A Hydroponic Garden Design

January 2004
(1st draft May 1996)

Forward

Since this was originally written, I have continued to modify the system herein described. The most significant changes include moving from a condensate pump to a submersible mag-drive pump, removing drippers and using 1/8" irrigation hose instead, and adding 2" PVC tubes in between the 3 main (4") tubes for excess seedlings (to support sexing). I have also added full-time TDS and pH monitoring capabilities.

I am noting this because the only part of this document that I have rigorously kept up to date is that of the nutrient formulation and summary appendix, page 27.

Table of Contents

1. Overview

The hydroponic garden design presented herein is the result of several years of development, using information from conventional commercial systems and methods. It was developed in the desire to have a good quality hydroponic method for the smallest possible space, without having to buy expensive and faulted commercial systems. Additionally, building your own saves the scrutiny that often accompanies the purchase of a commercial system.

This document will not try to cover all aspects of hydroponic growth -- it is only intended to provide one method that has been developed and proven. In addition, this document is still in development and should not be considered complete. Should you see something questionable, an error, or have questions, please feel free to contact the author directly.

2. Growth Area Requirements

Chose your hydroponic garden area carefully. Ideally, it should be an enclosed and lockable space such that entry and hence, pests can be controlled. For the design discussed in this document, a small room of approximately 5-1/2' by 8-1/2' by 6-1/2' high will be sufficient. This size should also provide supplemental seedling starting space as desired. Note that the ceiling of the area should be such that hooks and other support hardware can be put into the ceiling, and that there is at least one outlet group on each of the walls.

The area you select should be able to be sealed for light, both for security and for hormonal / flowering considerations. Sealing the room will also help you control pests -- which not only include insects, but also house pets and visitors. The area itself needs only nominal ventilation, typically only internal recirculation will be sufficient.

One further consideration should be made to facility ease of cleaning -- that of access to a floor drain and a water source. If it is not possible to drain directly onto the floor of the area you select, you should consider putting plastic over the area's floor to protect it.

If you do have a larger space, you may want to reconsider the PVC structure dimensions given in the drawing. As the drawings are presented, there is 9" center-to-center between plants. Expanding this may increase your yields. As an example, if you plan to grow full-size tomatoes, I have found that 12-18" would be a good range to consider.

3. Fabrication

3.1. PVC Structure

Fabrication of the design is mainly focused on the PVC growth structure. Refer to the drawings for dimensions and parts necessary. The fabrication should only require a PVC saw and a drill. Note that the PVC structure is designed to give maximum density for the area specified, while providing optimal growth and health for the plants. In constructing the PVC structure, construct the long sections first (the 3 growing tubes) and cement with PVC cement. If you desire the capability to take the unit apart, the interconnecting sections can then be cemented using silicon RTV. Finish the structure by drilling the 4" holes for the pots and the 1" air vent holes.

Before moving on, cement in 1-2 1/8" dowels along the entire length under the holes for the pots (either side of the bottom run) -- this will provide a support for fiberglass screening which you need to cut and lay in next. The purpose of the dowel / screen combination is to ensure that the nutrient return flow is unimpeded and that the roots have a place to run without sitting in static nutrient solution.

3.2. The Primary Reservoir

The primary reservoir is another area of attention and tools. The (condensate) pump listed in the appendix / parts list can be substituted by a submersible pump. {If a submersible is employed, skip the pump mounting instructions herein.} The (condensate) pump is mounted to a lexan plate which must be cut such that the unit bolts to it. Begin by taking the condensate pump and removing the basin that comes with it. Next, cut a sheet of 1/4" lexan large enough such that it fits over your reservoir tub with an overhang of 1-2" on all sides. Position the condensate pump such that it is against one of the lengthwise ends and so that it will sit almost on the bottom when mounted. Cut out the sheet and build the necessary supports to mount the unit. Next, drill the return hole (from the PVC structure) large-enough to accommodate the filter, but next to the opposite lengthwise edge.

Continue the construction with the fabrication of the nutrient level float assembly per the drawing. The float employs a standard microswitch (level switch) in which the actuator arm is a wire that you can replace with your own. You can find these at an electronic surplus house, mail-order, etc. Alternatively, commercially-available floats may be used instead. Modify the microswitch such that the arm is now a piece of stiff wire (like music wire) approximately 6" long. Mount the microswitch on a piece of lexan perpendicular to the reservoir cover, and provide a cutout such that the lever can extend down into the reservoir and that the position can be adjusted (use mounting slots). On the other end of the wire lever, affix this to the ping-pong ball through a small hole, using epoxy (sand the ball surface first).

Finish the reservoir plate by drilling and cutting openings for your aquarium heater (mount such that it sits ~1/2" above the bottom), thermometer remote, and the secondary reservoir hose.

Fit the plate onto the tub and recheck all. With the plate in place, mark a line just below the bottom of the condensate pump on both ends (max-fill line). Next, drill overflow holes on one end to prevent the tub from getting over-filled. With the condensate pump's cover off, adjust its float so that it will go all the way to the bottom of the tub (or just above) before it cuts out. Adjust the float assembly so that it turns on when the level drops ~1/2" below the max-fill line, and that it turns off at the line. Finish by marking the tub with maximum and minimum levels.

Wire in an 18 AWG AC power cable such that the black wire (hot) is interrupted by the level float's microswitch. Typically this will mean you want to go between the normally-closed and the common such that when the reservoir is full, the microswitch opens the circuit. Make the AC cable such that it has a plug on one end to plug into a timer, and on the other end, an AC 3-prong socket to plug in the fill pump.

3.3. Room Setup

Place the PVC structure into the space you have setup. Mount your lights, CO_2 lines and gas controls, fan(s)[1], and position the primary reservoir into place. Follow the drawings and configure / interconnect all. Make sure that the gas line is perforated along the length that it runs over the growing area, and that the end is terminated with some type of plug. Perforation can be done with a small drill bit.

When mounting your lights, make sure that you use eye hooks or cleats such that the lights can be raised and lowered with ease. The minimum height should be ~15" above the PVC frame, while the maximum should be the ceiling (or at least 36" above the PVC frame).

Now you will need to run the nutrient hoses and mount the drippers. Using the drawings, route the line as indicated. Note that it starts as 1/2" polyethylene hose, and drops to 1/4" vinyl at the drippers. Also, note that the section of tubing on which the dripper is affixed is wrapped with floral wire. This is to provide a means of bending the dripper to a desired position and having it stay there.

The last thing that gets set up is the secondary reservoir. I find the 10 liter (2-1/2 gal.) jugs the easiest to handle and they can be used in the space specified. For the line that goes into the jug, weight the siphon end with a 1-2 ounce egg-shaped fishing weight (with the center drilled out for the hose).

