AGRO-ENVIRONMENTAL TECHNOLOGY GRANT PROGRAM

FINAL REPORT

Solar Powered Cold Frames for Hydroponic Production

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ABSTRACT

A research and development project was undertaken to compare several variations in hydroponic growing strategies. The primary crop utilized was salad mix; a blend of various types of lettuces and greens made by harvesting only the largest leaves of the plants. Additional crops included herbs and squash. The two primary growing systems utilized were a tank system, referred to as a flooded basin technique, and a gully system using the nutrient film technique. Two tank systems and one gully system were located inside a greenhouse and two gully systems were located outside that greenhouse. One tank system and the greenhouse gully system were on the same recirculating loop thus had the same nutrient supply. A number of comparisons were made on crop production and yield of the various systems.

INTRODUCTION

Coonamessett Farm is a twenty acre farming and research enterprise located on Cape Cod. Crops include small fruit, vegetables, bedding plants, and flowers. Research and technical consulting services are offered in small scale agriculture, aquaculture, and fisheries. In 1997, Coonamessett Farm received funding under the Ag-Tech program to develop a polyculture system utilizing tanks that could be used for greenhouse production of either plants or aquatic animal crops. We now have this tank based system in place and fully operational. As part of the polyculture project we monitored the system and collected data on the hydroponic production of salad mix. Salad mix production includes lettuce, greens, herbs, and edible flowers. The polyculture system worked extremely well. The current project, reported here, continued to utilize the tank based polyculture system, to compare with gully systems, in order to evaluate hydroponic growing strategies for salad mix both in and outside of greenhouse structures.

Production of bags of pre-washed salad mix is a $1 billion industry nationwide with 600 million bags being sold last year. Ten million bags were sold in Boston in 1997; a 7 percent rise in sales compared to the previous year. Freshness is now being recognized as the key to the nutritional value of salad mix thus there is a growing opportunity for local producers to compete with the large western growers that currently dominate the market. Product variations are also of interest to chefs. Our work to date indicates that low cost hydroponic systems for salad mix may be a viable production alternative. Hydroponic systems are significant from an environmental perspective because the systems recycle water and contain the fertilizer.

Coonamessett Farm produces salad mix bags in two sizes; 8 oz for individual consumers and a 5 pound restaurant pack. We find an almost unlimited demand from restaurants during summer months on the Cape for our product as long as we meet the market price which is dictated by what comes off the plane from California; currently $4 per pound delivered. The restaurants prefer our mix because it contains the blend they desire and has a long shelf life due to its freshness. Our mix contains primarily larger leaves of lettuce and greens; it is not the typical “baby” mesclun mix. The demand for our individual bags is overwhelming during the summer as well. The 8 oz bags contain lettuce, greens, herbs, and edible flowers. The bags wholesale at $36/dozen and retail for $3.99 each. The high amount of labor to make these bags has limited our expansion into this market at present.

We have experimented with all types of strategies to grow the salad mix in the field and in the greenhouse in order to reduce production costs. The Ag-Tech funded polyculture system has now provided us the means to investigate further improvements in growing the crops hydroponically. Crops grown hydroponically use water and nutrients more efficiently. They can be planted at higher densities and grow faster than in soil culture. The more controlled environment reduces the need for pesticides compared to field conditions. From an environmental standpoint hydroponic recirculating systems completely eliminate chemical runoff (no groundwater pollution with salts).

Project Summary

Our objective was to determine which method of hydroponic production is best suited for growing salad mix. Optimizing salad mix production may be quite different than growing heads of lettuce for market. One big difference is that salad mix is sold by weight. In the first six weeks of operation of our polyculture system during the previous project we harvested 97 pounds of lettuce leaves from the 128 square feet of growing area. These leaves were blended with field grown lettuce and greens to make the final product. The field grown product seems to be heavier and more resistant to tearing and blemishing. This mix retails between $4.00 -$6.00 per pound depending on package size. In addition we harvested several pounds of hydroponic basil tops that were also used in our packaged salad mix. Roughly speaking this translates into about one dollar per square foot per week of production in this seasonal period.

