THE DESIGNING, INSTALLING and MAINTAINING of a HYDROPONIC NFT SYSTEM for COMMERCIAL PRODUCTION of Lactuca sativa UNDER GREENHOUSE ENVIRONMENT CONDITIONS

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ABSTRACT

Commercial hydroponic vegetable production is on the rise all over the world, especially in regions where people are increasingly health conscientious, yields and quality are important, or traditional farming is impossible as in regions with non-arable lands. Hydroponics is a powerful tool for vegetable production; however, it does have technological challenges and cost barriers. This project explored the practicality of designing, installing, and maintaining a commercial hydroponic Nutrient Film Technique lettuce production system under greenhouse environmental growing conditions. A medium scale system was designed and installed in a greenhouse and then the growth stages and the scheduling of lettuce for commercial production was practiced and studied. Lettuce grows rapidly from eight to 13 weeks and is suitable for quick harvest times in a hydroponic NFT system. The scale of the NFT system used to produce lettuce will depend on the customer base for any particular grower. Whether producing lettuce on a small scale or large scale, the proper cultural conditions such as light, nutrition, and temperatures need to be met in order to grow healthy and good quality plants. When considering commercial production, always consider customer base and proximity with regards to transport of the finished product.

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Introduction

The purpose of this project was to explore the design, installation, and maintenance of a hydroponic vegetable system under greenhouse conditions. Undertaking the entire process from beginning to end was a primary component to the learning process of how to successfully manage a lettuce production system. Becoming involved with the development with the system can allow for customization of the design for specific needs as well as allow for flexibility in the price range one is willing to spend to get the job done. Along with the design and installation of a hydroponic vegetable system, a primary focus of this project was to observe the cultural aspects of growing a particular crop in order to produce a commercially acceptable product, free from any diseases or pests or other cultural imperfections.

Currently there is a major trend towards locally grown produce and as well as being very health conscientious about the foods we are putting into our bodies, and how they may have been treated or managed when produced. Growing locally via hydroponics can allow a grower to be very confident about the quality control exerted over the product, as well as ensure the peace of mind about what actually goes into producing your produce. There are many options from synthetic to organic solutions that can be incorporated into hydroponic systems which allows for a versatile approaches for different grower needs and preferences. With closed systems a grower can essentially exclude potential pathogens and pests that would otherwise be a serious threat to the traditional grower who would typically be in the field where much less control can be exerted over the system.

This project was carried out at the newly installed hydroponics greenhouse C at the California Polytechnic State University Crops Unit. After determining the space that would be allotted to the various vegetable crops of the 36' X 48' house, it was determined that a region located along the West pad wall would be dedicated to a permanent re-circulating hydroponic Nutrient Film Technique (NFT) system that would be installed to continually cycle crops on a commercial production scale. For the duration of this project, the specific crop that was under study was lettuce (Lactuca sativa) of various cultivars; however specialty herbs, strawberries, and other crops are equally suitable to be grown in a similar system.

Included with a complete outline of how to implement the system and get it up and running for successful crop production, are valuable lessons which were learned along the way that will hopefully alleviate some of the stresses from being re-encountered by anyone wanting to start a project or enterprise such as this. In general, this concept can be scaled to the most modest of commercial scales, providing enough lettuce for a small local customer base or store, or up to much larger scales which are suitable to provide produce for whole cities or regions adequately. The hope of this report is to assist a designer or grower in establishing a successful production system under any scale desired from modest to massive.

Literature Review

Background of Hydroponics

Hydroponic History

Hydroponics is the art and science of growing plants with water and without traditional soil. Hydroponics essentially means working water and all great cultures have discovered its possibilities from the Aztecs, Chinese, Egyptians and Greeks (Resh, 1995). There are many different types of hydroponics from simple with no moving parts to complex systems that require monitoring and attention to detail. Some of these systems include ebb and flow, deep water culture, soil-less medias with or without drip emitters, nutrient film technique (NFT), aeroponics, and variations thereof. The NFT system was developed in the 1960's by Dr. Allan Cooper who was attempting to produce a system that has a recirculating film solution high in oxygen flowing at a low flow rate in wide troughs with a flat base and no depressions or stagnant points surround the root zones. This system has the great advantage of utilizing a low volume of solution which can easily be cooled in the summer or raised in the winter to provide the root zone with the optimal temperatures for growth (Morgan, 2007).

Originally a high priced venture, hydroponics has greatly reduced in price and has become more versatile due to the use of plastics and the overall demand for products relating to hydroponics. Hydroponics is a fast developing science that is bound to undergo tremendous development in the future which has been demonstrated by it use in submarines, in space, and in third world countries to meet the demands of both the need for food and growing populations (Resh, 1995).

