filled with 52 gallons of water. The initial fish stocking density was kept low, about 2 lb 3 oz of fish per tank, so that nitrifying bacteria could be recruited from the aquatic environment and colonize the biofilter.

We grew tilapia. The fish were fed twice daily, once in the mid-morning when water temperatures begin to rise, and once in the evening. Ten minutes after feeding, the number of feed particles remaining was counted and the next day's meal adjusted so that no more than 5–10 percent of the feed provided remained after 10 minutes.

Initially, we measured water quality weekly so that the accumulation of toxicants such as ammonia and nitrite could be monitored and their decline observed as the biofilter bacteria grew. Toxic levels at water pH 8 are 17 mg/L for ammonia and 8 mg/L for nitrite. It may be best if CTAHR Cooperative Extension Service aquaculture personnel can be consulted for advice about fish feeding and conducting water chemistry tests. Total ammonia and nitrite nitrogen may be measured with water quality kits (LaMotte Company, Chestertown, MD, USA). The pH may be measured with a pinpoint pH monitor (American Marine Inc., Ridgefield, CT, USA).

Bioremediating bacteria activity should stabilize water quality after about a month, resulting in levels less than 1 mg/L for total ammonia nitrogen and about 0.3 mg/L for nitrite. More fish can added as concentrations of ammonia and nitrite decline.

It was determined that 5½ lb of fish maintained in 52 gallons of water were consuming about 6.5 tablespoons of feed a day. The feed was Silver Cup Trout Feed (42% protein) and the nitrate level in the water was about 47 mg/L. This level supported good lettuce growth, but these specifications should be considered minimal specifications. Each lettuce tray received 5 gallons of fish water daily. Potassium hydroxide (KOH) flakes were added daily at a rate of ⅒ of the feed weight to maintain pH neutrality. This equates to 1 scoop (about a teaspoon) of KOH flakes for every 5 tablespoons of feed. Addition of KOH also provides the potassium required by lettuce. KOH flakes are added on top of the biofilter to use aeration to dissolve and mix them.

A hole drilled near the top of the wall of each lettuce tray allowed excess water to drain back into the fish tank as fish water is removed from the tank and added to the tray. This hole must be high enough to maintain a water level that allows the net pots to touch the surface of the water. Before stocking the first batch of lettuce sprouts, each tray was filled with 15.6 gallons of fish water; the rest of the tray volume was filled with tap water. At this point, the lettuce trays were stocked with seedlings, and daily additions of fish water were begun. Fish water is deficient in iron, and to make up for this ⅛ teaspoon of iron chelate must be added to each tray each week.

As a final note, several different kinds of physical set-ups, e.g., tanks instead of trays, constantly flowing water instead of static systems, etc., are acceptable. They can be adjusted according to pre-existing hardware or physical location. Some aspects of this production method are not optional, such as well-aerated plant roots, well-aerated fish water (oxygen is needed for both fish and bioremediating bacteria), and a sufficient biomass of fish eating a sufficient amount of food.

A list of materials and supplies used in this experimental set-up, their costs when purchased in 2008, and the vendors they were acquired from is given in the following appendices.

When using fish water to grow an edible crop such as lettuce, sanitation is important, particularly when the crop will be sold. Anyone practicing this method of food production should consult CTAHR's publication *On-Farm Food Safety: Aquaponics*, available at http://www.ctahr.hawaii.edu/oc/freepubs/pdf/FST-38.pdf.

Appendix 1. Costs of supplies in 2008 as sourced from vendors on O‘ahu and the U.S. mainland

Lettuce tray	Vendor	Cost per unit item	Cost per tray
HDO ply board	Hardware Hawaii	$50.00	$50.00
8-ft 2x4	Hardware Hawaii	6.00	18.00
screws	Hardware Hawaii	22.00	6.00
staples	City Mill	25.00	3.00
polyethylene liner	City Mill	110.00	6.60
hollow tile block	City Mill	2.20	13.20
polystyrene board	Pac. Allied Products	5.44	21.76
shims	City Mill	1.70	1.70
4-inch planters	City Mill	0.50	1.50
Total cost per tray			*121.76*