For longer reservoir durations (e.g. when I am away), I employ an 18 gallon Rubbermaid tub in which I have drilled a hose fitting to the bottom side. I then mark the inside off in 10 liter graduations and leave it outside the room with a line running in through a small opening. When I switch between the 10 liter jugs and the long-term

[1]Two fans are better for stronger stem growth -- one on each end of the room.

tub, I simply disconnect the line at the hand siphon pump.

Finish the room by duct taping reflective mylar such as that found with the low-cost reflective camping / survival blankets that can be found in camping supply stores.

While setting up the room, it is a good idea to setup a starter area with a single fluorescent fixture on a variable height chain, over a small bench. Use conventional grow tubes and timers as desired for this.

3.4. Programming the Timers

The timers are defined based on the number of cycles per day and collective output from the device being controlled. In most cases, the Radio Shack digital timers are employed as they have 4 separate cycles that can be defined. I have listed my setup for each timer employed in the appendices, with an explanation for the timing in the section on Rapid Growth, beginning on page 5.

Note that in the case of the system timers, one alternative that would provide for centralized (and remote) control, is the use of a computer controlled X10 system. Radio Shack sells such a package that runs on a standard PC using your AC outlets to communicate with remove control modules. In this system, up to 255 cycle times can be configured, versus the more conventional 4 for the digital timer modules listed in the parts list of this document. Such a system also provides both the capability to remotely monitor CO2, lighting, and temperature (with additional sensors), as well as to have a single remote shutdown control for security purposes.

4. Starting the Seeds

The most efficient way I have found to start seeds is through a product called AirFoam. These are seed starter foam cells, ~1" x 1" with a pre-cut hole for the seed. They are available for ~$10/50 and come in sheets. To use them, simply place *one* seed in each one, place the starters in a tray filled with water up to the lower section of the airfoam (~½") and place them under your starter lights. I typically see sprouts within 2-3 days. Should you use other starter types, you should avoid any soil-based products.

Also, when starting seeds, prepare twice as many as you have hydroponic spaces for. This will provide for loss during sexing and non-germination or unhealthy starters.

As for the seed germination period, your lights should be set to 24 hours and should be positioned ~6" above the starters. After the 1st week -- or when the roots start appearing out the sides of the starters -- slice the starters into individual cells (e.g., using a plastic putty knife) and separate them by about 1/2". This will ensure that the roots don't begin growing into each other's starter cell thus making it difficult to separate for transplanting. Typically it will be 1-2 weeks before you transplant into the main growing structure.

5. A Rapid Growth Cycle Method

One of the advantages of hydroponics is being able to control nearly every aspect of the plant's growth cycle. This includes being able to optimize the growth cycle for such factors as time-to-yield. In my work developing this garden design, I discovered certain techniques to increase the growth efficiency such as to increase the final yield. Those procedures are outlined below.

5.1. Moving in the Seedlings

When the seedlings' roots begin to creep out of their cells it is time to think about transplanting them into the hydroponic garden. Begin by running fresh water through the system for a couple of days under normal timing cycles (lights, fans, etc. as well). During this period, fill up the pots half way with the LECA (Lightweight Expanded Clay Aggregate) material such that it will have time to get its surfaces thoroughly wetted. Note that standard (4") plastic pots can be used but they should be liberally drilled with 1/4" holes to ensure the roots can grow out and down into the PVC tubing. An alternative is to make your own pots using hardware screen and coating them with plastic or polyurethane.

Just before you are ready to move in the seedlings, drain the system (use the drain cap while the pump is running, followed by draining the primary reservoir tank). Next, fill it with the first nutrient solution (rapid growth) and allow it to cycle for one more day. Check the pH and the temperature of the nutrient solution and adjust as necessary.

The seedlings are moved in by simply placing each seedling cell into the pot that has been half filled with the LECA. Using a container, gently fill the pot up the rest of the way with additional LECA material. Lastly, bend the dripper into position such that it drips directly onto the seedling cell. Finish up by rinsing each pot (containing the seedling) with nutrient solution such as to wet the new LECA and to rinse out any residue added. Note that after a couple of days, you will need to clean out or replace the filter as it will have small grains of LECA filling it when you have completed the transplant.

For your extra seedlings, place these in the supplemental space (ref. The drawings) between the rows. This will provide them with full light and our attention until we need them to replace some waywardly sexed plant. In my space, I have used lengths of vinyl house gutter spouts, cut in half and laid on the boards compromising the supplemental space area. This also allows me to be a little sloppy in my watering of them. Alternatively, you may want to consider a similar idea, but employing the vent drippers (at the end of the dripper chain) to provide nutrients, allowing the other end to drain into the system.

5.2. Lighting

Plants of this type respond to light cycles as seasons. A plant starts growing when the days are still short, but lengthening. The plant produces its flowers and fruit in the fall as daylight hours begin to get noticeably shorter. More specifically, when light begins to fall below 15 hours, the plant's hormonal cycle changes and it begins to prepare for reproduction. Once 12 hours are reached, the plant is fully reproductive.

In the technique I have developed, The idea is to get the plant into the flowering stage early so that it can be sexed and can produce the highest yield for the growth time allotted. What I have found is that if the light cycle of the plant is maintained at 12-13 hours throughout its life, it will begin to flower within 3-4 weeks from germination and will continue to flower throughout the remainder of its life. One drawback to this is that you will see a higher percentage of males as well as females reverting to males (hermaphrodites), but this is acceptable as you still have plenty of seedlings with which to replace them. There is a advantage as well; when you operate at 12 hour days, electricity usage is much lower, allowing the option of running with two 400w lamps for the price of 1 under the opposite philosophy of rapid growth under 24 hour lighting.

When positioning your lights, keep them at least 6" from the tops of the plants. Ideally the plants are all growing at the same rate so I tend to try to keep the lights at a distance of 12-20" during the rapid growth stage. However, as the lights reach the maximum height your ceiling allows, you need to start thinking about moving o the next nutrient stage or to start trimming the plants back.

5.3. Nutrients

There are many schools of thought on the nutrients just as there are for the lighting periods. In developing this system, I reviewed many of the writings on the nutrient needs for these plants and then by trial and error, modified them to come up with the nutrient formulas as presented in the appendix (pg. 16).

As a short reference, for the major nutrients, the following can be said:

<u>N or Nitrogen</u> — Ammonic-based compounds (NH_4) encourage rapid vegatative growth, sometimes to the point that the plant becomes straggly. Nitrate based compounds (NO_3) encourage good leaf, flower, fruit and seed development. It is recommended to use no more than 25% Ammonic-based nitrogen in the nutrient mix.

<u>P or Phosphorus</u> — Promotes early growth and blooming. It stimulates root growth and hastens maturity and seed growth. Lastly, it contributes to the overall hardiness of the plant.

<u>K or Potassium</u>	Aids in the development of carbohydrates, starches and sugars. It increases fruit development.
<u>Ca or Calcium</u>	Builds strong cell structures, therefore good stems and root systems
<u>Mg or Magnesium</u>	Is part of the Chlorophyl molecule and aids in the formation of oils and fats. (Micro-nutrient)
<u>Fe or Iron</u>	Acts as a catalyst in photosynthesis. Note that using iron as a foliar spray may cause brown spotting and burns. (Micro-nutrient)
<u>Cu, Zn and Mn</u>	These micro-nutrients act as catalysts in chlorophyl synthesis.