Vegetable Production

Vegetable production has long been practiced to meet the food demands of societies, but in the 21st century the population levels are so large that shortages are inevitable. Couple this with the fact of crop failure and a changing environment, and the only way to meet the food demand is to confront production of food with emerging technology. In this way, production of vegetables has moved from solely field grown to being grown in greenhouses as well where more food can be produced throughout the year, taking advantage of the winter months. In the United States, hydroponic vegetable production is typically done in greenhouses, and originally began in the Northeast. Due to higher light intensities production has shifted toward the Southwest. Tomatoes are most commonly produced, followed by cucumbers, Leaf and Bibb lettuce grown in cooler areas, and other popular crops such as peppers, eggplant, and herbs like basil (Dickerson, 2001). In New Zealand, 10-20 hectares are dedicated to lettuce product via NFT alone. Common lettuce types produced are Butterhead (Boston Type), Crisp Head (Iceberg Type), cos (Romaine Type), Oak Leaf, Salad Bowl, and loose leaf types. Popular Bibb varieties include ‘Ostinata’ and ‘Salina.’ Popular Leaf lettuce varieties include ‘Waldmann’s Darkgreen,’ ‘Grand Rapids,’ and ‘Ruby’ (Dickerson, 2001; Morgan, 2007).

Greenhouse vs. Field Production

Greenhouse growing provides more control over the environment than growing in the field. A NFT system will work outdoors for production; however, issues such as the weather extremes and pest pressure will potentially cause issues with production. Therefore, a NFT system is typically installed in a greenhouse, where the controlled environment allows for superior control of the system (Morgan, 2007; Resh, 1995). Hydroponics and the Infrastructure can be expensive on a production level costing hundreds of thousands of dollars as an investment, followed by variable expenses. Field grown can be produced for much less, but also produces much less and isn’t capable of meeting the winter demands on a local basis as hydroponic production can. The vegetable greenhouse area under production in the United States is ~600 hectares with consumption, production and imports of vegetables rising steadily, especially during winter months. When comparing cost and production, it costs ~$600,000/hectare to invest plus variable costs to produce under greenhouse production, opposed to ~$3000-$16,000/hectare from California to Florida respectively under field production. However, current U.S. greenhouse tomato production produces 500 million tons/ha, whereas field grown production of tomatoes is only 32 million tons/ha (Cook, 2006).

Commercial Aspects

There is a great demand for fresh produce, and it is increasing due to the rising health consciousness of people. A great portion of this includes fresh salads, and the fresh cut Items is the fastest growing sector the American supermarkets. Great targets for any producer are the fancy gourmet consumers: restaurants, supermarkets, brokers, caterers, or produce markets (Morgan, 2007). Cropping times of two weeks can be achieved yielding 11,000 heads of lettuce each month under an area of 6,800 square feet or 632 square meters in an NFT greenhouse system (Resh, 1995). This production system implies that seeds are sown and grown to the six week stage elsewhere then transplanted into the system with only two remaining weeks to finish. This volume of production should be ample to satisfy most of the before mentioned consumer bases. Much variation can be applied at this level regarding the types of lettuce chosen to be grown and for which market, as well as how much to grow and how much space will be required to do so.

Pros & Cons

Hydroponics has both advantages and disadvantages. The advantages can be apparent to a grower with a high degree of competence and money to invest. However, these are disadvantages to hydroponics as well. It costs far more money than field production per acre to get started and then it can be rather difficult to operate without the proper maintenance (Anonymous, 2010). If these issues are overcome, then the true advantages are higher planting densities, non-arable land put into production, immediate control over the growing environment of the plant, and potentially higher yields and better flavor especially if sold locally (Anonymous, 2010). The flavor enhancement is due to picking and shipping ripe fruit to the market place as opposed to ethylene gassing to induce ripeness. Also it is thought to be achieved with tomatoes through a stressing trigger where a higher electrical conductivity may be used in induce a fruit with the taste beneficially affected (Anonymous, 2010). More benefits include lower water requirements for production, with completely controlled plant nutrition and environments light is the only plant limiting factor, there are no weeds or cultivation to deal with, no water stress on plants, and a longer shelf life especially with lettuce packaged with an intact root ball (Morgan, 2007). A benefit from hydroponics is that soils may have poor structure and harbor pests and diseases; however, when dealing with greenhouse hydroponics it may be more difficult to control some pest or diseases that in a field grown situation (Anonymous, 2010; Morgan, 2007).

Lettuce Requirements

Maintaining lettuce's required proportion of elements in the nutrient solution is required for proper plant growth and healthy saleable lettuce that will ultimately grow according to schedule. Seeds can come uncoated or pelletized to make handling easier. Seeds germinate in 2-15 days depending on conditions. Temperature should be below 20C for germination to occur. For hydroponics NFT production a highly hygienic media with a high water holding capacity is preferred but cost is also a factor as well as the system, as one system may perform better with various media mixtures. Common media used are Oasis, bark, pumice, perlite, vermiculite, rockwool, and potting mixes (Morgan, 2007). Once seed is sown, water in and do not water until seed has germinated to prevent stunting or retardation of seedling growth. Lettuce seed requires light to germinate so do not cover seed with media. Night time temperature are most important for this winter flowering crop, 46F (8C) night time temperature is ideal, and a daytime temperature range from 53-70F (12-21C) being acceptable. Once established in a NFT system, lettuce can use 5%-30% of the systems water volume per day (Resh, 1995). Lettuce in greenhouse NFT systems based on variety requires a spacing of 8-24 plants/square meter to receive adequate light and grow optimally. With butter head types, a spacing of 10 inches on center is best to allow for full head development (Overgaag, 2009). There is a general range of nutrient levels based on parts per million that has been developed over the past few decades, and has generally been more refined over the years as experience and understanding changed. The proportions of the elements in the solution with relation to each other, plays an important role in nutrient uptake and plant health and development. Nutrient levels are measured as a value of total soluble salts which are dissolved in a water solution; this total value is known as the Electrical Conductivity (EC) of a solution. The proportions can vary slightly, but what is of real importance is the EC of the solution which can have acute and chronic effects on plant growth. The fertilizer elemental requirements for lettuce are listed in Table 1 based on parts per million with respect to water in the reservoir. The ideal part per million of each element is listed in the bottom row of each elemental column in the table, and will create a nutrient solution with an EC value of 2.0 (Morgan, 2007).

