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Indoor Cultivation Instruction at Rutgers School of Environmental and Biological Sciences

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Introduction

Controlled environment agriculture is the next frontier for producing healthier food in less space, and with less energy and water. This is compelled by the significant increase in human population projected for the 21st century and the shrinking land area available for conventional field agriculture due to population pressure and associated competing demands for land. Other equally compelling reasons include the challenges of climate change and the need to enhance human health through the consumption of high-quality foods. At the Rutgers University School of Environmental and Biological Sciences (SEBS), these emerging realities motivated a team of faculty members to propose the establishment of an Indoor Cultivation program intended to train students and the public to deal effectively with the future challenges of food security in New Jersey and beyond. The Indoor Cultivation Initiative (ICI) at SEBS operated between 2016 and 2019. It was set up to provide experiential learning opportunities for SEBS students and involved both geoponic (growing plants in pots filled with growing media) and hydroponic (soilless) plant production systems. The initiative also provided an opportunity to display novel indoor plant production systems to a wider audience. Figure 1 shows several of the growing systems used for instructional purposes. This bulletin was developed as a **practical guide** for greenhouse operators interested in using these indoor cultivation systems. It can also be used as a teaching manual for controlled environment courses at tertiary institutions in New Jersey and elsewhere across the United States.



Figure 1. Several indoor cultivation systems used for the Rutgers University School of Environmental and Biological Sciences instructional activities: A, geoponic bench; B, two 8-foot tall octagonal pods; C, two mini pods (foreground) and two vine column pods (background); D, nutrient film technique (NFT) platform. ***Photos by Albert Ayeni.***

Indoor Cultivation Growing Systems

Six types of indoor cultivation systems (geoponics, vertical and horizontal hydroponics, aeroponics, Bato bucket system, and floating hydroponics) were demonstrated as part of the ICI. All but one of the growing systems were installed and operated in section B5 at the NJAES Research Greenhouses located at 10 College Farm Road on Cook Campus, in New Brunswick, New Jersey. The aeroponic growing system was demonstrated in the Floriculture Greenhouses on Nichol Avenue, Cook Campus, New Brunswick, New Jersey.

Greenhouse conditions were maintained using an Argus control system (Controlled Environments Ltd., Winnipeg, Canada): lighting was provided to achieve a 14-hour light/24-hour cycle (combination of natural sunlight and high-pressure sodium (HPS) lighting). HPS fixtures (P.L. Light Systems Inc., Grimsby, Canada; Model PL90M, 400 watt) were used for supplemental lighting. The average supplemental light intensity at bench level was 85 µmol/(m^2s), winter air temperatures were set to 55-65ºF, summer set points were 75-85ºF, and the relative humidity was not controlled, but typically ranged between 75 and 85%. The irrigation system was a combination of manual watering and trickle irrigation for the geoponic system, and for the hydroponic systems, the nutrient solution was supplied via pumping from reservoirs and gravity flow back to the reservoirs in a closed loop design.

Geoponic system: This growing system consisted of two 6 x 18-foot expanded metal frame benches. Each bench accommodated multiple pot spacing depending on the crop space requirements. Typically, the benches were used to grow conventional vegetable crops that could be grown to marketable size in 4-inch pots (0.5-liter volume). For this pot size, each bench held 24 pot rows with 10 pots per row for a total of 240 pots per bench or approximately 2.2 pots per square foot. The benches (Figure 2) were equipped with drip irrigation lines programmed to deliver irrigation water at computer-regulated intervals that were adjusted based on the crop needs.



Figure 2. Geoponic bench fitted with irrigation hose and drip lines. ***Photo by Albert Ayeni.***

Vertical hydroponic systems: Vertical hydroponic growing towers consisted of:

a) Two octagonal units (pods) manufactured by AERO Development Corp (West Chester, PA), each with eight 8-foot tall columns. There were two types of columns: (i) eight single-row columns with 15 staggered cups in each of the four sides (for a total of 60 cups per column); (ii) eight double- row columns, with 30 cups on each of the four sides (for a total of 120 cups per column) (Figure 3). Combined, the two octagonal pods contained a total of 1,440 plant-holder cups.

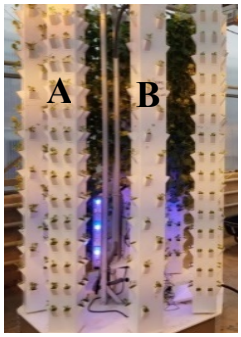


Figure 3. An 8-foot tall octagonal pod showing A, double-row column, and B, single-row (staggered) column with young seedlings. ***Photo by Albert Ayeni.***

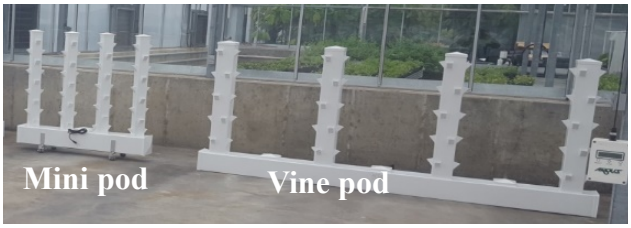


Figure 4. A 4-column mini pod (left) and a 4-column vine pod (right). ***Photo by Albert Ayeni*****.**

b) Two units of vine pods (Figure 4) manufactured by AERO Development Corp, each with four 4-foot tall columns. Each column had a total of 20 cups with 5 cups on each of the four sides. Combined, the two vine column pods held 160 cups (or 80 cups each).

c) Two units of mini pods (Figure 4) manufactured by AERO Development Corp, each with four 4-foot tall columns. Each column is 4-sided as described above for the vine pods. Of the four sides, two opposite sides each contained five cups (total of 10 cups) and the other two opposite sides each contained four cups (total of eight cups). Thus, each mini-pod unit held 18 cups per each of 4 columns for 72 plant-holder cups in total. The two mini pods held a maximum of 144 plants.