Shade structure	Vendor	Cost per unit item	Cost per 8 trays
steel pipe (10 ft)	City Mill	$38.00	$38.00
cement (25 lb bag)	City Mill	6.67	20.00
shims	City Mill	1.70	13.60
50% shade cloth (1 x 6 ft)	City Mill	1.70	170.00
zip ties	City Mill	10.00	10.00
rope	City Mill	10.00	10.00
PVC pipe (10 ft)	City Mill	5.00	200.00
PVC connectors	Diamond Head Sprinkler	NA	50.00
Total cost per 8 tray set-up			*511.60*

Aquaculture supplies	Vendor	Cost per unit item	Cost per 8 trays
cattle watering tray	Waimanalo Feed Supply	$75.00	$450.00
tarp	City Mill	10.00	40.00
50-watt air pump	Aquatic Eco-Systems	88.00	176.00
plastic netting 1 x 4 ft	Aquatic Eco-Systems	4.00	16.00
biofilter media	Aquatic Eco-Systems	11.00	33.00
pH meter	Aquatic Eco-Systems	42.00	42.00
dissolved oxygen test kit	Aquatic Eco-Systems	49.00	49.00
TAN water quality kit	Aquatic Eco-Systems	65.00	65.00
nitrite-N water quality kit	Aquatic Eco-Systems	74.00	74.00
nitrate-N water quality kit	Aquatic Eco-Systems	73.00	73.00
weighing scale	Aquatic Eco-Systems	55.00	55.00
Total cost per 8-tray set-up			*1,073.00*

Consumables (aquaponics)	Vendor	Cost per unit item	Cost per 48 heads
lettuce seeds (1 ounce)	Johnny’s Selected Seeds	$10.00	$0.05
Oasis cubes (5520)	DPL Hawaii	182.00	1.58
potassium hydroxide (55 lb)	BEI Hawaii	65.00	0.94
iron chelate (55 lb)	BEI Hawaii	103.60	0.03
manganese sulfate (55 lb)	BEI Hawaii	44.40	0.01
Silver cup trout feed (40 lb)		27.20	3.29
Cost to produce 48 heads of lettuce			*5.90*
Cost to produce 1 head of lettuce		*0.12*	

Consumables (hydroponics)	Vendor	Cost per unit item	Cost per 48 heads
lettuce seeds (1 ounce)	Johnny’s Selected Seeds	$10.00	$0.05
Oasis cubes (5520)	DPL Hawaii	182.00	1.58
Chem-Gro (25 lb)	Hydro Gardens	38.00	0.59
magnesium sulfate (50 lb)	BEI Hawaii	16.00	0.08
calcium nitrate (55 lb)	BEI Hawaii	22.00	0.17
Cost to produce 48 heads of lettuce			*2.47*
Cost to produce 1 head of lettuce		*0.05*	

Appendix 2. List of vendors

Aquatic Eco-Systems, Inc.
www.aquaticeco.com

BEI Hawaii
311 Pacific Street
Honolulu, HI 96817
Telephone: (808) 532-7401
www.beihawaii.com

City Mill
Waialae Avenue
Honolulu, HI 96816
Telephone: (808) 735-7636

Diamond Head Sprinkler Supply
899 Waimanu Street
Honolulu, HI 96813-5201
Telephone: (808) 591-1122

DPL Hawaii
681 Kalanikoa St
Hilo, HI 96720
Telephone: (808) 935-8785

Hardware Hawaii Lumber
704 Mapunapuna Street
Honolulu, HI 96819
Telephone: (808) 831-3100

Hydro-Gardens
www.hydro-gardens.com

Johnny's Selected Seeds
Website: www.johnnyseeds.com

Pacific Allied Products, Ltd.
91-110 Kaomi Loop
Kapolei, HI 96707-1776
Telephone: (808) 682-2038

Waimanalo Feed Supply
41-1521 Lukanela Street
Waimanalo, HI 96795-1331
Tel: (808) 259-5344

Disclaimer

Names of products and companies are given to illustrate the materials and resources used by the authors to develop the system described in this publication, as well as for the convenience of readers. Mention of these product and company names should not be considered a recommendation in preference to other products and companies that may also be suitable.

Pesticide use is governed by state and federal regulations. If instructions on a pesticide label differ from those given in this publication, follow the label.

The results obtained with the system described may not be obtained under all conditions. Those following the procedures suggested in this manual should be prepared to modify them to reflect their different conditions, including climatic variations, fish stocking density, vegetable types grown, fertilizer formulations used, and other factors.