Prepare the working mixtures as outlined in the appendix and then prepare nutrient solutions as needed based on the growth cycle you are currently in. Note that under normal growth with this system, 3 liters a day or more may be used by the plants so be prepared to check your nutrient levels at least twice a week.

One concern of many people is the depletion of the nutrients from the solution, or the buildup of salts. The system design presented in this document has not experienced this to any detrimental degree. Much of this can be attributed to the mixtures, as well as to the constant recirculation of the nutrients, not to mention that we are employing a rather short growth period (3 months) and the system is flushed at least once a month.

I have also found that pH monitoring is not a problem. As new nutrient is constantly being added, I have not experienced problems with the pH level changing noticeably. One simply needs to be vigilant when mixing the nutrient solutions to ensure their pH monitoring equipment is performing properly (e.g. with reference solutions).

As far as knowing the time to change from one nutrient mixture to the next, this is somewhat up to your whim. The simplest approach is presented below. Note that when switching from one nutrient to the next, the old is not drained -- the new is simply added.

Nutrient Mix	Period
Fast Growth	Seedling start until plant height is approximately ~18"-24" high.
Pre-Flower	Use this mixture to slow the plant’s stem growth down and to provide the transition to the Flowering mixture (typically 1 week to 3 weeks).

Flowering	This mixture is employed until you are ready to harvest the flowers. Typically this will be indicated by darkening of the flower's hairs (pistils), the spicy or skunk-like odor, or by the plants getting so top heavy with the weight of the flower.
Flower, last 10	I use this mixture in the last 10 days before I shut down the system. Because it is devoid of nitrogen, it reduces the green taste due to reduced chlorophyl and sugars being produced. Ideally in the last 3 days, you should flush the system and move to a straight water solution to flush any nutrients from the plant.

One other topic -- that of misting the plant should be touched on here. Misting the plants helps them get rid of poisons that are exuded from the leaf pores and it helps to strengthen the stems. However, misting later in the plant's life can also affect the quality of the flowers and fruits by promoting the growth of molds. I recommend misting only for the first 2 months of the growth cycle, and typically at the end of the day. Never mist the sections plants near the lights (it may intensify the light and burn the plant, and it may also cause the light bulb to fracture!).

5.4. Sexing

Sexing your plants can be a traumatic process as none of us want to cut down a beautiful plant -- even if it is a male! However, if we don't, seed production takes over and all of the plant's resources become dedicated to this process rather than to the production of the oils we are pursuing.

As I have mentioned previously, signs of flowers will begin to appear 3 to 4 weeks from germination. Male flowers appear much larger, typically as seed-shaped nodules at the leaf joints. These nodules continue to expand and then open into a 4-petaled flower that literally keeps dumping pollen until either it dies or is pinched off. Female flowers on the other hand typically appear at the end of growing stems (typically on the top of the plant on the primary stem first) and appear more as clusters of hairs (pistils) growing out of leaf masses that are growing consistently tighter.

Note that female flowers can produce males in their midst, and solitary male flowers have been know to form at the lowest branch of the plant where they are the last to be discovered. Often in these cases, the male flowers can be pinched off to allow the female flowers to continue to grow.

Any plant that is definitively sexed as male should be removed and one of the spare seedlings swapped into its position.

6. Pests and Growth Problems

6.1. Pest Prevention

Most garden supply houses carry a product used for white flies that appears as a sticky yellow card. The card is hung around a garden and is covered with a sticky glue -- much like fly paper -- that is supposed to attract and capture white flies. Most gardeners say they don't work.

However, in a small enclosed space like the one this document details, these cards provide another service -- that of trapping a proportion of flying insects to give us an indication of when pests are present. Hang one between the lights, or in other warm places in the room and check it regularly.

Other pests such as aphids take a keen eye and can be removed by misting the plants with a dilute mixture of insect soap or oil. *Note that this misting of dilute oil or soap should only take place in the first 5-6 weeks as after that, you risk it being a residual on the plant.*

6.2. Plant Problems

One of the more common problems you will see with the plants is chlorosis (or the yellowing of the leaves in a mottled pattern). This is most frequently a problem with the pH being too high (> 6.5) or a magnesium deficiency. A careful monitoring of the pH usually resolves the problem but be aware that the leaves already affected will not recover and that the plant's growth will be noticeably be slowed.

The other common problem is that the plants will begin to fall over at some point. This is a product of optimizing the growth cycle for the highest yield. Two things can be done; 1) stake the plants, and 2) when the plant is top heavy with flowers, harvest them selectively such as to balance the plant's weight distribution.

There are many other pests and problems that can affect your plants -- often the result of a growing area not completely isolated, not completely cleaned, or the introduction of pests from you working outside on your lawn or garden; but these are outside the scope of this document. A good gardening or greenhouse book is a good investment here.

6.3. Algae Problems

A hydroponic system, filled with nitrogen, is prone to algae growth. Algae by itself is not harmful, but in a system like this it will clog the system and tend to derive it from oxygen.

The best way to avoid excessive algae growth (some will always occur) is to ensure the system is thoroughly cleaned between usage, and to keep the pH at or below 6.5 (algae doesn't seem to like acidic environments). Also, regularly change the filter and clean old ones with a 10% bleach solution before putting them back into use.

In the case of cleaning -- which will be visited later in this document -- always take the time to clean the system thoroughly, both by hand and by flushing the system with a 10% bleach solution over several days.

6.4. Weak or Dead Drippers

One last area of concern needs to be noted before leaving this section -- that of the nutrient drippers. Because these are in the system to provide a regular flow of nutrient and water to the plants, they must always run unimpeded. Check your drippers regularly (during the nutrient recirculation cycle) to ensure they are flowing freely. If one appears to be clogged, replace it immediately. If several appear to be clogged, check that the vent dripper (the last in the chain) is not clogged by removing it and ensuring that you have a good flow all the way down. Most often air in the system (caused by a clogged vent dripper) can create the latter condition. Clogged drippers can often be rejuvenated by the use of vinegar, or similar solutions.

One final approach regarding drippers -- if you have a serious problem with clogging, you may want to consider abandoning them and using 'spaghetti tubing' instead. This is a fine tubing (1/8") that provides a reasonable degree of flow restriction. However you may have to increase the gph rating of your pump to ensure equal nutrient distribution to all plants.

7. Harvesting & Drying

7.1. When to harvest

Harvesting of the plant flowers is performed when ~75% of the flower hairs (pistils) begin to brown and the flower begins to exude a sweet-to-skunk smell or when the plants become top-heavy with the flowers and begin to need excessive staking.

Ideally, you should have been running straight water for your nutrient solution for a few days before harvesting to deplete any residual nitrogen and to reduce the chlorophyl taste.