Each of the vertical hydroponic systems had a small reservoir at its base that contained the nutrient solution. A submerged pump brought the nutrient solution to the top of each column where it was released and directed toward the inside of each of the four sides of the columns. This ensured that the nutrient solution was available to each plant grown in the cups.

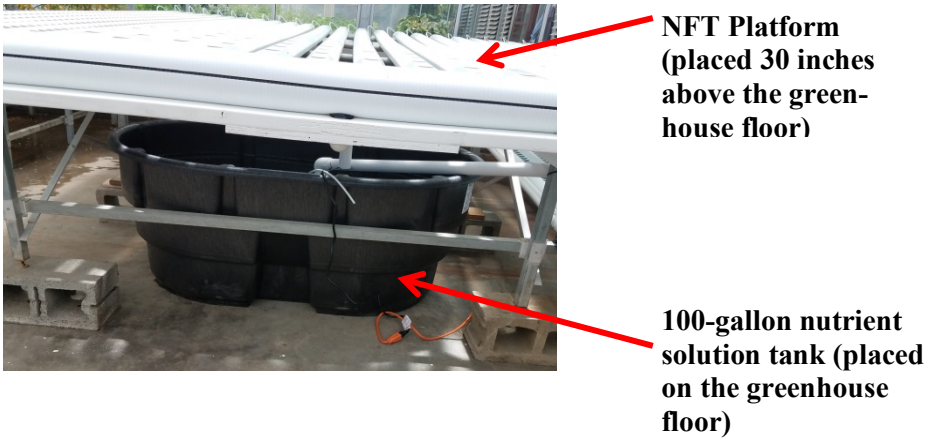


Figure 5. The Nutrient Film Technique (NFT) system installed in the greenhouse. ***Photo by Albert Ayeni.***

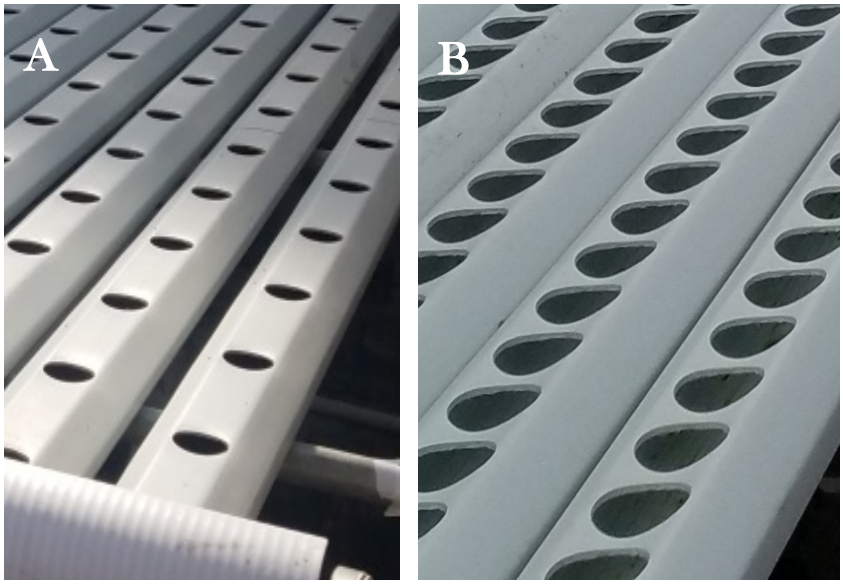


Figure 6. Nutrient film technique troughs: A, wide-spaced (8 inches apart) troughs (18 holes total); B, narrow-spaced (2 inches apart) troughs (72 holes total). Each trough is 12 feet long. ***Photos by Albert Ayeni.***

Horizontal hydroponic system: The Nutrient Film Technique (NFT) production system was a 12 x 12-foot, horizontal hydroponic platform that was mounted on a 2.5-foot tall metal frame (Figures 1 and 5). The NFT troughs plus accessories and water holding tank were manufactured by AmHydro (Arcata, CA) and installed by the ICI team. The NFT platform held a maximum of thirty 12-foot long troughs. Holes were configured two ways (Figure 6): (i) the narrow-spaced (72-hole) trough (NST); and (ii) the wide-spaced (18-hole) trough (WST). Plants were spaced at a minimum of 2 or 8 inches apart for the NST and WST, respectively.

The total number of plants accommodated per square foot depended on the spacing between troughs. For example, for NST with troughs spaced 6 inches apart (center to center), the plant density is 12 plants per square foot; for WST, also 6 inches apart, the plant density is 3 plants per square foot. The NSTs were used to start plants from sowing to early seedling stage; from there, the seedlings were transferred to the WSTs, where they grew to mature market size. The system was designed to operate in batch mode: every week, 2 NSTs were sown. When all 6 NSTs were full, the oldest plants were transplanted into 8 WSTs. Thus, the total system consisted of 6 NSTs and 24 WSTs for a total of 30 troughs. The production time in the system was up to 6 weeks when operated in this batch mode. The NSTs were also used alone to grow herbs such as cilantro and basil to market size without transfer to WSTs. Figure 6 shows the design of the NSTs and WSTs used on the NFT platform. The NFT platform was sloped approximately 1.5-2 inches over the entire length of the troughs (12 feet). A submerged pump brought the nutrient solution to the high end of the troughs, where it was released and allowed to flow (by gravity) the entire length of the troughs before it was collected and returned to the nutrient solution tank.