In the polyculture project the lettuce was grown using a tank based float system. The nutrient solution is constantly maintained at a depth of two inches in the growing tank and recirculates continuously. The crop is supported in net baskets placed in holes cut in a sheet of Styrofoam that floats on the nutrient solution's surface. In this current project we compared the polyculture growing strategy with a nutrient film technique (NFT). The NFT system was designed and constructed as part of this project and will be detailed in this report.

Bio-cord technology is being used as a means of maintaining water quality in the closed polyculture system as part of our project. The cord is basically a core covered with many rings of thread that provides a large surface area for the attachment of microbes. In the first four weeks of operation of our hydroponic system, during the polyculture project, the pH values were found to fluctuate considerably and dropped quite rapidly. We tried to buffer this movement by adding ground limestone and crab shells which seemed to help reduce the fluctuations and rate of pH decline. However, as the Bio-Cord filter began to age and get covered with algae the system pH stabilized. We do not know if there is a correlation here and attempted to research this aspect of system operation. Biological filters may have a stabilizing affect on hydroponic systems. We attempted to study how the filter impacted nutrient consumption and balance.

Temperature is very important in lettuce production. High greenhouse temperatures can be a problem. High electricity costs accrue since ventilation fans run almost continuously on sunny days to keep the temperature down. We compared similar NFT hydroponic systems; one located in the greenhouse and one located outside the greenhouse. In Australia, 180 acres of hydroponic lettuce are grown outside on NFT gully tables with wind barriers and shade screen as the only protection. An outside table-based hydroponic system eliminates one of our biggest problems; weeding. During our project, compared to field growing, cut worms and root eating nematodes were eliminated as a concern; stem rots were minimized. Other problems surfaced, primarily wind related, as the project proceeded.

Statement of Objectives

1. Operate two types of hydroponic production tables using float and NFT techniques in the greenhouse in a manner that the production can be compared.

2. Design, set up, and operate a low cost NFT system outside the greenhouse that can be compared to a similar system located inside the greenhouse and field production.

3. Utilize Bio-Cord filters in a controlled experiment in the greenhouse system to determine the product's impact on water quality maintenance.

4. Monitor and record production parameters including crop yields, environmental and economic data.

5. Write a report completely documenting the project's results.

Facilities

The tank system and one set of NFT gullies were installed in an existing 30' x 96' greenhouse on Coonamessett farm. The greenhouse is heated by a Seibring Model OT210 oil heater controlled by a Dayton single stage thermostat. Ventilation is provided by two 48-inch fans and two thermostatically controlled shutters. The greenhouse is covered with doubled poly and the floor consists of gravel. The water supply is from a well.

SYSTEM DESIGN

Tank (Float) System

The polyculture tank design was driven by the need to hold at least eight inches of water for aquatic species. A twelve inch tank depth was chosen to allow for additional flexibility. The tank width of 48-inches was a compromise between the three proposed uses. The tank length of 96-inches was flexible. We found a boat builder in Rhode Island that had a mold for a worm growing tank that met our need. He was willing to supply ten 3/16" gel-coated fiberglass tanks at his construction cost ($225.00) because of his interest in aquaculture applications.

The ten tanks have been piped together in two systems. Each system has two under-bench holding tanks. One holding tank contains the Bio-Cord filter and is connected to the second tank that contains a 1200 gph submersible pump. A U/V sterilizer has been connected so that it can be placed in-line with either system. The tanks are blocked up slightly on the inlet side to allow for easy draining during cleaning.

The tanks are supported on a table type structure. The design load specified was one cubic foot of water per square foot of bench area (65 lbs/sq ft). The structure is assembled with Speed-rail fittings and 1.25-inch inch galvanized steel pipe. In fact, it would be much less expensive to build standard greenhouse benches using this approach compared to marketed greenhouse bench systems for the same design loads. The bench assembly took two men about eight hours. The tank builder recommended that the bench have a continuous solid top so the bench was covered with three-quarter inch plywood supported by 1 x 4 cross-pieces on 24-inch centers laid flat. The top was secured to the steel bench by the use of galvanized pipe clamps. This is not an optimal design but it works. In the long-term builders may want to consider a closely spaced galvanized steel cross section (i.e, square tubing) to support the tank tops.