Table 1. Recommended Nutrient Level Ranges for Hydroponic Lettuce

Element	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Bo	Mo
PPM Range	100-200 PPM	15-90 PPM	80-350 PPM	122-220 PPM	26-96 PPM	N.A.	5-10 PPM	0.5-1.0 PPM	0.5-2.5 PPM	0.1-1.0 PPM	0.4-1.5 PPM	0.5-1.0 PPM
Ideal PPM	206 PPM	52 PPM	247 PPM	186 PPM	52 PPM	68 PPM	6.5 PPM	1.92 PPM	0.25 PPM	0.07 PPM	0.70 PPM	0.05 PPM

Design of NFT Systems

Various Types of NFT Systems

All NFT systems attempt to maximize space whether they use vertical, horizontal, or movable gullies. Through experimentation it has been concluded that a trough with width of 80mm, a depth of 40mm, a length of 3.1 meter, and a slope of 1.5% with a flow rate of 0.2 liter/minute is ideal for production of lettuce. 1.5% - 2% slope is acceptable, while a 1% slope is not (Morgan, 2007). Most systems incorporate some sort of Polyvinyl Chloride (PVC) trough with various channel shapes, some with pre-punched holes or removable lids, supported by benches. Because it is a small plant, lettuce can be stacked or tiered up to eight plants high, but tiers of three have been found to be an ideal balance between production yield and quality and light reduction levels. Short run troughs are superior to long run troughs due to the aeration and replenished fertilizer levels of solution when compared to the large root to leaf ration of lettuce which can deplete a solution over a long run rather easily. Movable channels offer the best option for space maximization. The primary factors to be concerned with regarding a successful NFT system are the volume of solution reservoir, size of the pump in relation to water volume and height of water pumped, size and configuration of delivery pipes, and the drainage of the trough channels. Ideally allow for a buffer of 50% volume of solution, meaning that if the crop requires 25 gallons to fill the troughs adequately, there should be a 50 gallon reservoir, which will leave 50% or 25 gallons in the reservoir at all times buffering the nutrient solution (Morgan, 2007).

Home vs. Commercial scale systems

Of the 10-20 hectares of NFT produced lettuce in New Zealand, a great deal is produced by both home and commercial growers alike. This is part is the reason for the discrepancy of the figure stated. There is not enough data to conclude a precise number of all producers ranging from the off the grid grower to the grower growing for wholesale markets. The range is stated as being from one quarter acre being produced on a private scale to many acres for commercial operations (Morgan, 2007). Home scale systems can be of the size to simply supply personal needs, whereas a commercial operation may grow tens of thousands of heads a month. A balance will be struck based on the market demand and what can be afford, hence the need to figure costs and the quantity of lettuce produced whether growing for a profit or just a single household. A home system could pay for itself rather easily with regards to costs and productivity. A large commercial system will cost considerably more, which is the most limiting factor for startup businesses (Morgan, 2007).

Available Space

Any system requires a well designed layout for ease of maintenance and cleaning, as well as for efficient delivery of the nutrient solution to the troughs and back from the reservoir. The nutrient reservoir linked to stock tanks containing fertilizer solutions, acid tank for pH adjustments, as well as the pump and irrigation are all usually housed inside the greenhouse, or in an enclosed space outdoors.

However, if the home owner has land available upon which they would like to build a greenhouse, and growing commercially becomes a serious option, then planning for potential market products being produced in order to gauge the possible production levels and space required to accomplish those numbers is vital (Morgan, 2007).

Site Location

Regardless of size, the proper location is essential to growing successfully. A greenhouse is best suited for production, especially during the winter months, when it is positioned with full exposure to the sun. This will ensure the maximum amount of light will enter the structure providing the most energy for photosynthesis and plant growth. It would be ideal to have access to roads, and potentially even freeways or routes for distribution should the scale necessitate transportation over distance. The site should be for the most part level, and be chosen in an area with the most amount of sunlight available during the day with the least amount of wind. A site that is located near a large population is helpful for the commercial grower, intending to sell locally (Resh, 1995).