Indoor Cultivation System Guidelines and Best Practices

Geoponics

What is Geoponics?

Geoponics is the science and art of cultivating crops in a controlled environment using growing media (soil or potting mix) as the rooting medium.

Production and management processes

Materials:

- 4-inch round plastic pots
- 6 x 18-foot greenhouse bench
- Drip line irrigation
- Commercial growing media
- Water soluble fertilizer or slow-release fertilizer (assuming the commercial growing media was not already pre-charged with fertilizer)
- Seeds

Methods:

- Seeding
    - 240 4-inch pots will fit on one 18 x 6-foot bench.
    - Fill all pots to the top with the commercial growing media.
    - Water the pots with regular water until the growing media is completely saturated. The media is saturated when water begins to drain through the bottom of the pots.

- Direct seed into the middle of the pot if planting head lettuce, other non-mixed lettuce types, or other crop types. For spring mix or other mixed-seed crop types, evenly distribute seeds over the top of the growing media and cover lightly. (Use tweezers if needed when handling smaller seeds.) Do not plant seeds deeper than 0.5 inch (approximately 1 cm). Deep planting may delay emergence or cause uneven germination.
- Place the pots on the bench in 24 rows (lengthwise), with 10 pots per row.
- Position a drip line emitter on the top of the growing media in each pot.
- Drip lines can be controlled by an irrigation controller or by the greenhouse controls. Duration and number of irrigations may be changed depending on the growth stage of the plants and greenhouse conditions.
- Make sure that the drip lines are operating properly (some systems require the emitter to be turned on by pulling the weighted end of the drip line out; if the end is pushed in, then the water flow is shut off).

- Fertilizing
  - Use 2 tablespoons (~30 gm or 1 oz) of 20-20-20 water soluble fertilizer (20-10-20 might work better for some plants) and mix into 5 liters of water.
  - Use a watering can to water the pots manually.
  - Fertilize the plants after they germinate, and then continue to fertilize them once every two weeks until harvest. At each fertilizer application, apply solution until water drips out of the bottom of the pots.
- Harvesting
  - Materials
    - Scissors
    - Boxes
    - Weighing scale (if collecting weight data)
  - Procedure
    - Remove all drip lines from the pots.
    - Use scissors to cut at the base of the plants and place the harvested plant material in a bag/container/box. Remove any old, damaged, or soiled leaves from the plant before placing it in a bag/container/box.
    - If cutting a crop that you want to regrow for another harvest, do not cut plants too short; ensure the meristem is intact so that new leaves can form. For best results, keep at least 2 inches of plant material above the growing media intact.
    - When harvesting leafy greens, boxes are filled and weighed to hold 5 pounds of produce per box.

        - When harvesting leafy greens, place boxes in a cold room (40-45°F) after final weighing as soon as possible, to avoid plant wilt.
- Cleaning pots after each growing cycle
    - Materials
        - Sufficiently large water container/reservoir (for example, a long and narrow 270-gallon horse trough)
        - Household bleach (5.25% sodium hypochlorite)
        - Water
        - Brush
    - Procedure
        - Discard all used growing media inside the pots.
        - Use the brush to remove any residue or debris.
        - Fill the container with water and add bleach using a 1:30 ratio (1 part bleach to 30 parts water).
        - To thoroughly clean pots, place pots brushed free of any debris in the bleach solution and soak for 24 hours.
        - Thoroughly rinse clean pots with clean water.
        - Permit pots to air-dry on the growing benches before the next crop cycle.

Figure 7 shows geoponically-grown spring mix at different growth stages. Growing conditions: 14-hour photoperiod (with supplemental HPS lighting), 65-75°F, 75-85% relative humidity, and manual watering (early growth stages) or computer-controlled trickle irrigation (later growth stages).



Figure 7. Geoponically-grown spring mix lettuce at different growth stages. ***Photos by Albert Ayeni.***

Troubleshooting:

- Drip irrigation is much more water efficient and convenient than watering by hand. Inspect drip lines daily to ensure they are functioning properly.
- When growing spring mix lettuce, the plants can be harvested multiple times; during each harvest, cut back the leaves and continue to grow the plant for another harvest. Following the second harvest, however, the leaves can become tough and bitter, and the plants may start to bolt and go to seed. Do not cut back plants lower than 2 inches above the media surface to ensure that they will grow back in a reasonable amount of time.
- Plants positioned on benches closest to the ventilation inlets may grow more slowly; lower temperatures and/or higher evapotranspiration rates and subsequent moisture stress might be responsible.

Vertical Hydroponics

What is vertical hydroponics?

Hydroponics is a method of crop production where roots grow in nutrient-rich water instead of in a rooting medium. It is often a soilless system that supplies macro- and micronutrients to the plants through soluble fertilizer that is incorporated into the irrigation water. Inert rooting media, such as vermiculite or perlite is commonly used, as well as manufactured products such as mineral wool (sold under the brand name Rockwool) or manufactured materials (e.g., Oasis) to start the seedlings. At ICI, we used different styles of vertical hydroponic systems: octagonal towers, vine, or mini pod styles.