In each tank system the water flows from a 1200 gph submersible pump, in continuous operation located in the holding tank, either through a recirculating line or an electrically controlled valve to the tank inlets. The recirculating line can pass through the U/V sterilizer and back to the filter tank. This line also contains a venturi that aerates the water and/or injects ozone from the ozone generator on the sterilizer. The tank inlets contain manually controlled valves to adjust the flow rates. The outlets of the hydroponic tanks in System One contain stand pipes to keep the water level at two inches; the hydroponic tanks in System Two have stand pipes that maintain eight inches of water because the system contained golden shiners and crayfish. The hydroponic tanks contain sheets of foam with holes for plastic net baskets. Lettuce and other crops are started in oasis cubes and are placed in the net baskets. Additional aeration is provided by a separate blower supplying air stones in each tank.

Gully (NFT) System

Three gully systems were constructed in order to utilize the nutrient film technique (NFT). Each system is forty feet long by four feet wide and consists of five gullies. Each gully is constructed of four ten foot sections of plastic rain gutter, four inches wide and two inches deep, purchased at a local hardware store. The gullies are held up off the ground on a four foot wide table or frame constructed of four foot lengths of 2" x 4" lumber spaced four feet apart. In the outside systems, these crossbars are supported on legs made of one inch EMT tubing, cut into five foot lengths, held to the lumber by pipe clamps. The EMT tubing is driven into the ground to provide a slope to the table of 1/4" per four feet of table length; a total of ten inches for the forty foot table. The height from the ground to top of the gullies ranged from 3'6" to 4'4". The gullies are held in place by blocking attached to the crossbars. The legs of the inside system are made out of lumber and sit on cement blocks. The table slope is obtained by utilizing additional blocks at the high end and setting the blocks into the ground as required. The table has wooden bracing for stability.

The top of each gully is covered by sections of vinyl siding cut to the width of the gully. Two inch holes were cut into this cover at ten inch intervals providing 48 planting sites per gully. Two inch diameter plastic mesh hydroponic growing pots snap fit into the holes in the cover and reach down to within 1/8" of the gully bottom. In the wind-exposed outside gully systems the vinyl siding covers are held in place with tie-downs. Some of the vinyl covers were cut to fit inside of the gullies and were held up by small blocks. This allowed the net baskets to sit on the gully bottom eliminating the need for developed roots extending from the oasis cube.

The supply end of the gully system is closed off by a rain gutter end piece. A 3/4" poly pipe from the nutrient tank supplies a header with a valve above each gully. The discharge side of each gully is terminated with a rain gutter down spout that delivers the nutrient solution to a return pipe to the nutrient tank by gravity. In the inside gully system the nutrient tank is the same one for Tank System One. Each outside gully system contains an independent supply tank. The tanks are simply Rubbermaid 50 gallon plastic storage boxes with covers purchased at a local Bradley's store. The supply pump located in each tank is a Surpreme 350 gph mag-drive submersible utility pump powered by 110 volts (see Appendix).

Initially the outside gully system supply tanks were placed outside under the gully systems. As cold weather approached we moved the supply tanks inside the greenhouse to keep the nutrient solution as warm as possible. This worked very well.

Monitoring System

We continued the use of existing greenhouse and aquaculture monitoring systems. Continuous automatic data logging of the tank systems was accomplished with an Aquadyne Octopus 3000 environmental controller. Parameters measured were water temperature, ph, and conductivity. The system also has the potential to measure oxidation reduction potential (ORP). The unit can hold up to seven days of data, can activate electric controls, and send alarms. The unit can also be attached, via remote access, to a computer for downloading of data or continuous monitoring.

Two water test kits were acquired to monitor additional water quality parameters. The hydroponics test kit is used to measure pH, nitrate nitrogen, ammonia nitrogen, phosphorus, sulphate, calcium, magnesium, and potassium. The freshwater test kit is used for detecting lower levels of nitrogen and ammonia, alkalinity, carbon dioxide and hardness. An electronic test pen was used for routine checking of pH and conductivity (EC).