Installation of an NFT System

Typical Costs vs. Do It Yourself Costs

Costs of hydroponics can vary dramatically especially with the scale of the operation or system in mind. Costs are a huge part of setting up a system for the first time and more often than not unexpected events occur along the way which may or may not cost more money than intended. For this reason, sometime the do-it-yourself approach is not always the best approach. Experience with tools, and assembly of some form of irrigation system is highly recommended for a smooth installation of a system such as this. The system is simple, yet complicated at the same time, requiring all the simplicities to work in harmony. If the balance is upset the system does not function, and otherwise the crop will be unsuccessful. That being said, a successful installation is a must. Assuming a greenhouse structure exists for system placement, typical complete systems range in size and price dramatically. A modest 4’ X 4’ model with 30 lettuce head sites, and the bare minimum for the system to operate, costs $650 from Hummert International (Hummert, 2010). A small-medium scale system with 576 sites, and the option of harvesting 288 heads/week costs $8,350 and takes an approximate footprint of 15’ X 15’ and comes complete with a fertilizer doser controller and propagation system (American Hydro, 2010). A medium scale commercial NFT system offered from Crop King consists of ~6200 sites and costs about $21,000. This same system can be scaled up from the same supplier up to 16 times producing a large commercial NFT production system capable of producing ~75,000 heads of lettuce, but will also cost $262,000 (Crop King, 2010). A complete do it yourself option exists where a trough can be purchased by the foot, and all the individual parts of the system can be obtained, which may be more practical on the smaller custom design scale. These prices are all inclusive minus the labor in most cases, which can either save time or money, depending on ability to assemble the equipment properly or having it done for you. Depending on the scale and design, although hydroponics may initially be expensive, the installation need not be (Morgan, 2007).

Tools Required

Tools can be as simple as a drill, a mallet, a tape measure and a permanent marker according to the instructions that accompany the American Hydroponics 2012 NFT System Package (American Hydro, 2010). This is typically of a well designed and packaged hydroponics kit, the package includes everything you need to get started including instructions. However, as the scale increases the task becomes a bit more challenging. For instance the part numbers increase, assembly hours required to do the work increases, complexity increases as well as room for mistakes, and essentially becomes a project not just an assembly task. With the medium to large scale Crop King systems, although they claim to be complete systems a note at the bottom of their catalog states that additional items to complete the system are not included and the buyer needs to request a list of further supplies needed (Crop King, 2010). These are unknown costs. Other than paying for installation from a company who may offer the service, most installations will be do it yourself and they will save on the installation costs, as the equipment investment may already be substantial. Similar systems can be set up in greenhouses with open ground as opposed to concrete floors; however this issue will need to be considered with regards to sanitation practices (Resh, 1995).

Maintenance of an NFT System for Commercial Lettuce Production

Reservoirs and Pumps

Reservoirs in a NFT system are very important as they function as the source and sink of the fertilizer solution that is used in the system. In a delicate balance the system needs to have enough water to fill all of the troughs in use with a thin 1-3mm film on the bottom, as well as a 50% surplus or buffer of water to maintain a reservoir water level. This maintained reservoir level is critical to the system maintenance as it prevents the pump from running dry with no water which will ultimately burn out the pump. As well as losing a pump to overheating and burning out, the crop will then be left un-irrigated leaving the roots quickly exposed to the air where they will suffer damage if they are allowed to dry out. Reservoirs also need regular cleaning to both refresh the water and nutrient balance as well as to remove any algae or pathogens that may begin to build in the water (Resh, 1995; Morgan, 2007).

Water Concerns and Fertilizers

Water quality is a big issue with hydroponics. The water may contain sufficient or even toxic levels of micro elements or even unwanted elements or compounds. Therefore initial water tests are recommended to ensure that you account for these figures when creating your final solutions of fertilizers based on crop needs (Resh, 1995). Fertilizers can become out of balance as the crop grows as well as when the solution ages. For these reasons it is recommended to do reservoir change outs and cleanings monthly and never more than 4 months apart (Resh, 1995). High levels of fertilizer will burn plants and cause reduced yields, lettuce does not require high levels of fertilizers to grow well just the right proportion. Do not mix solutions over an EC of 2.0 and aim for 1.0-1.5 based on results. Use half this strength when propagating. Adjust the pH of the water to around 5.5-6.3, with the range around 6 being considered more beneficial (Morgan, 2007).

Sowing, Transplanting, and Trough Shifting

Depending on your demand schedule and the growing season, sowing, transplanting and shifting may be occurring weekly, bi-monthly or monthly. Lettuce can finish anywhere from 7-13 weeks under ideal to slow conditions. Typically a grower will sow and let seed germinate and grow for 3 weeks, then transplant to small liners or pots for 2 or 3 more weeks, then under ideal conditions after only 2 weeks in the actual NFT system the lettuce should be a finished head. During the winter season, after the 5 weeks in the germination and vegetative phases, the lettuce can take up to 8 weeks to finish in the system opposed to the 2 weeks to finish as in spring. This process will need to be developed for your schedule and demand as well as location and time of year (Morgan, 2007; Resh, 1995).

Sanitization

Starting with a clean system does not mean it will stay clean. To keep a pristine clean working and growing environment takes practice and a lot of effort. This effort can make all the difference in a crop that is to be a success or a failure. A clean system will promote proper plant growth and water flow and does not contain pathogens, algae, or odors. This is critical issue considering that the system re-circulates and all the plants are exposed to the same solution. Keeping any plant debris out of the system is vital, as well as blocking out any light from penetrating the flowing solution to discourage algae growth. Lettuce is prone to water borne pathogens so good sanitation practices are essential to avoid these issues (Resh, 1995).