In vertical hydroponics, the nutrient solution is pumped to the top on the inside of tall plastic columns, where it flows by gravity down over the roots and into a bottom reservoir (Figure 8). These columns have small plant-holder cups attached to the outside walls with openings through which plant roots are bathed in the nutrient solution.

A growing cube holding the seed or seedling is inserted into the plant-holder cup where the plant grows to market size in 5 to 6 weeks for leafy greens or longer for fruiting vegetables (e.g., vine crops) (Figure 8). Figure 9 shows fully grown leafy vegetables on the octagonal, vine, and mini pod units.



Figure 8. Photo of the vine pod showing the relationship between nutrient solution tank, the plant growth column, and the plant-holder cups. ***Photo by Albert Ayeni.***



Figure 9. Vertical hydroponic columns ready for harvesting 5 to 6 weeks after seeding: A, octagonal tower with eight columns; B, vine pods; C, mini pods. ***Photos by Albert Ayeni.***

Crop Production and Management Processes

Materials

- Soluble fertilizer
- Fresh water and hose
- BlueLab Combo (BlueLab Corporation Limited, Tauranga 3110, New Zealand) handheld meter for pH, electrical conductivity (EC) (an indication of the total concentration of nutrients dissolved in the solution), and temperature monitoring

- Extension cord
- Irrigation timer
- Ruler (to measure water levels and plant growth)
- Three 5-gallon tanks/containers for fertilizer/stock solutions (for example, Jack's Water Soluble Fertilizers, JR Peters, Inc., Allentown, PA)
- Tank A: 480 grams (17 ounces) of Jack's 15-0-0 per gallon
- Tank B: 510 grams (18 ounces) of Jack's 5-12-26 per gallon (includes secondary and micronutrients)
- Tank C: 250 ml (8.5 fluid ounces) pH Down per gallon (for example, BlueLab Corporation, Tauranga 3110, New Zealand) (see Figure 10)
- Methods
    - Three fertilizer injection pumps manufactured by Dosatron International, Inc. (Clearwater, FL) pump the concentrated fertilizer and pH control solutions from the stock tanks into the fill hose (connected to the hose delivering make-up water), which is used to manually fill (or top-off) the reservoirs of the vertical hydroponic pods. The pumping rate of the Dosatron injectors can be adjusted so that based on the concentration in the stock tank and the injection rate, the correct concentration in the nutrient solution can be applied.
    - Tank A supplies nitrogen; Tank B supplies nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and micronutrients (both tank A and B are needed to prevent precipitation of some of the nutrients); and Tank C supplies an acid that is used to lower the pH of the nutrient solution.

Seeding/transplanting

- Soak the germination media (e.g., Rockwool or Oasis) until water seeps through the bottom and allow to stand for 2 to 3 hours before sowing seeds.
- For very small seeds, use tweezers.
- For seed lots with unknown or suspect germination rates, place more than one seed per hole.
- After seeding, place the media cubes with seeds in the growing systems.



Figure 10. Three Dosatron injection pumps used for mixing concentrated nutrient solutions with municipal water prior to feeding the plants in the hydroponic systems. Bucket A holds a nitrogen (N) solution, bucket B holds a NPKCaMgS solution plus micronutrients, and bucket C holds a "pH Down" control solution (an acid). ***Photo by Albert Ayeni.***

Managing plant growth

- Balancing the pH, EC, and water level:
  - Tank C balances/lowers the pH (as the plants take up nutrients, the remaining solutions gradually become more basic).
  - Tanks A and B are used to raise the EC.
  - Maintain the depth of the nutrient solution reservoir levels between 3 and 4 inches maximum.
  - Methods:
    - Use the Bluelab handheld meter to measure the pH and EC.
    - Most plants, including leafy greens, require a pH of 5.5-6.0. Maintained the EC between 1.8 and 2.0 mS/cm.
    - The pH probe should be calibrated once a month to maintain accurate readings. Follow instructions, using pH 4 and pH 7 calibration solutions.
    - The pod reservoir nutrient solution might require more acid to reduce the pH than what the Dosatron injector is able to deliver. In these instances, use plastic measuring cups with pH Down to manually adjust the pH in the reservoir. Always use proper precaution when handling any (concentrated) acid solution.
    - Use the ruler to monitor the reservoir level so that it does did not exceed a depth of 4 inches. When the reservoir level is too high, water may leak out of the system.
- Rotating the columns
  - Columns placed in the octagonal towers are designed to rotate 360 degrees.

- Manually rotate the columns 90 degrees every 24 hours to provide relatively uniform light conditions to all the plants (note that columns can be rotated slowly using a motorized system that can be added as an option when purchasing the vertical octagonal growing systems).

- Plant growth
  - Observe plant growth daily and record observations in a notebook for future reference.
  - Inspect plants for overall health. If plants appear unhealthy, check the nutrient solution pH and EC, and make corrections if necessary.
  - Inspect plants for damage due to insects or disease. The most common insect pests are aphids and thrips, as well as the common disease powdery mildew. When plants are intended for human consumption, control these pests or diseases using organically approved control measures such as neem oil (for insects) or copper octanoate (for disease control). Always carefully check pesticide labels for instructions, timing, and application rates.