Cut the ripe flowers off at their base, leaving the rest of the plant undisturbed such that it can continue to produce. Trim off the excess leaf length from the flower body (pruning) and then place it aside to dry. The removed material (as can any material removed by the plants) can be dried separately for other uses.

7.2. Drying

Drying the flowers and associated material is actually very simple and there are many methods people will be happy to tell you about. However, my preferred method requires only a paper bag hanging from the ceiling in a ventilated area (e.g. from the ceiling of the room the hydroponic garden is in with the fan moving the air nearby).

Prepare the material removed from the plant (e.g., remove excess leaf from the buds) and then place the material into the paper bag loosely. Keep different grades in different bags. The material should dry completely within 1week depending on the size of the bag and how much material is in it.

7.3. Expected Yields

With the design and techniques presented in this document, one can expect the following yields over a 3-month seed-to-seed cycle (cured smoke):

Approximately 200-500g mature flowers (depending on variety)
Approximately 100-300g secondary material (depending on how harvested)

8. Preparing for the Next Cycle

One full growth cycle typically runs between 3 and 3-1/2 months from seed to last harvest with this system. When it is time to shut down, everything must be cleaned and checked over. During this cleaning cycle, the next seedlings can be germinating.

The first step is to remove all plant material. Begin by pulling the pots out and dumping the LECA into 5 gallon buckets so it can sit in a bleach solution for a few days. Be sure to remove as much of the plant material (roots) while dumping the LECA as this can be a source of root bacteria in future crops. Start another bucket or tub with just bleach solution to put items like the empty pots, plant stakes, etc. into.

Within the PVC structure itself, remove the fiberglass screening and discard (it is probably full of intertwined roots!). Scrub the inside of the PVC tubes as much as possible with a sponge and bleach solution. Cut and place new fiberglass screen into the tubes.

Dump the primary and secondary reservoirs. Wash them both, including the pumps and floats with a 10% bleach solution. Oil components as necessary and clean up any corrosion encountered. Fill the reservoir with clean water and allow it to pump the water throughout the system. While it is pumping, remove the vent drippers and allow each line to be flushed completely. Also perform the same with the vent cap. Continue running and flushing for several hours.

If possible, spray the system and the room down to wash out debris (unplug the system first!). Once dry, remove and clean the reservoir once more as well as the filter. Also replace any drippers that have been removed. Fill it again with 10% bleach solution and allow it to run under normal cycles for 3 or 4 days.

Take pots that have been soaking in bleach and rinse them and replace them in the PVC slots.

Remove the drain cap and vent drippers and run the reservoir empty. Dump the reservoirs and flush the system. Refill the reservoirs with fresh water (no bleach) and set it up to cycle for a couple more days.

Once complete, go back to page 5 and restart the cycle!

Appendix A. Parts List & Sources

A.1. Parts List

All parts are from McMaster-Carr unless otherwise specified

PVC Components (4" sewer)

90 deg. Elbows	9102K114		1.75
T-fitting	9102K154		1.91
Caps	9102K224		.87
10' length	2426K12		12.67

Gas Handling

Regulator, CO_2 (4000psi in, 60psi out max)	7997A66		66.98
Solenoid valve, normally-closed, bronze piston, 1/2" pipe, min. pressure differential, 10-250psi	4635K23		70.15
Panel-mount gas flow meter w/control valve 0.4-4.0 SCFH	41945K73		40.82
CO_2 20lb cylinder	Local		125.00
CO_2 fill	Local		13.00
Rigid 1/4" tygon or Parflex gas tubing	McMasters, Local		
Miscellaneous fittings / adapters	McMasters, Local		

Reservoir

Ball check valve (anti-siphon), PVC construction, 1/2" pipe size, 150psi max	4721K13		22.71
Condensate Pump, 1/30 Hp, 1.3GPM, 115VAC	99575K11		55.66
Aquarium heater	Local		~13.00
Fill pump, Supreme Mag-drive Utility Model 2, 250 GPH; Danner Mfg. #02512 (E160713)	Local (aquarium or garden supply)		~65.00
1/2" polyethylene or PVC flexible tubing	McMasters, Local		
16oz yogurt strainers	Local kitchen store		

Feeders

1-GPH P/C drippers (50pc)	PC4050	Rain Drip	18.13
2-GPH P/C drippers (50pc)	PC8050	Rain Drip	18.13
50' 1/4" vinyl dripper tubing	R250D	Rain Drip	5.09
T-adapters, etc.	McMasters, Local garden supply, Rain Drip		
1/4" polyethylene or PVC flexible tubing			

	McMasters, Local		

Timers

Appliance timer	61-1071	Radio Shack	15.99
24-hour digital timer, 4 periods	61-1060	Radio Shack	24.99

Lighting

Super Grow Wing 400w units w/Agrogro bulbs (e.g. MVR400/u)
Local, Hydrofarm ~350.00

Fluorescent fixture (2 tubes) for starting seeds) w/ standard gro
or aquarium lights Local ~25.00

Growing Media

LECA (Lightweight Expanded Clay Aggregate)
Local Garden (orchid) supply

Airfoam starting cells " " "

Starter trays

Chemicals

see appendix on solutions...

Misc.

Desk fan, modified for wall mount	Local	~12.00
Fiberglass screen	Local	
1/8" PVC or other inert dowels	McMasters, Local	
Floral wire	Local	
4" hole saw	Local	
1" hole saw	Local	
Saw horse kits (2)	Local	
Tub (primary reservoir), min. 15"l x 11"w x 6"d	Local	
10-15A microswitch w/replaceable arm		
Ping-pong balls		
10 liter jugs		
1 liter bottles for working solutions (e.g. Rubbermaid)		
Lexan plastics (reservoir plate)		
Thermometer, indoor/outdoor type with remote sensor		
Siphon pump; hand-operated, squeeze-bulb style (e.g. outboard siphon pump)		
Reflective mylar camping / survival blankets		
pH meter	McMaster	~45.00
pH reference solution (tablets)	McMaster	~7.00
Misting spray bottle		

A.2. Parts Sources

The following is only a partial list of places to obtain parts and chemicals. Use the WWWeb for a more comprehensive view of what's available...

Brew and Grow (alt. hydroponic supply)
19555 W. Bluemound Rd.
Brookfield, WI 53045
414.789.0555

33523 W. 8 Mile Rd. #F5
Livonia, MI 48152
248.442.7939

Hydrofarm
3135 Kerner Blvd
San Rafael, CA 94901
800.634.9999

208 Route 13
Bristol, PA 19007
800.227.4567

McMaster-Carr
PO Box 440
New Brunswick, NJ 08903-0440
732.329.3200
732.329.3772 [fax]

Rain Drip
2250 Agate Court
PO Box 5100
Simi Valley, CA 93062-5100
805.581.3344
805.581.9999 [fax]

Light Manufacturing Company [great chemical AND equipment source!]
1634 E. Brooklyn Street
Portland, OR 97202
800.669.5483
www.litemanu.com

Worm's Way
7850 North Highway 37
Bloomington, IN 47404
800.274.9676
www.wormsway.com

Appendix B. Nutrient Mixes

Although off-the-shelf commercial fertilizer mixtures can be employed, it is difficult to obtain information about the exact compositions. Because of this, and in the effort to provide a standardized nutrient mixture, raw chemicals are used in developing the feeding mixtures to be used. This will ultimately prove to be a cheaper method and will provide you with much greater control over the plant's growth cycles.