Inspection

Once in place, the system needs to be monitored basically on a daily basis in order to keep a current perspective of the state of the greenhouse. With the great rewards of hydroponics, comes great responsibility (Morgan, 2007). Lackadaisical action will only result in worse problems regardless of what issues may arise. With water levels, make sure to replenish if low, and check daily to avoid pump and crop losses. Constantly monitor for insects, pests, and diseases and if possible isolate and remove the problem immediately (Morgan, 2007; Resh, 1995). Problems are more often more difficult to get rid of than to prevent in the first place. Be especially vigilant when encountering any pest at all as small problems turn into larger ones when untreated. Monitor temperatures of both the house with day and night temperatures, to better understand the crop's growth, and the nutrient solution in order to provide the best growing conditions at all times (Morgan, 2007; Resh, 1995).

Materials and Methods

A basic outline of the procedure taken to the project was as follows. Initially the location of the hydroponics system was located within the greenhouse space available. Once the location was selected the design and layout of the benches was determined in order to support the troughs. Once installed, the benches were set at a 2% slope towards the reservoir so that the troughs could drain. Irrigation was then run from the reservoir in between the benches to the higher ends of the troughs so that a complete cycle of water was maintained. A pump of adequate size was installed to maintain the proper flow rate. Initial water quality and pH were tested. The appropriate volumes and fertilizers were then calculated and added to the system. After calibrating the use requirements the AMI fertilizer injector system was then linked via an irrigation line to the reservoir to maintain the proper nutrient and water levels. The appropriate lettuce varieties were then acquired. The seeds were sown into the appropriate media and allowed to grow. When significantly large these seedlings were then transplanted into the NFT system where they began to grow.

Physical Materials

After the greenhouse in which the NFT system was to be installed was analyzed and the space that was to be available for the system was determined, a custom footprint for the system benches was drawn out on paper. Figure 1 and Figure 2 show the initially empty greenhouse space and a footprint diagram of where a potential system could be positioned within the house.