Bio-Cord Filters

The Bio-Cord, a man-made Bio-Reactor, was utilized within the polyculture system. Racks containing the Bio-cord were constructed of PVC and placed into the filter tanks under the bench. In spite of our efforts, we still were not able to conduct a controlled experiment of the Bio-cord filters because too many variables are uncontrolled. We firmly believe that the Bio-cord adds a great deal of stability to the system. Ph was highly stable and we never had a build up of nitrites or ammonia. The nutrient solution was biologically active; never sterile.

Nutrient Solutions

The control nutrient solution is a standard solution recommended by Peters. The mix for 100 gallons of solution consists of 5-11-26 Hydro-Sol (13 oz), 15-0-0 Cal-Lite (9 oz), and 10-0-0 Magnitrate (6.5 oz). The EC level of the components is 0.98, 0.74, and 0.34 respectively for a total EC value of 2.02. The EC level and pH are continuously monitored using an electronic data logging system and also checked using a Hanna Instruments Agritest pocket pH/EC pen. Calibration is routinely checked with test solutions provided by Hanna.

The experimental organic solutions are based on liquid fish and seaweed blends provided by Neptune's Harvest; a Division of Ocean Crest Seafoods. The fish blend had an NPK of 2-4-0.5. The blend contains a host of vitamins, amino acids, enzymes, growth hormones, and other micro nutrients. The supplier asserts that university studies have shown the product to outperform 20-20-20 chemical fertilizers. Our initial trials with this material had problems with foaming at levels needed for adequate plant nutrition.

We also experimented with a compost "tea" in one of the tanks in Float System One. Several pounds of compost were placed in a loosely woven cloth bag and placed directly into the tank. The water in this tank was not recirculated.

CROP PRODUCTION

Five tanks (tanks 1-5), referred to as Float System One, were placed into the hydroponic operational mode. Each tank was outfitted with an outflow standpipe that maintains a nutrient solution level of two inches. The nutrient is constantly recirculated so that the exchange rate is about four times per day. Each tank has two sheets, 2' x 4', of one inch thick Styrofoam floating on the nutrient solution. Each piece of foam has 36 holes for plastic mesh pots on eight inch centers allowing for 72 planting sites per tank. During part of the project we isolated tank four from the recirculating system and informally experimented with a compost “tea”. The other five tanks (tanks 6-10) were in Float System Two. This system operated in the same manner as system One except the nutrient solution depth was kept at eight inches and the tanks contained various amounts of golden shiners and crayfish throughout the project.

Three gully systems, set-up for Nutrient Film Technique (NFT), were constructed and placed into test status. One system (NFT One) was placed in the 30 x 90 greenhouse and two systems (NFT Two and NFT Three) were placed outside in the space between two greenhouses. Each of the outside systems consists of five 40-foot long gullies; a sump tank, and a pump. NFT One is provided nutrient solution from the Float System One recirculating system.

Up until July, 1998, we tested a number of crops in the hydroponic systems including lettuce, greens, herbs, squash, and edible flowers. At the end of July the hydroponic systems were cleared of most of the spring crops, cleaned, and set-up for a production experiment. There are five systems; four were placed into production throughout the summer and fall while the fifth, NFT Three, was modified. To summarize, System One contains tanks 1-5; System Two contains tanks 6-10; System Three contains gullies 1-5; and System Four contains gullies 6-10. System Four was located outside of the greenhouse. System Five also outside of the greenhouse, containing gullies 11-15, was left empty to allow for re-design. Systems One and Three run off the same recirculating supply.

The hydroponic solution during this production experiment was the same formulation in all systems as specified earlier in this report. Float System Two also contained crayfish and bait fish which were fed a minimal diet of fish flakes. The crayfish and bait fish thrived and reproduced in the hydroponic solution! This has significant ramifications for polyculture, or aquaponic, activities.

During the July period we had significant problems with lettuce and basil suffering major leaf burn in the outside gully system. To remedy this situation we installed row cover over the gullies for the production experiment which solved the problem. The row cover also protected the crop through several frosts late in this production period. System Five was modified to be closer to the ground to allow the row cover to completely enclose the gullies and ground underneath the system. In addition, the supply tank and supply piping were moved into the greenhouse to provide extra warmth during the fall/winter test period.