Harvesting

- Materials
  - Ladder (for reaching the top of the octagonal towers)
  - Scissors
  - Boxes
  - Weighing scale (if collecting weight data)
- Methods
  - Use scissors to cut at the base of the plants and place the harvested plant material in a bag/container/box.
  - When cutting plants you want to regrow for another harvest, make cuts at least 2 inches above the growing media.
  - Fill and weigh boxes to fit 5 pounds of produce per box. To avoid spoilage from higher post-harvest temperatures, do not pack the box too tightly.
  - Place boxes in a cold room (40-45^{o}F) after final weighing as soon as possible so that the plants do not wilt.

Cleaning/sanitizing

- Materials
  - Water container/reservoir (for example, a long and narrow 270-gallon horse trough)
  - Household bleach (5.25% sodium hypochlorite)
  - Water
  - Brush
  - Hose/sprayer

- Methods
  - Drain the pod nutrient solution reservoir.
  - Remove all dead plants, plant debris, and Rockwool/Oasis cubes from the columns.
  - Rinse the columns with water using power hose to remove any roots/plant matter/or debris from inside and outside the column. This will ensure optimal effectiveness of bleach action in the next steps.
  - Prepare the bleach solution: fill the water reservoir with water and add bleach (5.25% sodium hypochlorite) at a 1:30 bleach:water ratio.
  - To thoroughly clean the columns, place them (one at a time) in the trough with bleach solution, soak, and use a brush followed by a power hose to remove any roots/plant matter/or debris that may remain on the inside or outside of the column.
  - Take the column out of the trough and thoroughly rinse off the bleach.
  - To thoroughly clean the entire hydroponic system, fill the pod nutrient solution reservoir with the bleach solution, place air dried columns back onto the pod, and let the bleach solution cycle through the pod for 24 hours.
  - Drain the bleach solution from the pod, and rinse with three changes of fresh water to remove any residual bleach.



Figure 11. The vertical hydroponic system: (a) and (b) seedlings at different stages after seeding; (c) vegetables growing on a mini pod; (d) vegetables growing on a vine pod; and (e-f) vegetables growing on an 8-foot octagonal pod. ***Photos by Albert Ayeni.***

Figure 11 shows the plant propagation method for the vertical hydroponic system. To increase space efficiency, seedlings can be germinated in trays (as shown in Figures 11a and 11b) prior to placing them in the hydroponic systems.

Troubleshooting:

- When dealing with an infestation of aphids, be alert: inspect plants often for tell-tale signs of aphid activity, such as honey dew, and manually squash as many as possible to keep populations low. If this is not effective, products containing neem oil may be applied. Make sure your spray covers both the upper and lower leaf surfaces. Check the pesticide label for instructions, timing, and rates.
- During the summer months, elevated temperature and light conditions may cause plants to wilt. Overhead shade curtains (we used curtains made by Ludvig Svensson Incorporated, Charlotte, NC; Model: "Harmony 5047 FR" flame retardant material; 50% shade, 47% energy retention) do a good job of reducing the solar radiation. Our shade curtains were computer controlled: they were fully open below an outside light intensity of 1,000 µmol/(m^2s); closed halfway at an outside light intensity of 1,100 µmol/(m^2s); and fully closed at an outside light intensity of 1,250 µmol/(m^2s).
- Light (sunlight or supplemental light) is not evenly distributed along the columns in vertical hydroponic systems. Supplemental lighting may be used on plants located on the lower portions of the column to enhance their growth and color.
- We observed that Rutgers Scarlet Lettuce does not always develop the deep red/purple color when cultivated in the indoor systems (probably due to a lack of UV radiation). Supplemental lighting with the correct spectrum can improve the red pigmentation in leaves.
- High pressure sodium vapor (HPS) lamps get very hot. Plants located near the top of the columns can get too hot if they are located close to the lamps. We positioned the octagonal pods so that the HPS lamps were not too close to the plants.
- Algae may grow in stock solutions stored in 5-gallon translucent buckets. If this is an issue, use opaque buckets for stock solutions or use smaller buckets and replenish the stock solutions more frequently.
- To prevent dropped leaves from contacting the floor while harvesting, use food safety-approved floor covers so dropped leaves can be retrieved and packed for consumption.

Horizontal Hydroponics: Nutrient Film Technique (NFT)

What is NFT?

Nutrient film technique (NFT) (Figure 12) refers to a hydroponic system where a thin stream of water with dissolved plant nutrients is constantly recirculated over the roots of plants in watertight channels or troughs.

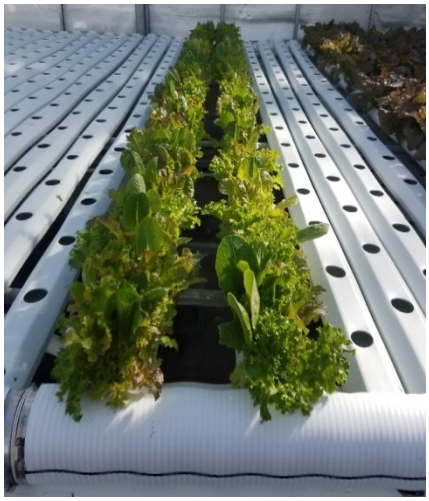


Figure 12. The nutrient film technique (NFT) platform showing two planted rows of spring mix near the harvesting stage. ***Photo by Albert Ayeni.***