FIGURE 1. The Empty Greenhouse

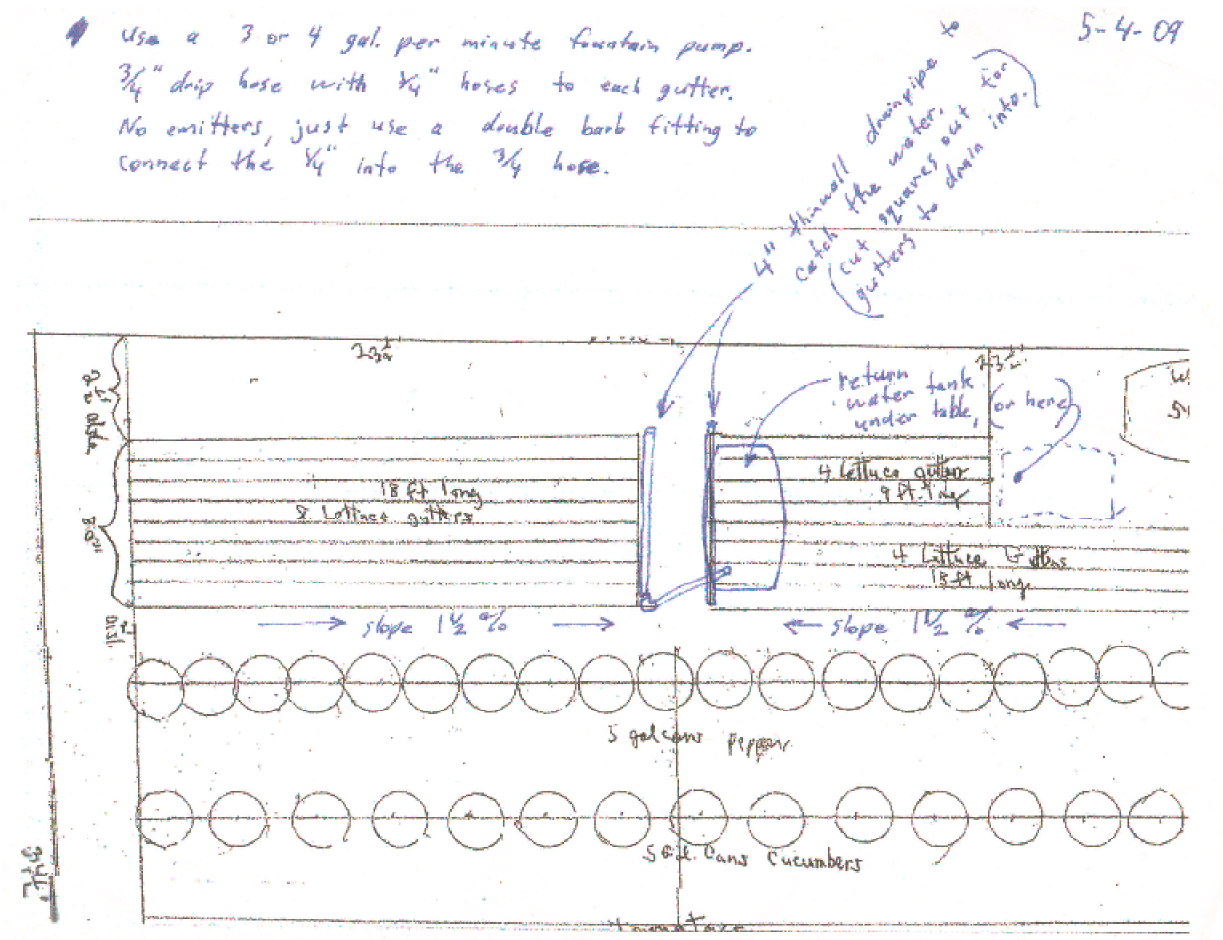

FIGURE 2. Initial Greenhouse Floor Plan Diagram

This system footprint was diagramed out on a layout of the house floor plan in order to understand its space relation to the other crops in the house. The footprint was used to create the design for the benches that were acquired from AgraTech. Tools required to get the system completely installed were fairly minimal. In order to get the benches properly set up, a chalk line was used to snap the location of the bench legs to the proper locations on the concrete for holes that needed to be drilled. A wax pencil helps for any other marks that need making. Once the holes were properly located, a Macho concrete drill was used to drill holes in the concrete in which anchor bolts were installed to anchor down the bench leg supports. A shop vacuum was used to vacuum up concrete dust. A drill and socket wrench set coupled with a wrench was used to assemble the benches together. After rough assembly, a level was used to properly slope the benches. Figure 3 below is a snapshot of the construction process, and Figure 4 and Figure 5 also below show the completed AgraTech benches.

FIGURE 3. Beginning of Bench Construction

FIGURE 4. End of Bench Construction I

FIGURE 5. End of Bench Construction II

Pete Overgaag from Holandia Produce was kind enough to donate the required troughs for the system as he owns and runs a commercial lettuce production facility in Carpenteria, California. We acquired 24 troughs. 18 troughs were 18' in length, 4" in width and 2" in height, and had 18 sites for lettuce heads. The other 9 troughs were 9' in length, 4" in width, and 2" in height with 9 sites for lettuce heads. The troughs atop the completed benches can be seen in Figure 5.

FIGURE 6. Bench with Empty Troughs

A 100 gallon general purpose tub was utilized as the reservoir for the system. A 1/3 horsepower pump to provide adequate flow required for the system. Half inch polyethylene Irrigation lines were used to run main water lines from the reservoir and pump to the feeding ends of the troughs. These lines were teed off with half-inch PVC valves and ells that fed each trough. Rain catching gutters were improvised to be used as trough solution catchers which directed the return trough water back to the reservoir to be redistributed. Figure 6 shows a close up of the systems reservoir, and Figure 7 shows the irrigation lines which feed the troughs.

FIGURE 7. System Reservoir

FIGURE 8. Trough Irrigation Manifold

A fertilizer injector system was linked to the reservoir system via solenoid valve and half inch poly tube. This was used to maintain a specific water level with the properly proportioned fertilizer solution and the optimal pH for plant growth, when configured properly. The fertilizer injector system used was the AMI Completa model. The fertilizer used in the system prior to specific formulation on the elemental part per million basis, was a generic 20-20-20 complete formulation blend of GrowMore fertilizer was used. In order to test the reservoir solution for the proper pH and EC a Bluelab Combo Meter was used in conjunction with the AMI Completa system sensors. The AMI Completa System can be seen in Figure 9 in the final stages of the installation process.

FIGURE 9. AMI Completa Fertilizer Injector System

Lactuca sativa 'Le Carre' was grown from seed in a ProMix media in plug trays typically of 96 plugs. Also used for propagation were Oasis, a soil-less media, plug tray flats and humidity domes. The light intensity inside the house was kept at full sun with the curtain open during the daytime. The environmental temperatures were kept at approximately 75f during the day and 65F during the night, with a relative humidity of 65% and 75% respectively.

Procedure

Prior to any action, planning took place. Measurements of the house and the space dedicated to the system were very important in proceeding. Once the measurements were taken, the numbers were sent to Agra-Tech who custom designed and shipped the NFT system bench supports to Cal Poly. The benches were promptly assembled and put in place. In order to do this, chalk lines were snapped onto the concrete where the bench feet were supposed to be anchored into the greenhouse floor. A concrete drill was used to drill out the holes required for the anchor bolts and after vacuuming out the concrete dust the anchors were hammered in. With the bolts in place, the bench leg supports were bolted in place on the floor and the bench legs were attached.. After the legs were erected, the bench's top frame was attached to the legs. After this the basic shape began to take form and the cross supports were screwed in along the benches length which were to support the troughs roughly every foot. After this step the benches were complete and only further leveling was needed to set each bench to the proper slope.

Having the benches installed in their correct locations, the reservoir was positioned in between the two benches, the benches on either side, draining towards the reservoir. To catch the water returning down each trough a rain gutter collector was improvised to catch the water and direct it back to the reservoir for a complete cycling of the water to be pumped out again. Following this step, the troughs were sanitized and then placed on the bench tops. Irrigation lines were installed from the reservoir beneath the benches to a distribution manifold at the head end of the troughs designed to divide up the flow evenly among the troughs. After installing the pump in the reservoir and linking it with the irrigation lines, the system was essentially complete and only required fine tuning of the water flow. With a reservoir of water, and a working pump, the water was able to make a complete cycle from the reservoir, through the lines, to the head of the troughs and through the troughs to the catch drain where it was directed back to the reservoir.