Crops

Initially we planned to try primarily varieties of lettuce and greens. Johnny's Selected Seeds provide us some promising varieties of lettuce to test. The variety names and Johnny's descriptions are as follows:

Two Star (51 days): A darker green and slower bolting Waldmann's type. Waldmann's is a dark green Grand Rapids type with frilled, ruffled leaves forming a well bunched head. Two Star is darker green, somewhat less frilly, sweeter flavored, and about a week slower to bolt. The head tends to stay open.

Samantha (45 days): A compact red oakleaf with lobed red leaves. Deep wine red color like Red Salad Bowl, but the heads are much more compact and earlier. Recommended where Red Salad Bowl can get too large, and for the greenhouse.

Loma (46 days): A green summer crisp with extra crisp green leaves. Frilly, compact, and crisp. Early to form dense heads with frilly, toothed deep green leaves. Excellent tender, crunchy, mild taste. Head is about 3/4 that of a regular green leaf type. Resist tip burn and bolting.

Sierra (48 days): A French-bred Summer Crisp lettuce that has shiny, slightly puckered and wavy, bright green, red-tinged leaves. As Sierra matures the outer leaves form a whorl around an upright, oval head with a cream-colored, crisp heart. Tip-burn, bottom rot, and bolt resistant, for growing spring, summer, and fall. The best-tasting red-tinged Summer Crisp variety.

Diamond Gem (42 days): A baby green bibb that matures early into a "mini-romaine". Upright, compact. For year-round outdoor and greenhouse production.

Pirat (46 days): A red butterhead lettuce especially for warm weather crops. The medium green, gently savoyed leaves are overlaid with a soft brick red. Medium large, well folded, tender hearts. Reliable and well adopted to growing throughout the season, spring through fall.

A number of tables are attached to this report. There were many variables that had an impact on the results that are difficult to analyze. We had significant problems related to aphids and leaf eating caterpillars (referred to as worms in the tables). We were hesitant to apply chemical and biological sprays because of the crayfish and bait fish in the systems. During the production period we did develop strategies for dealing with these pests which will be detailed in this report.

Results

As previously stated, there were a large number of uncontrolled variables during this project. For example, if aphids set upon the plants in one of the tanks their growth was stunted compared to plants they were being compared to at another location. Thus the comparison was more affected by the presence of aphids than, for example, the hydroponic methodology and the results could not be quantified or attributed to a particular test condition. Other problems of this nature besides aphids were cabbage moths, mechanical failures, tip burn, bottom rot, inadvertent harvest (usually by PYO visitors), etc.

When things worked right the test method was as follows. Each tank was divided into four eighteen plant sections. Each section was planted one variety of lettuce or a lettuce mix chosen at random. These lettuce starts were in oasis cubes and when placed in the net pots did not have roots extending beyond the baskets thus they could not be placed directly into the gullies. There were at least two replicates of each variety. When roots were established on the transplants, one set of each variety were moved to the gully systems.

The results of the August through October experiment are contained in the appended tables. The first point made obvious in the summary table is that Tank System One significantly out-performed Tank System Two. There were a number of reasons for this difference in performance. Only three of the five tanks in Tank System Two were being utilized for growing lettuce; the other two tanks contained herbs and squash. Of the three lettuce tanks, two (tanks 8 and 10) came under heavy caterpillar damage without being observed. This lead to rotting of the leaves.

If we compare Tank System One to the Inside Gully System (NFT One), both on the same nutrient supply, we find the gullies outperformed the tanks. One major reason for these results is the head spacing; there was a lot more room for the heads to grow in the gully system. Additionally, aphid and caterpillar attack was easily observed and treated. Each tank has 32 square feet of growing area with 72 planting sites; thus five tanks cover 160 square feet and have 360 plant sites. The gully system covers the same square footage (40' x 4') and the five gullies each contain 44 plant sites for a total of 220 sites.

A comparison of the inside gully system (NFT One, gullies 1-5) to the outside gully system (NFT Two, gullies 6-10) shows that the inside system may have slightly outperformed the outside system during this test period. The outside system was covered with Remay type row cover and produced some excellent whole heads averaging 0.97 lbs each. We were able to sell these heads for $2.25 at the Cape Cod Harvest Festival which is still substantially less, even with the additional processing labor, than what we would get if we sold the leaves from the head as salad mix.