Production and Management Processes

- Materials
  - Fertilizers
  - Water supply with hose
  - Extension brush
  - BlueLab handheld meter (pH, EC)
  - Ruler (to measure water level and plant growth)
  - Harvesting scissors
  - Work table
  - Growing media
  - Seeds
- Fertilizer/stock solutions (for example, Jack's Water Soluble Fertilizers)
  - Tank A: 480 g (17 ounces) of Jack's 15-0-0 per gallon
  - Tank B: 510 g (18 ounces) of Jack's 5-12-26 per gallon (includes secondary nutrients and micronutrients)
  - Tank C: 250 ml (8.5 fluid ounces) pH Down per gallon

- Methods
  - Three Dosatron injectors (see Figure 8) inject the concentrated fertilizer and pH control solutions from the stock tanks into the fill hose (connected to the tap), which is used to manually fill (or top-off) the large nutrient solution tank place below the troughs.
  - Tank A contains only nitrogen, Tank B supplies nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and micronutrients, and Tank C supplies an acid that is used to lower the pH of the nutrient solution in the tank placed below the troughs.

Seeding/transplanting

- Soak the germination media with fresh water until completely saturated. Repeat a few times and let the media sit for a few hours.
- Seed each individual media cell (cube):
  - For head lettuce, one seed per cube.
  - For leaf lettuce (Spring Mix), 7-10 seeds per cube.

- Break off individual cubes and place each of them in an opening in the NFT channels.
- If cubes are shorter than the depth of the holes in the NFT troughs, be careful that they are properly centered in each hole and do not fall over.
- It may be easiest to insert cubes first along the outside perimeter of each 12-foot trough and then move underneath to insert cups in the middle of the trough.
- Straighten out each trough and insert the irrigation supply line into the supply (higher) end.
- Make sure irrigation lines are inserted correctly and that the lower (return) end of each trough is pushed into the main return channel far enough to prevent leaking.

Managing plant growth

- Balancing the pH, EC, and water level:
  - The injector connected to stock tank C is used to balance/lower the pH.
  - The injectors connected to stock tanks A and B are used to raise the EC.
  - Keep the large nutrient solution tank level between 17 and 19 inches.
  - Methods:
    - Use the Bluelab handheld meter to measure pH, EC, and nutrient solution temperature (the latter just as a check).
    - Most plants grown in hydroponic systems, including leafy greens, require a pH of 5.5-6.0. Maintain EC between 1.8-2.0 mS/cm.
    - The pH probe should be calibrated once a month to maintain accurate readings. Follow instructions, using pH 4 and pH 7 calibration solutions.
    - The NFT solution reservoir may require more solution from stock Tank C to decrease the pH than what the Dosatron pump is able to deliver. Use a plastic measuring cup filled with a small amount of solution from stock tank C to manually adjust the pH in the NFT solution reservoir.

Harvesting

- Turn off the supply of nutrient solution for the through/troughs you will be working on.
- Remove the irrigation lines from the supply end of the trough/troughs.
- Lift and move each trough to the work table.
- Harvest the product by using harvesting scissors (or a knife).
  - Head lettuce: cut at the very base of the plant to keep the head together.
  - Spring mix (full harvest): cut at the base of the plant to remove as much plant material as possible.

    - Spring mix (re-growth): cut the lettuce straight across and leave at least 2 inches of plant material at the base. This will give the plants a better opportunity to grow back quickly.
- Discard all remaining rooting cubes from the troughs (channels) and place the troughs to the side for cleaning.

Cleaning/sanitizing

- Turn off the supply of nutrient solution for the section that you are working on, or unplug the pump if cleaning the entire system.
- If removing all channels, use an extra hose and sump pump to drain the nutrient solution from the tank.
- Bring empty troughs over to the cleaning station, soak each trough in a 30:1 water:bleach solution, and clean both outside and inside with the extension brush.
- After cleaning and triple rinsing, air dry the troughs and return them to the NFT system.
- If the entire NFT system is cleaned, run a 30:1 water:bleach solution through it overnight and carefully triple rinse the system afterward.
- Drain the system one last time; it is now ready for the next growing cycle.

Troubleshooting:

- Ensure that the water level is not too low in the reservoir tank. The outlet of the submerged pump is split two ways: one hose delivers nutrient solution to the troughs, and another hose is used to keep the nutrient solution in the reservoir well-mixed. If the water in the reservoir drops too low, the mixing process becomes exposed and nutrient solution may be forced out of the reservoir.
- The ends of the troughs where the nutrient solution is delivered are not sealed and may leak. Make sure the supply tubes are pushed in far enough and aimed down the trough to prevent nutrient solution from spilling out of the open ends at the top of the troughs.

Bato Bucket System

What is the Bato bucket system?

The Bato bucket system (Figure 13) consists of a series of containers (buckets) filled with a (soilless) growing medium connected at regular intervals to a drain line. The containers typically hold several gallons of growing media (e.g., perlite or expanded clay particles) and are used for growing vine crops (tomatoes, peppers, cucumbers). Each bucket typically supports one or two plants that are irrigated with a drip system. Excess nutrient solution is collected in the drainage

pipe that typically returns the solution to a holding tank that is part of a recirculation system but can also divert the solution to a regular floor drain.