The troughs were spaced in a way to maximize lettuce production in the space available. The two benches each had 12 troughs, one bench with 12 full troughs, the other with six full troughs and six half troughs. They were spaced in such a way that the troughs always shifted to the west side of the house, and to have a weekly or bi-monthly harvest come from eight fully spaced troughs 10 inches apart, with the remaining younger troughs ready to space out in their place, and have the harvested troughs replanted at the beginning of the line with younger plants from the propagation bench ready to be planted. This would allow for a weekly harvest in spring considering three weeks germination, two weeks establishing, and then three weekly shifts through the system until harvest. During winter this schedule should expand to twice as long providing harvest every two weeks.

At this point, the design and install of the system was essentially complete and the hydroponic NFT system was fully functioning. However, that was on a static level. To prepare the system for lettuce production, lettuce was then sown, transplanted, and allowed to grow until they were large enough to be planted in the troughs. After having sown lettuce seed on the propagation bench and allowing for a developed roots system, the lettuce system was almost completely functional. Seeds were sown in 2 plug trays with 96 plug spaces with a ProMix media every week prior to this phase in order to build up enough lettuce seedlings to plant into the system at the right stage. After they were established enough they were planted in the first 8 troughs at a spacing of trough tight three inches on center. After a week these troughs were shifted westward to a spacing of seven inches on center and were replaced with 8 troughs with younger plants. After another week the original set of troughs was shifted into their finishing positions of 10 inches on center, the second set shifted into the middle position, and the last 8 troughs were planted with the youngest plants in the system.

At this point the NFT system was full of lettuce at three different stages, the oldest 8 troughs were the heads almost ready to harvest on their eighth week, the second oldest troughs were getting there on their seventh week, and the youngest troughs were beginning to develop on their sixth week. With a continued program of sowing, transplanting, and shifting, this cycle was maintained and lettuce was able to be harvest on a weekly basis. Adjustments to the growing schedule were made along the way making growth rate observations.

Summarizing and Analyzing Data

The way data was collected in the project occurred in a number of various ways but not in a tabular form. Statistical measurements were not employed, so actual values of plant growth such as fresh and dry weights and sizes or numbers were not recorded. Rather an assessment of overall plant health in the system and ability to produce a quality salable product was assessed. The numerical figures of note would be the pH and the EC of the nutrient solution; however, these figures were kept relatively constant through use of the AMI Completa system coupled with the BlueLab Combo Meter which allowed physical monitoring and adjustments of the reservoir solution itself. The EC was kept within the 1.0-2.0 range with 1.5 being average. The pH was kept around 6.0 staying fairly constant. This being coupled with a complete fertilizer formulation in rough proportion to the lettuce requirements of Table 1, the primary way of analyzing the performance of the system was observing plant growth and the adherence of the system to the proposed schedule. Root and shoot growth were constantly monitored as plant health indicators signs that the system was functioning properly. The foliage was used as an indicator of nutrient and water uptake, and the roots were used to observe the functionality of the system with regard to water flow, and oxygen availability, and potential algae or pathogen issues. Water flow entering, running through, and exiting at the end of the troughs were monitored to make sure the system was properly functioning. Often times, leaks were indicators that something was not working properly with the irrigation or flow and needed adjustment. Water levels of the reservoir were also helpful indicators of total water usage by the plants on a daily basis.

Results and Discussion

The Design and Installation of the NFT System

The system was designed and installed with a lot of hard work, extra effort, and time, but the end result was a system capable of lettuce production at a reasonable price. A true cost comparison cannot be made due to the acquisition of the materials that were required to complete the project from start to finish. Having much of the equipment donated or purchased on behalf of the university, only an assessment can be made on its functionality and construction. When it comes to the DIY portion of the project, I can assert that this project can definitely be done by anyone with reasonable experience with tools and a scope of what it takes to complete a job to the end. The designing and building phase of the project took the most time and work, but the maintenance portion of the project continued on throughout the project as reservoir and trough cleanouts needed to be done on a regular basis.

The building phase of the benches went fairly smooth without many unexpected issues arising. Some recommended tools for concrete work, which may be required to install a proper bench setup, are chalk lines, wax pencils, short and long tape measures, a concrete drill and bit set for anchor bolts, and potentially even equipment for small concrete mixes and pours. For bench assemblies the parts may come included and simple bolting together may be required, requiring wrenches and a socket set, others may require that you drill holes or cut in order to make pieces fit properly. What is important is that you look into the requirements for assembly before a decision or purchase is made, as this is a significant issue. A level will be required for setting the slope of the troughs to the desired 1.5-2% which turns out to be very important for the system to run properly. The tubes and fittings should fit together with little need of tools other than something to cut and puncture with. A keen eye for detail and proper planning will help the job go smoothly.

The ability to design and install a system such as this was a wonderful opportunity as it allowed me to understand the intricacies of a complex project and built my skills as a grower. Using a system to grow plants and creating one to grow plants in a particular fashion can be two very different approaches. That being said, one might not always want to start from scratch, and especially not if you do not have much in the way of equipment such as tools or parts to facilitate the job, as constant errands and trips to places to pick up a spare or unique part for the job had to be made throughout the project. Also, the propagation bench which was not in the initial design was built after noting a need for one considering the available space that remained free between the bench and the cooling pad reservoir. The bench is displayed in Figure 9 with cucumber, tomato, and lettuce seedlings being propagated.