In some circles, Molar Solutions are employed in the nutrient solution preparation. This works well for pH adjustment compounds (for better estimation of impact as well as for comparison to other off-the-shelf / commercial compounds); but in my method, I am targeting a specific parts per million (ppm) of the nutrient desired since we are most interested in the plant's needs. For reference, molar solutions are calculated as follows:

Using KNO_3, the atomic weights are K=39.1, N=14.0, O=16.0.
1 gram Mole weight = 39.1 + 14.0 + (16.0 x 3) = 101.1g
Therefore, 101.1g KNO_3 in 1 litre gives us a 1 Mole (1N) solution

With respect to plant nutrient concentration (and mix sequence) considerations, one should also be aware of Anions [H^+ (acids), Ca^{++}, Mg^{++}, K^+, Na^+, Fe^{++}, $NH4^+$, in order of dominance] and Cations [OH^- (bases), SO_4^{-}, PO_4^{-}, NO_3^-, again in order of dominance]. Specifically, these concern the nutrient component ions important to the plants and the ability of one to dominate others (i.e. render others unavailable to the plant). It is for this reason that we want to work with fairly low concentration source solutions, mixing them into fairly large volumes (e.g. 10 litre H_2O base solutions).

Note that given the information below, commercial mixtures can be used if you are willing to tolerate the additives they provide (e.g. coloration, etc.) and that you are willing to experiment to determine proper ratios.

B.1. Preparing the Concentrated Nutrient Solutions

These solutions are concentrated solutions of the specified nutrient (typically 10,000 ppm of N, P, or K). They are formulated from laboratory or commercial grade chemicals to provide some control over the solution impurities and feeding effects. These chemicals are not controlled and may be purchased through a distribution house, or from a university stockroom.

The chemicals – as sources of nutrients (e.g. NH_4NO_3) -- were selected based on water solubility. This was in a desire to have as little undissolved solids as possible. The mixtures were derived by looking at the molecular weight of the desired nutrient within the compound and the solubility rates in water[2]. For example, Potassium Nitrate (KNO_3) is 13.86% Nitrogen and 38.67% Potassium by molecular weight (in solutions below, percentages for each are given in the square brackets). If I desire 10000ppm, I use the formula: % x grams = ppm x 1000. Therefore for 10000ppm nitrogen using KNO_3, the weight for 1 liter working solution would be 72.15g {grams = 10/0.1386}. This working solution will also have 27900ppm potassium {xkppm = 72.15g x 0.3867}.

All solutions below are prepared with the quantities of the chemicals indicated into 1 liter warm water. The compounds marked with an asterisk are components of common fertilizers.

Macro Nutrients

KNO_3 (10000ppm Nitrogen, 27900ppm Potassium)
72.15g Potassium nitrate [N=13.86%, K=38.67%]

KH_2PO_4 (10000ppm Potassium, 7923ppm Phosphorous)
34.81g Potassium phosphate, Monobasic [K=28.73%, P=22.76%]

NH_4NO_3 (10000ppm Nitrogen)*
28.57g Ammonium nitrate [N=35%]

$(NH_4)H_2PO_4$ (10000ppm Nitrogen)
90.9g Ammonium Phosphate, Monobasic [N=11%, P=20.87%]

$Ca(NO_3)_2$ (10000ppm Nitrogen, 14000ppm Calcium)*
58.58g Calcium nitrate [Ca=24.2%, N=17.07%]

K_2SO_4 (10000ppm Potassium, 4100ppm Sulfur)*
22.3g Potassium sulfate [K=44.87%, S=18.4%]

$(NH_4)_2SO_4$ (10000ppm Nitrogen, 11450ppm Sulfur)*
47.2g Ammonium sulfate [N=21.2%, S=24.27%]

$CaH_4(PO_4)_2$ (10000ppm Phosphorus, 6470ppm Calcium)*
37.8g Calcium Phosphate, Monobasic [P=26.47%, Ca=17.12%]

pH Adjustment

H_3PO_4 (10000ppm Phosphorous, ~1/3 Mole Solution)
22ml (37.22g) Phosphoric acid, 85% [P=26.87%, 1M=112.7g/litre]

---

[2] The Merck Index at your local library is an invaluable guide for this type of information.

KOH (pH adjustment solution, ~39000ppm Potassium, 1 Mole Solution)
56.1g Potassium hydroxide [K=69.69%]

Micro Nutrients

MoO_3 (10ppm Molybdenum) {5ml = 0.05ppm}
0.022g Molybdic acid, 85% [Mo = 45.32%] {mix large & dilute: 1g MoO3 to 1 litre = 455ppm (2.2ml = 1ppm); 22ml of 455ppm to 1 litre = 10ppm}

$MgSO_4.7H_2O$ (10000ppm Magnesium, 13130ppm Sulfur as supplements)
101g Epson Salts [Mg=9.9%, S=13%]

$C_9H_{13}FeN_2O_6$ (100ppm Iron)
1g Iron Chelate (Iron pemoline) [Fe=10%]

$CuSO_4$ (10ppm Copper) {5ml = 0.05ppm}
0.025g Copper Sulfate [Cu=39%, S=20%] {mix large & dilute: 1g CuSO4 to 1 litre = 400ppm (2.5ml = 1ppm); 25ml of 400ppm to 1 litre = 10ppm}

You will also need to purchase Dragon liquid cheleted Iron, MicroGold or the equivalent to provide trace amounts of the necessary micro-nutrients Fe, B, Mn, Zn, Cu and Mo[3]. This may be purchased at garden supply stores or by mail-order.

Note that in the list, there are several compounds that can be employed for each compound. My preference is to employ common fertilizer components first. As far as the choice of N-components, note that the ammonic (NH_4) component can cause rapid vegetative growth and inhibit flower development, while the nitrate (NO_3) based compounds do just the opposite. In this case you would use ammonic compounds in the early stages and nitrate compounds during flowering, or nitrate compounds throughout. Whatever proportion of ammonic and nitrate you use, keep the ammonic ratio to 25% or less.

Before deciding on the primary chemicals you will use, have your water tested. If you have no calcium you may want to use Calcium Nitrate rather than Potassium Nitrate. If your water tests for an abnormally high or imbalanced mixture of minerals[4], you may

---

[3] Sulfur is also present in this mixtures as sulfates of the micro-nutrients. The remaining required minerals Mg, Na, Ca, Cl, and Co are common in your water and/or these mixtures and they should not be added explicitly with the exception of calcium (major nutrients typically contain the latter as described in the section above).