Figure 13. Bato bucket system used to grow tomato and cucumber plants. Note the white drainage pipe connected to the bottom of each plant bucket. ***Photo by A.J. Both.***

Design and operation

The Bato bucket system was demonstrated at ICI for growing tomatoes and cucumbers as shown in Figure 13. The 3-gallon buckets measure 12 inches long, 10 inches wide, and 9 inches high, resulting in a media volume of 2.9 gallons. In this design, buckets are staggered along a 1.5-inch PVC drain line that is pre-drilled with drain holes on 12-inch centers. The buckets are made of UV-resistant plastic and therefore are reusable after thorough cleaning, similar to the procedures described for the geoponic pots.

Floating Hydroponics

What is the floating hydroponics system?

The floating hydroponic system (Figure 14) consists of a shallow volume of nutrient solution (typically 8-12 inches deep) covered with lightweight water-repellent boards (e.g., Styrofoam™ insulation boards). Holes are drilled in the boards and seedling cubes are positioned in the holes so that the plant roots are fully submerged into the nutrient solution. Because the surface of the nutrient solution is fully covered, preventing or significantly reducing the diffusion of oxygen into the nutrient solution, the nutrient solution must be aerated to provide the plant roots with sufficient oxygen. Floating hydroponics is sometimes called the Deep Flow Technique (DFT).



Figure 14. Floating hydroponics system used to grow a variety of leafy greens. Note the aeration pump sitting on top of a cinder block on the right of the growing system. ***Photo by A.J. Both.***

Design and operation

The floating hydroponics system demonstrated at ICI consists of a 4 x 4-foot wooden frame made from 2 x 12-inch boards and placed on the heated greenhouse floor. The wooden frame is lined with a 6 mL polyethylene film and filled with nutrient solution. An aquarium pump (GH2716, General Hydroponics, Santa Rosa, CA) is used to aerate and mix the nutrient solution through four air stones that are submerged in the nutrient solution. The aquarium pump operates continuously. The pH and EC of the nutrient solution is checked manually on a regular basis and adjusted when needed. We grew a variety of leafy greens in this system as shown in Figure 14.

Aeroponics

Plants grown in an aeroponics system have their roots hanging in an enclosed airspace, and water and dissolved nutrients are delivered to the roots by way of a spray consisting of very small droplets. This is different from growing plants in a geoponic or hydroponic system where the roots develop in a rooting media or in a nutrient solution, respectively. The system demonstrated at ICI consists of a covered bucket (Figure 15), but much larger and specially designed systems are used by commercial growers. The bucket system is easy to use and maintain and facilitate educational activities. Examples of the trials conducted by students are shown in Figure 16.



Figure 15. Components of an aeroponic bucket system: A, a 5-gallon bucket including a lid with 18 plant holes; B, a submerged spraying water pump; C, Rockwool cubes for growing seedings/cuttings. ***Photos provided by Bill Sciarappa.***



Figure 16. The Aeroponic system: A, William (Bill) Sciarappa (left) demonstrating the aeroponic system to Ameen Lotfi (right), student assistant for the Indoor Cultivation Initiative; B, Pablo Kunkel, student in the Indoor Cultivation class, measuring plant height of premier kale grown in an aeroponic bucket system; C, mixed leafy greens produced in an aeroponic bucket. ***Photos by Bill Sciarappa and Xenia Morin.***

Notes on Plant Growth in Geoponic and Hydroponic Systems

During our student-led growth trials, plant growth was generally slower in the geoponic system than the hydroponic systems (Figure 17). The leafy greens grew to market size in 6 weeks or less in the hydroponic systems, while for many leafy greens, market size was reached in 7-8 weeks in the geoponic system. Among the hydroponic systems, leafy greens grew faster in the NFT system compared to the vertical hydroponic systems. Among the vertical hydroponic systems, the growth of leafy greens was fastest in the mini pods followed by the vine pods and

slowest in the octagonal towers. In the hydroponic systems, the final plant size per cup at harvest (5-6 weeks after seeding) was approximately equal in the NFT and mini pod systems, followed closely by the vine pods. However, in the octagonal towers, plant size per cup was substantially smaller and varied with the location of the plant along the columns. The plants located at the top of the column in all cases were bigger in size than those near the base of the columns. This difference in growth was due to the difference in light intensity at different heights along the columns; those at the top of the column had more light than the ones towards the bottom. Other factors such as nutrient distribution along the columns and temperature variations (resulting from different exposures to light) might also have played a part. The roles of all of these factors should be further assessed as part of future studies.

Plant growth on the geoponic benches and the NFT system varied with the location of the plants relative to the location of the ventilation inlets (Figure 18). The plants positioned near the wall mounted ventilation inlets displayed stunted growth. It was observed that these plants were continuously exposed to higher airflow rates, which might have accelerated evapotranspiration and induced significant water stress and subsequent reduction in growth. Figure 18 shows examples of growth variations observed for both systems. The differences in growth might also have been a response of the plants to the cooler temperatures of the incoming air and/or a wind-blown effect that often causes stunting. This observation made it clear that efforts must be made to shield young seedlings from airflow-induced injuries.