FIGURE 9. Lettuce Propagation Bench

Maintenance of the NFT System

Once the system was in place, growing in the NFT fashion was interesting and rather productive. The system can be hard to balance in the sense that there are quite a few dynamics. The pump and its flow rate are very important to the whole system working properly. The height the pump has to work has a great influence on its efficiency and power it can supply. The tubes that feed water to the heads of the troughs can be a bit of a challenge as well. In an ideal system, there should be a pump with the proper pressure for the water head and the trough numbers, and the lines should be kept really clean to avoid and issues with particles clogging the lines and impacting flow. Also the flow through and out of the troughs needs to be monitored as roots may dam up the trough or algae biofilm may disrupt the flow of water back to the reservoir. With a proper cycling of the solution maintained the system works as expected, if not, water may be too deep in the troughs affecting root oxygenation, or even the overshoot the return drain running onto the floor. Running onto the floor can drain the reservoir, and burn out pumps. Pumps can also burn out if let to run dry as well, which happened during the project over the Christmas break with a lack of monitoring and attention.

When the system functioned, algae began to be an issue, but it was somewhat controlled via reservoir clean outs which are always recommended, however total control was not quite achieved. More on this issue should be explored as algae was annoying as a grower, and was most likely impacting plant growth on some level. It definitely disrupted water flow, which lead to other issues such as damming and dripping to the floor. Pathogens were never an issue in the system, however potential was there with leaf debris and insufficient sanitation practices. Despite the occasional leaf drop, and dead plant here and there from too much stress of some sort, most plants grew normally.

Production with the NFT System

In the beginning of the project, the light for lettuce production was plenty intense for growth and the temperatures were more or less in the ideal ranges, during the last months of 2009. Growth during this period was the best so far and most normal. With the exception of some Romaine we grew which bolted, the Buttercrunch which was planted in Oasis turned out really well. Over time it was realized that plugs of the ProMix both contaminated the system with soil debris and sludge unless they were really well rooted, as well as lead to poor root conditions which lead to spotty losses. It is important to note that greenhouse temperatures were not ideal for the lettuce plants, as we were growing tomatoes and cucumbers in the house as well, which require higher temperatures to grow well. Growth through January 2010 had temporarily declined under both the combinations of poor light due to weather, and high house temperatures. The system was overgrown with algae and nutritional formulations became an issue as the project ran out of the appropriate fertilizers. Taking this opportunity as an advantage, the system was completely cleaned out: troughs, irrigations lines, and reservoir. A reservoir lid and light deflectors around the trough openings were added to the system to attempt to reduce algae growth. A media switch was made using only Oasis, and new plugs were planted into the system for the spring harvest season.

While there is seldom a project that transpires without any difficulties, this project had its fair share regarding pest presence, nutritional and environmental issues, and pesticide applications. It should be noted that once you notice a problem, whatever it is, proper identification is the first step to the appropriate solution. Whether the issue is an unknown pest, or unknown plant symptom, research must be done diligently to find the correct solution to the appropriate causal agent (pest or pathogen). Whitefly and aphids posed particular problems and control was never really gained. However, the adult populations were somewhat suppressed by an insecticidal soap registered as M-Pede. If diligent applications would have been made at a much earlier pest threshold level, I believe the problem could have been controlled, but once populations became heavily established before any action, the any real control was practically impossible. Pesticide applications are an essential tool for gaining control, however these tools are among the last to be used in a successful integrated pest management programs, where good cultural controls, observational skills, and quick actions can render could be problems, as insignificant and curable problems. Nutritional formulations are essential and need to be maintained throughout the crops life as an utmost priority. Stressed plants do not grow as vigorously or produce nearly the same as unstressed plants are able to. Allocating the required fertilizer for the duration of the project ahead of time is a wise decision, as issues may arise where they are unavailable to you at that moment.

Production of lettuce is a tricky balance with light, temperature, hydroponic challenges, marketing issues, and all the other factors along the way. Through this project it has been proven to me that a commercial NFT system can be designed and installed in a custom do-it-yourself fashion and it can be maintained for production purposes once the kinks are worked out of your unique system. A strong importance should be placed on your market and what they would like to purchase, as there are many options to choose from and they will offer some direction for you as the grower. An even bigger importance should be placed on the cultural environment of your crop. Provide the best environment for the lettuce as possible, as our temperatures in the greenhouse were too high for optimal production levels of lettuce, but managed to produce decent heads. When all the factors are in balance, commercial lettuce production can be carried out successfully and the lettuce will be an easy sale, but when they become out of tune, quality and production may decline at a rapid pace, and the financial gain aspect of the operation may be circumvented. Figure 11, Figure 12, and Figure 13, which were taken towards the midpoint and latter stages of the project when sowing and transplanting had become more of a routine instead of an experimental trial demonstrate the various productive stages of the system as the project progressed from growing just one or two basic types of lettuce, into growing a variety of lettuce which was grown to meet a particular demand of some higher end restaurants or the local markets who expressed particular preferences, or just for observing various type and their performance results when grown in the system.

FIGURE 11. Growing Lettuce Heads Example I

FIGURE 12. Growing Lettuce Heads Example II

FIGURE 13. Growing Lettuce Heads Example III

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