[4] E.g. a higher proportion of Mg than Ca would definitely require increasing Ca or removing both and then adding Ca as a major item and Mg as part of the trace/micro-

want to consider a reverse osmosis water system in line to your nutrient mixing area. For what they provide, they are worth the ~$300 cost (Sears carries them!). Whatever you do, do not use 'soft' water (i.e. from a water softener) as this water contains harmful levels of sodium (Na)!

If you do employ a reverse osmosis device, note that levels of Mg and Ca need to be boosted. Refer to the quantities in your micro-nutrient mix, then add those deficient. If the quantities are given as a percent, **1ppm = 0.001%**. For reference, the following minerals must be present for proper growth:

Sulfur (S)	60-330ppm
Magnesium (Mg)	25-75ppm
Chlorine (Cl)	small amount of tap water
Boron (B)	~0.25ppm
Copper (Cu)	~0.1ppm
Iron (Fe)	~2.5ppm
Manganese (Mn)	~0.25ppm
Molybdenum (Mo)	~0.05ppm
Zinc (Zn)	~0.1ppm

---

nutrients. The ideal ratio of Ca to Mg is ~5:1.

B.2. Preparing the Nutrient Mixtures

The nutrient mixtures are those that are fed to the plant and vary for the point in the plant's growth cycle. The mixtures given below employ the solutions formulated in the previous section.

After the use for each solution, the brackets indicate the proportions of Nitrogen, Phosphorous and Potassium [N-P-K] based on ppm figures derived. If you are using commercially-available fertilizer mixtures, the goal is to attain the specified ppm (parts-per-million) for your final nutrient mixture.

For the pH adjustment, the target is a pH of ~6.0[5]. All solutions listed are slightly acidic. In using your pH meter, it is a good idea to have a 7.0 pH reference solution to periodically check the pH meter against. I typically have a reference solution in my crate of working mixtures so that it is always at hand.

To prepare the nutrient solution, start with a 10 liter jug and fill it to just under 10 liters with clean water. Add the quantities noted below of the prepared mixes and then fill the jug to the 10 liter mark. Stir it thoroughly and then measure the pH. Adjust as necessary. If you need to drop the pH (make it more acidic), it is preferable to use phosphoric acid or nitric acid as very little will be required and the compounds are beneficial to the plants.

The compounds employed in this document are only suggestions based on experience[6]. What is important in these formulations is the N-P-K concentrations (in ppm) achieved not what compounds were employed.

<u>For Reference:</u>

there are ~3.785 litres per gallon
there are ~30ml per fluid ounce
1ppm = 0.001%

---

[5] 5.5pH if rockwool is used.

[6] For conventional vegetables (e.g. tomatoes, 40+days), university research has shown that the formulation (ppm): 140-65-400-200-45-60 (N-P-K-Ca-Mg-S) is ideal. Feel free to experiment!

Appendix C. General Growth Requirements

This information is only provided as reference. The design discussed in this document takes most of these needs into consideration.

CO_2:

~2000ppm (0.2%)[7] (emit when fans are off)

Nutrients:

pH 5.8-6.2 (higher slows growth and causes chlorosis)
volume ~1/6GPH during daylight
temperature ~80˚ F
Use Soft water < 8˚ dh
NaCl < 50ppm
Flush system every 2 weeks or so

Light:

1000-2000 lumens/ft^2 - growth
1500-3000 lumens/ft^2 - flowering
($\geq$40 watts / ft^2)

Temperature:

65˚ F night, 75-85˚ F daytime (temperatures < 65˚ F slows growth)

Humidity:

40-60%

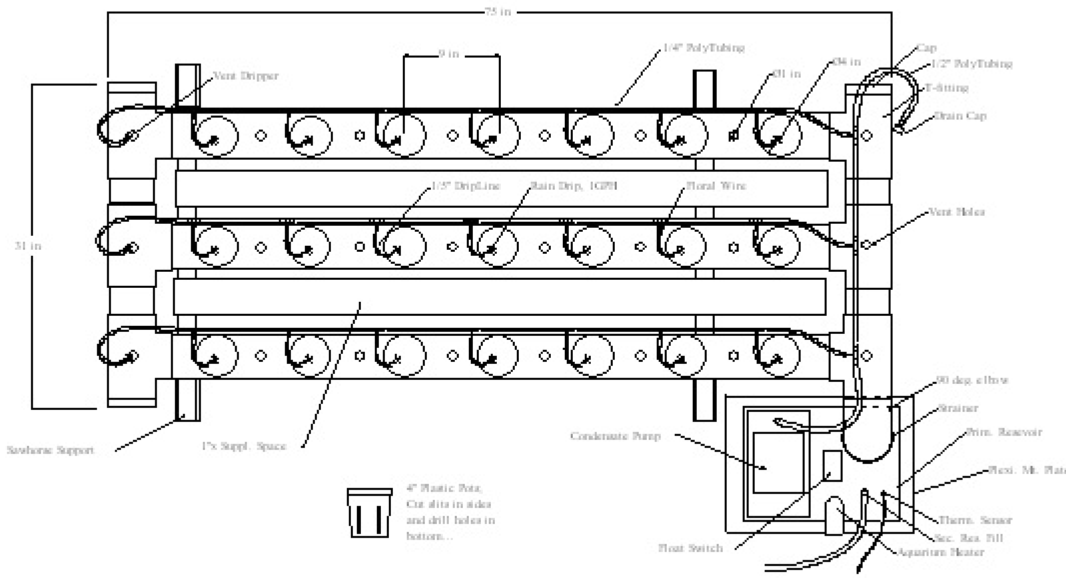
Air:

Gentle breeze
Air replaced every ~10 minutes

---

[7] To determine flow rate of CO_2, first determine volume of the grow room. Multiply that volume by 0.002 (0.2%) to get the quantity of CO_2 needed. Based on 4 gas cycles per day of 1/2 hour (2 hours total) and negating existing atmospheric CO_2 content, divide the needed gas volume by the 2 hours to get the flow rate to set on the CO_2 flow gage. Note that a 20lb tank holds ~175 ft^3.