Discussion And Other Observations

<u>Seed starting</u>: We have found the best way for our operation is to start the hydroponic

lettuce in oasis cubes. There is no oasis cube of the ideal size for our purposes so what we do is to take the 2" x 11/2" x 1" cutting sized cube and cut it into four pieces. It takes about ten minutes to cut 50 cubes into 200 pieces and place them into a solid 1020 tray. Then a pointed pencil is used to poke a seed hole half way into each cube. The cost of each cube comes to about one cent each with the labor. Seeding the cubes is a little more time consuming because we found it is best to get only one seed per cube. Two or more plants per cube do not grow as well as one and pulling out or pinching off excess plants is time-consuming. We usually get 90% or better on the germination usually within three days. We then can reseed cubes that have not sucessfully germinated. The trays of cubes are germinated on a light table using standard flourescent lights on 14 hours per day. The room temperature is kept between 55 and 70 degrees F.

Wind and cold: One of the many advantages listed when espousing hydroponics as a growing strategy is that the crop is grown under controlled conditions which usually means inside. As stated previously, in Australia lettuce is grown on outside tables from which our design was taken. We apparently have a much harsher climate than in the Australian growing area. Our main problem with our first lettuce and basil crop, planted in July, was wind burn. We located the outside gully systems between to east-west running greenhouses; the space between the greenhouses being ten feet. This turned out not to be adequate wind protection. The combination of wind and sun dried up the plants. When we planted the next crop (the August crop discussed above) we covered the gullies with hoops and row cover. This worked really well but added the extra work of lifting the cover to get to the crop. Our next generation system will rely on heavier duty row cover with velcro stripped hatches.

We then moved the nutrient tanks inside the greenhouse to gain some extra warmth as the season progressed. Since the row cover did not reach to the ground we decided to lower NFT Three so that it was closer to the ground; from 1.5' to 2.5 ‘ off the ground. The row cover then was stretched over ½" EMT tubing bent into hoops from ground to ground. The higher system, NFT Two, withstood below freezing temperatures up to December 15th before freezing up and losing the crop at 18 degrees F. The lowered System NFT Three went until December 23rd before freezing at about the same temperature. Higher flow rates would of prevented the freezing but the crops were not growing very much anyway to justify changes.

Economics: We ran Tank System One and the inside gully system from October through March in a salad mix production mode growing lettuce and greens (see Appendix table for weekly yields). The salad mix was being packed in 8 oz bags and wholesaled for $3.00 each to a local market and retailed at our stand for $4.00 each. Our average price received for this crop was about $7.00 per pound. We produced about 800 pounds of mix over a 22 week period averaging about 36 pounds per week or $252.00 per week. This yield came from 320 square feet of greenhouse floor space; thus the gross return was about $0.80 per square foot per week over the entire growing period. Given that the yields were higher in the fall this matched our previous experience quite well. All indications are that a greenhouse equipped with gully systems producing salad mix, provided there is a market, should provide a profitable return.

The cost of the gully system can be kept very low. Rain gutters sell for as low as $4.00 per ten foot section. Our forty foot long five gully tables required 20 sections for a cost of $80.00. Gutter connecting and end fittings added another $100.00 The 50 gallon nutrient tank cost $20.00 and the pump cost $36.00. Lumber and EMT tubing for the table cost $50.00; miscellaneous plumbing another $50.00. The vinyl siding covers cost $20.00 for a total cost of $356.00.

Cleaning: We did not maintain a sterile system. Our system was loaded with algae but this causes no apparent problems with the lettuce. Every now and then a piece of algae clogged the small feed lines to a gully shutting off the water flow. We normally replaced plants in a tank as needed. Occasionally we harvested a tank completely, took it off line, drained and scrubbed the tank. Some tanks were on line for more than a year without this cleaning with no apparent problems. We put in an additional 11/2" drain in each tank to facilitate draining and cleaning. The gullies were simpler to clean as they did not require draining and were more accessible.