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Figure 17. Premier Kale growth comparison six weeks after seeding in NFT, mini pod (vertical hydroponic) and geoponic systems. ***Photo by Albert Ayeni*****.**

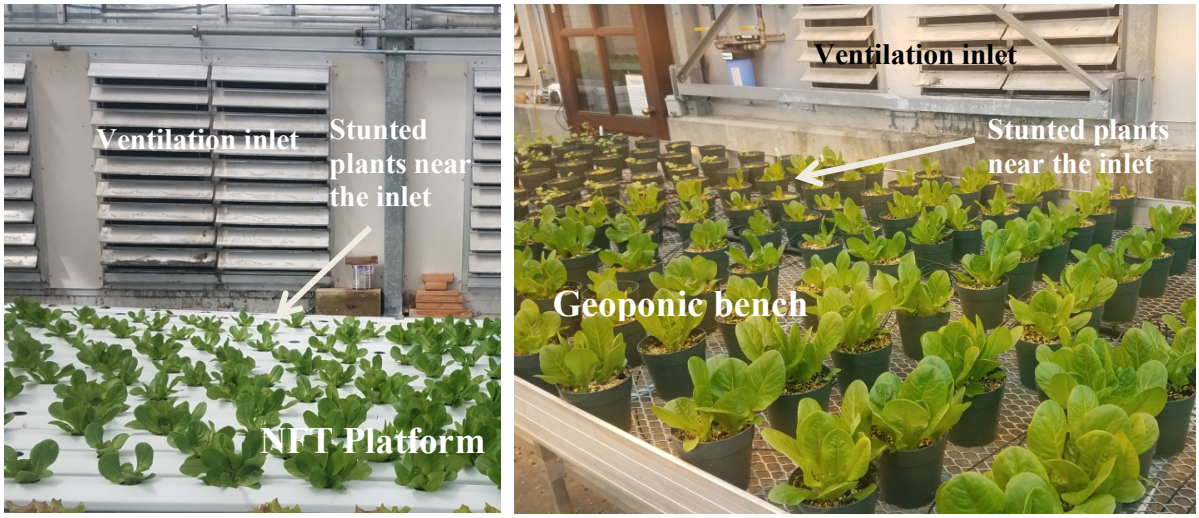


Figure 18. Plants grown in the NFT system (left) or one of the geoponic benches (right) and positioned closest to the wall mounted vents that let fresh air into the greenhouse showed reduced growth compared to those further away from the vents. ***Photos by Albert Ayeni.***

Food Safety Issues

Since some of the produce from the Indoor Cultivation (IC) room was used for human consumption, it was important that production practices met the FDA standards outlined in the Food Safety Modernization Act (FSMA). Listed below are the standards we adopted to comply with the minimum standards stipulated in the FSMA:

1. Provide an area designated for hanging coats, jackets, and other clothing, as well as backpacks, water bottles, phones, etc. that need to be kept out of the way while entering and working in the facility.
2. Set a minimum of two mice traps (with sticky pads) at strategic locations across the room. Traps should be placed on either side of any outside entrances and about every 20 linear feet of wall space.
3. Provide a hand wash station at the entrance of the room, so workers and visitors can wash their hands before entering the room.
4. Provide a foot mat at the entrance of the room for disinfesting shoes before entering the room (optional).
5. Provide a hanging rack for sweepers, brushes, other cleaning materials, etc.
6. Bleach-wash benches, columns, and troughs between growth cycles. Make sure the bleach product is labelled for food (*Home Depot sells a "germicidal" Clorox bleach product with the correct label*).
7. Workers are to wear gloves at all times when working in the room.

8. Sanitize vegetable cutters before and after use for harvesting (soak in a disinfesting solution before use).
9. Use a turbidity meter to monitor water quality regularly.
10. Packaging boxes for harvested produce can be used only once, and boxes cannot be re-used.
11. Keep the (cold) storage room for harvested produce clean at all times.
12. Keep the floor of the IC room clean at all times: remove all plant debris dropped on the floor or left on benches promptly. There should be a regular cleaning schedule for the space; use a daily cleaning schedule when there is work being done that impacts the floor.

At the time we operated the IC room, the FSMA standards were still being rolled out and more recent standards have not been included in this publication. For this reason, updates to the above listed best practices might be available and should be used. We mounted a poster explaining these food safety issues in the IC room, so that all individuals involved in crop production activities were fully aware of the food safety standards that were to be followed.

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Further Reading/Websites

<u>Selected books with information related to controlled environment crop production systems</u>

Geelen, P.A.M., J.O. Voogt, and P.A. van Weel. 2019. Plant Empowerment: The Basic Principles. Published by LetsGrow.com.

Kozai, T., K. Fujiwara, and E.S. Runkle (eds.). 2016. LED Lighting for Urban Agriculture. Springer Science + Business Media Singapore.

Lopez, R. and E.S. Runkle. 2017. Light Management in Controlled Environments. Meister Media Worldwide.

Nelson, P.V. 2012. Greenhouse Operation and Management, 7th Edition. Pearson.
Resh, H.M. 2013. Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower, Seventh Edition. CRC Press.
Sonneveld, C. and W. Voogt. 2009. Plant nutrition of greenhouse crops. Springer.
Stanghellini, C., B. van 't Ooster, and E. Heuvelink. 2019. Greenhouse Horticulture: Technology for Optimal Crop Production. Wageningen Academic Publishers.

Selected websites with information related to controlled environment crop production systems

Cornell University CEA Program: http://cea.cals.cornell.edu
Michigan State University: https://www.canr.msu.edu/floriculture/resources/light-management
The Ohio State University: https://u.osu.edu/cepptlab
University of Arizona CEAC: https://ceac.arizona.edu
University of Georgia: https://hortphys.uga.edu
Utah State University: http://cpl.usu.edu

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