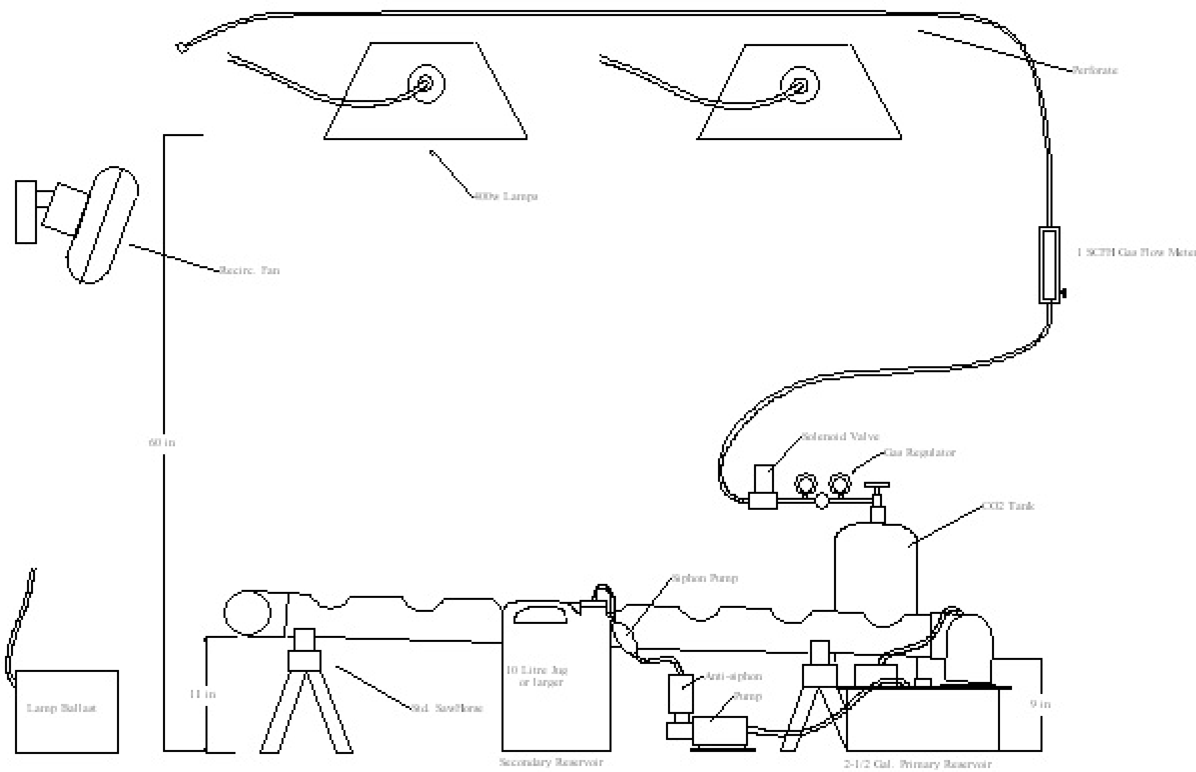
Appendix D. Fabrication Drawings



Use duct tape to affix 1/4" feed lines.

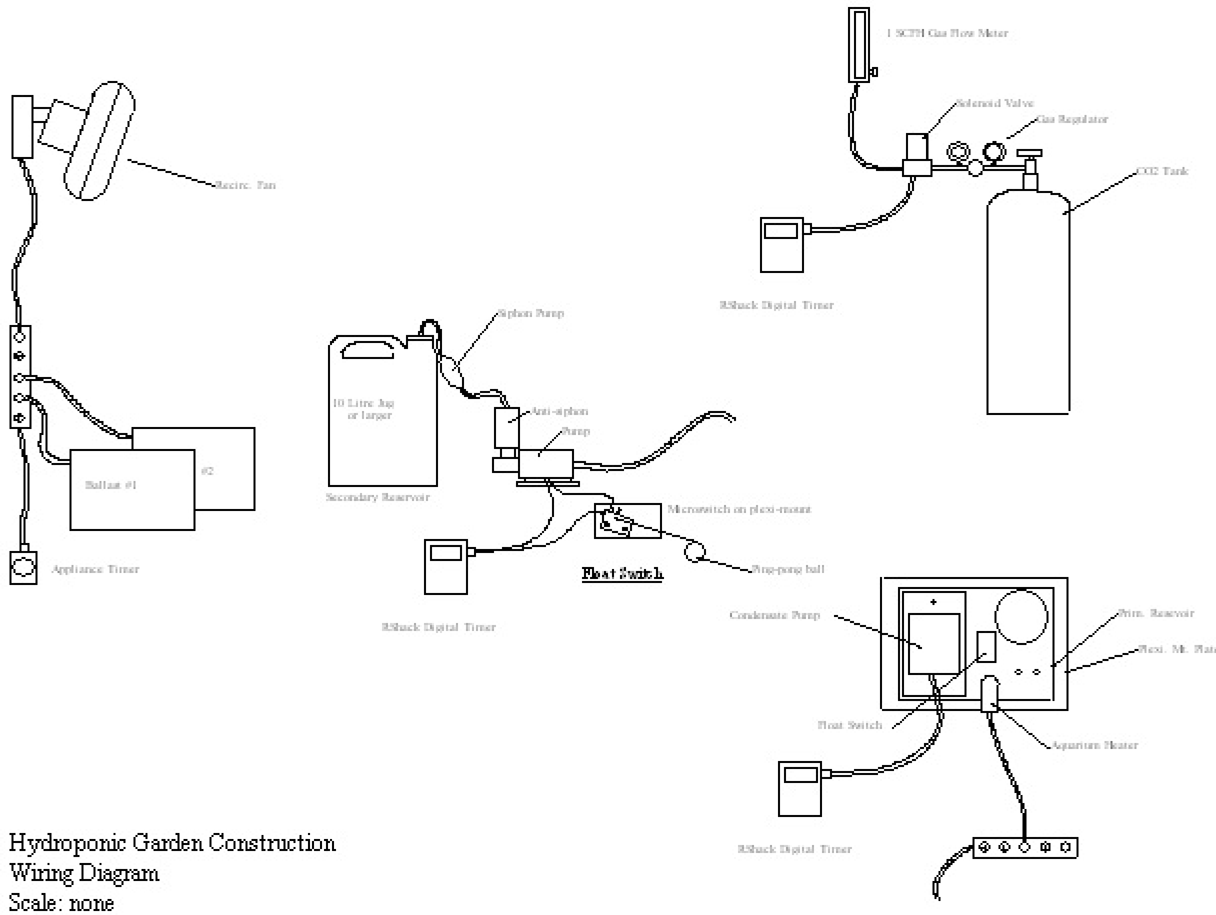
Hydroponic Garden Construction
Structure Details, Top View
Scale: 1" = 1'

All pipes & fittings = 4" PVC sewer



Hydroponic Garden Construction
Major Components
Scale: 1" = 1'

All pipes & fittings = 4" PVC sewer



Hydroponic Garden Construction
Wiring Diagram
Scale: none

Appendix E. Mixtures

E.1 Quick Reference Chart

For 10 liters nutrient solution (note [N(NH_4)-P-K-Ca-Mg-S] format, values in ppm)
Note that formulation is based on reverse-osmosis-treated water (no minerals, etc.), rockwool seed starters in Lecra aggregate.