Lettuce varieties: We used the six Johnny's Seed varieties identified in this report as well as a mix of many different lettuces. Two Star, Loma, and Sierra produced large numbers of heavy excellent quality leaves very important for salad mix sold by weight. The Loma heads were crisp to the point that the heads were fragile in transport; not important for salad mix production. The Sierra did not get a very red tinge at the leaf edges. Samantha was very compact and hard to pick for salad mix, however, the leaves were very nice looking. The plants did not produce much biomass. We had mixed results with the Pirat which seemed more susceptible to stem rot than the other varieties. We let these heads matured then harvested them and stripped them for leaves since they had tight hearts. The Diamond Gem tip burned easily and did not produce much weight. The leaves are nice in the salad mix. Of the mixed lettuces red and green romaine, salad bowl, and oak leaf are our best producers.

Insect pests: The insect situation in the greenhouse can be tough with a crop such as salad mix because the plants are around for a long time; sometimes three months in the winter period. We keep the greenhouse relatively cold; 45 degrees F at night, which helps some over the winter but not during warmer periods. We start controlling aphids from day one by utilizing biological growth inhibitors and insecticides (Naturalis-O, Azatin, Botaniguard), spray oils, and insecticidal soaps. When the plants reach harvest size we stop using soaps and oils because they leave a residue. As the biomass increase in the hydroponic systems it is difficult to make contact with the insects especially when they get down by the center of the plants. We do have lady bugs and parasitic wasps that control the aphids, however, the juvenile stage of the lady bug and the parasitized aphid are hard to wash off the leaves. The lady bug juveniles are ugly and have caused some complaints. The other major insect pest are caterpillars, primarily from the cabbage moth. They are hard to see in the tank systems because of the density of the product and they caused significant damage.

System reliability: In many ways the gully system (NFT technique) seems to outperform the tank system (flooded basin). The gully system requires less nutrient solution, is easier to maintain, and has a lower capital cost. There is one major drawback; it requires continuous power and uninterrupted flow. On a hot sunny day the crop can be lost in two hours if the flow of solution stops for any reason. Alarms and back up pumping can mitigate most of the potential causes of flow failure but a blocked line or gully is more difficult to ascertain. We had several failures of this nature. On the other hand, we ran one tank for several months without any recirculation; we just added nutrients and water as required every few weeks.

Nutrient solutions: Lettuce and greens are an excellent crop because the color of the leaves tells you when to add nutrient in plenty of time to correct any deficiency. We were not able to trace tip burning to any nutrient deficiency; tip burning seemed to be caused by temperature stress more than anything else. Straight organic solutions worked quite well at times; we grew some very nice squash plants in the organic solution. We did run into a major problem with trying to get nitrogen levels using organic solutions as high as with the chemical fertilizers. At those levels of organic solution there was major oxygen depletion in the nutrient solution; enough to kill off all our bait fish. Compost solutions also had high levels of nitrites and ammonia which did not seem to bother the plants. In examining all the nutrient solution under a magnifying glass we found that there were many living organisms present. There was some suggestion that these were insect larvae or possibly airborne zooplankton. We do not know and have no indication of the importance of this finding. We do know that our crayfish and golden shiners thrived and reproduced in the chemical hydroponic solution with no apparent ill effects.

CONCLUSION

This project fundamentally investigated the potential of outside gully systems, as utilized in Australia, as a growing concept in Massachusetts. As with nascent enterprise there were many problems that had to be solved. We did not solve them all but we believe we do have answers and plan to continue the development. The outside system can be a three season system in our area if use can be made of solar energy for heating the nutrient solution. Weirs can be constructed at the drain end of the gully to prevent flow interruptions drying up the crop. Ideally a gully system should be relatively portable and require no electrical power. Wind action on the crop needs to be dealt with effectively one way or another. One possibility is to enclose the gully system within a cold/hot frame structure.

Gully systems can be a part of a mixed use greenhouse operation if they can be made multi-functional. One idea is to widen the gully to six or more inches across with a removable cover. This way the system can be used as a bottom watering trough system for potted plants in the spring and then converted to hydroponics at other times. Portability would allow the system to be relocated outside.

Our purpose is not to develop a mono-crop type of hydroponic operation producing salad crops and herbs. We are interested in developing flexible growing systems for multi-crop operations. A gully system that can move in and out of greenhouses and to various field locations on the farm seasonally fits this criteria. We also desire the flexibility to use chemical or organic nutrient solutions. This project has allowed us to move closer to this objective.