All solutions / all stages (Micro nutrients & vitamins):

5ml	SuperThrive (optional)
30ml	Golden Grow's MicroGold Trace Minerals or equivalent (MicroGold has no Mg, Cl)
5ml	MoO_3 (+0.05ppm Mo)
5ml	$CuSO_4$ (+0.05ppm Cu)
50ml	$MgSO_4$ (+50ppm Mg, +65ppm S)
20ml	Fe Chelate (+2.0ppm Fe)

Note: KOH (pH up) = 39ppm K per 10ml

Germination (0-5days) [125(0)-100-170-140-50-65]

100ml	KH_2PO_4	[0-80-100-0]
100ml	$Ca(NO_3)_2$	[100-0-0-140]
25ml	KNO_3	[25-0-70-0]
20ml	H_3PO_4	[0-20-0-0]

pH ~= 3.7 therefore ~5 ml KOH (~4.3)
TDS ~= 750 **** Fan @ #2, mist ****

Fast Growth (6-21days) [175(25)-100-240-140-50-65]

100ml	KH_2PO_4	[0-80-100-0]
25ml	NH_4NO_3	[25-0-0-0]
100ml	$Ca(NO_3)_2$	[100-0-0-140]
50ml	KNO_3	[50-0-140-0]
20ml	H_3PO_4	[0-20-0-0]

pH ~= 3.6 therefore ~5ml KOH (~4.3)
TDS ~= 1300 **** CO2 started ****

Pre-Flower (21-28days, when **lights to 13** hours & **pinch**)
[125(0)-100-170-140-50-65]

100ml	KH_2PO_4	[0-80-100-0]
100ml	$Ca(NO_3)_2$	[100-0-0-140]
25ml	KNO_3	[25-0-70-0]
20ml	H_3PO_4	[0-20-0-0]

pH ~= 3.85 therefore ~5ml KOH (~4.5)
TDS ~- 1180

Flowering (rem time) [110(0)-140-175-140-50-65]

150ml	KH_2PO_4	[0-120-150-0]
100ml	$Ca(NO_3)_2$	[100-0-0-140]
10ml	KNO_3	[10-0-28-0]
20ml	H_3PO_4	[0-20-0-0]

pH ~= 3.45 therefore ~5ml KOH (~4)
TDS ~= 1090 **** No Misting! ****

Flowering (last 5-7 days) [0(0)-0-0-0-0-0]
pure H_2O

Seeding (flowers) [125(0)-100-170-140-50-65]

100ml	KH_2PO_4	[0-80-100-0]
100ml	$Ca(NO_3)_2$	[100-0-0-140]
25ml	KNO_3	[25-0-70-0]
20ml	H_3PO_4	[0-20-0-0]

pH ~= 3.75 therefore ~ 11ml KOH (~5.9)
TDS ~= 1380

Mixing:
1) Nutrients & stir
2) pH adjust & stir
3) Micro nutrients & growth enhancers & stir

Timers:
Nutr.Pump - 0500-0800, 1100-1400, 1700-2000, 2300-0200
Lights - 0800-2100 (24 hours, germ->21days)
Resev. - 0830-0835, 1430-1435, 2030-2035, 0230-0235
Fan - 0700-0830, 1100-1430, 1700-2200
CO_2 - 0900-1000, 1500-1600

General Considerations
Nutrient flow @ ~1/2 gph during light
Desired nutrient solution pH = 5.2 to 5.8 (5.5 ideal)
Ideal nutr. ratios [1.0-0.5-3.0-1.0-0.3] (N-P-K-Ca-Mg)
pkTDS: 1100 (germ)-1800(fast growth)-1900 (flowering)
EC: 0.75-1.8
CO_2 @ ~2000ppm (emit when fans off)
Humidity @ 40-60%
Temperature air:75-85 F, nutr: 65-68 F (males if hotter!)
Lighting @ $\geq$40 watts / square foot
Gentle breeze (Air replaced every ~10 minutes)
Flush system every 2nd nutrient batch (40 litres) or so
Check reservoir pH with each batch @ minimum

Abbreviated Growing Guide
Use only seeds from plants raised for seeds (genetics of misc seeds support hermaphrodites)
Seeds planted in air foam or rockwool on ebb/flow board (cover first week)
Seed medium at ~80 deg (F), nutrient @ ~70 deg
Lights at 24 hours for 3 weeks (ht = ~1') then 13 hours for remainder (~9-11 weeks)
Flowering should start at ~1 foot height
Mist every <= 2 days until flowering
Treat insects with sticky traps or Neem – flush after!
For mold, use sulfur dust
Harvest when 3/4 of pistils turn brown
Flush & feed only plain H_20 last 7 days
Cure by manicuring then place in paper grocery bag (~8days)

E.2. Nutrient Formulation

For the Nutrient Mixtures given, the following are considerations made regarding the mixtures (ratios) as given.

E.2.1. MicroNutrients

Using Golden Grow's MicroGold product, the manufacturer gives the following percentages as constituents (1ppm = 0.001%):

MicroGold		
Boron	0.036%	36 ppm
Copper	0.006%	6 ppm
Iron	0.31%	310 ppm
Manganese	0.14%	140 ppm
Molybdenum	0.0012%	1.2 ppm
Zinc	0.048%	48 ppm

Using 30ml of MicroGold (in each 10 litre batch) gives the following:

MicroGold, 30ml		Desired
Boron	0.1 ppm[8]	0.1 - 1.0 ppm
Copper	0.02 ppm	0.02 - 0.2 ppm
Iron	0.9 ppm	0.5 - 5.0 ppm
Manganese	0.4 ppm	0.1 - 1.0 ppm
Molybdenum	0.004 ppm	0.01 - 0.1 ppm
Zinc	0.15 ppm	0.02 - 0.2 ppm

Therefore we will need to add the following:

MoO_3	5ml of 10ppm	+0.05ppm Mo
$CuSO_4$	5ml of 10ppm	+0.05ppm Cu
Fe Chelate	20ml of 100ppm	+2.0ppm Fe
$MgSO_4$	40ml of 10000ppm	+40ppm Mg
		+52ppm S

See section below for Ca(lcium) considerations.

[8] Reverse Osmosis removes ~50% Boron and ~70% Silicon (all others at >90%). Considering a water supply of 1ppm, we need to add 50% of this to our formulation.

E.2.2. MacroNutrients

In general, the following are the viable ranges for macro nutrients

NH_3	0 - 31 ppm [ammonic]
NO_3	70 - 300 ppm [nitrate]
P	30 - 90 ppm [phosphorus]
K	200 - 400 ppm [potassium]
Ca	150 - 400 ppm [calcium]

For Tomatoes:

0-40 days:
248 - 45 - 359 - 200 - 40 - 53 [N-P-K-Ca-Mg-S]

41 days - finish
140 - 65 - 400 - 200 - 45 - 60 [N-P-K-Ca-Mg-S]

Note that when using these concentrations, especially in a reservoir system, it is very important to flush the system regularly. I recommend every 40 litres of nutrients.

Also, note that your pH adjustment compounds impact these relationships

pHDown (H_3PO_4), 10ml = 10ppm P

pHUp (KOH), 10ml = 52ppm K