

Cornell Controlled Environment Agriculture



Hydroponic Spinach Production Handbook

Baby spinach has become a very popular produce item in the last decade. Hydroponic production methods allows for the production of consistent high quality produce anywhere in the world. This handbook describes the method we have developed for the production of spinach whose leaves are small enough to be considered 'baby spinach'. A significant barrier to hydroponic spinach production is a water-borne pathogen called *Pythium aphanadermatum* that attacks the roots and causes poor crop quality and crop death. We have devoted significant time to investigating ways to prevent and treat this disease and that method is described in this handbook.

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Table of Abbreviations and Units

A	Area	Square feet or square meter.
CEA	Controlled Environment Agriculture	Producing plants in a greenhouse or other space.
cm	centimeter	A unit of length
CWF	Cool White Fluorescent	A type of supplemental lighting
DLI	Daily Light Integral	The sum of photosynthetic (PAR) light received by plants in a day.
DO	Dissolved Oxygen	Oxygen concentration in nutrient solution measured in parts per million.
EC	electrical conductivity	An indirect measurement of the strength of a nutrient solution.
HID	High Intensity Discharge	A type of HID supplemental lighting
hp	horsepower	A unit of power
HPS	High Pressure Sodium	A high intensity discharge lamp/luminare type for supplemental lighting
kPa	kilopascals	A unit of pressure, force per unit area
MH	Metal Halide	A type of HID supplemental lighting
mol	pronounced 'mole'	A number of anything equal to 6.02×10^{23} items. We use it to quantify the number of photons between 400-700 nm of PAR light plants receive.
mol/m ² /d	moles per square	Integrated PAR light

	meter per day	
mol/m ² /s	moles per square meter per second	Instantaneous PAR light
nm	nanometer	Unit of length in SI, one billionth of a meter
PAR	Photosynthetically Active Radiation	The portion of the electromagnetic spectrum between 400-700 nm plants use for photosynthesis
ppm	parts per million	A unit that describes dimensionless quantities such as mass fractions
SI	System Internationale	International system of units aka metric system - built around 7 basic units of measurements
μmol/m ² /s	micro-mole per square meter per second	Instantaneous PAR light
uS/cm	microsiemens per centimeter	A unit of measurement for electrical conductivity

Chapter 1: Greenhouse Hardware

Of fundamental importance to hydroponic spinach production are the physical components of both the germination area and the pond area. It is necessary to have not only an idea of the physical components associated with each area, but also a good understanding of their purposes. The germination area is designed to promote uniform germination in a predictable length of time. The pond area is designed to house plants while they grow to a marketable size.

IMPORTANT DISEASE NOTE: Hydroponic spinach production on any scale has historically been limited because of a water-born oomycete pathogen called *Pythium aphanidermatum*. We have spent many years at Cornell working on ways to remove and/or manage this risk so that baby spinach can be grown to harvestable size. We have evaluated every control measure that seemed even slightly reasonable. We guarantee that if you take no special precautions to avoid *Pythium* damage and attempt to grow your hydroponic spinach as you would grow any other leafy green crop, you WILL eventually lose the entire crop due to *Pythium* damage. The disease is ubiquitous and may arrive in your facility on seed or in dust.



Figure 1. *Pythium aphanidermatum* damage to baby leaf spinach.

1.1 Germination Area

This section details environmental requirements to ensure optimal germination. For details about seeding the crop see Chapter 4: Spinach Production. The location where germination is to take place must have the ability to control temperature (72-79 F, 22-26 C) and humidity as close to 100% as possible. The germination area can be in a corner of the greenhouse or in a separate climate-controlled room that receives no sunlight. The flats should be kept warm and humid. The temperature the seedlings are exposed to will change the time to emergence. Often the flats are stacked for the first 24 hours to use germination space efficiently. The stack of flats is then covered with plastic to keep humidity levels high (See Figure 2). Be sure that all of the flats are put into the germination facility at the same temperature or temperature stratification will occur within the stack of flats and contribute to non-uniform germination. If flats are put in racks for germination (see Figure 3) care should be taken because the evaporative cooling from top flats results in them behaving differently than bottom flats (due to temperature differences between the flats).



Figure 2. Flats stacked during germination. Note sheets of plastic between flats and plastic in background used to cover the entire stack to keep humidity high.



Figure 3. Flats in a wooden rack inside a room that can be either cooled or warmed.

If seedlings are floated before germination occurs then the additional moisture added to the media will prohibit further germination, this is why uniform germination is essential.

Some seeds need illumination to germinate. Spinach is not one of these crops. It will, however, stretch if there is not enough photosynthetically reactive radiation (PAR) as the seedlings emerge. After 24 hours, must be able to provide enough PARs that plants do not stretch, at least $50 \mu\text{mol}/\text{m}^2/\text{s}$.

1.2 Pond Area

Concepts involved in the pond area are the following:

- Pond Size
- Pond Solution
- Construction
- Pond Design
- Lighting
- Temperature Monitoring/Aspirated Box

Pond Size

The spinach plants are grown in the pond area for 14 days .

Pond Solution

Equal portions of *Stock Solutions A and B* (see formulas in appendix) are added to reverse-osmosis (RO) or water in which salts have been removed to achieve an EC of 1300 (+/- 100) $\mu\text{S}/\text{cm}$ or 1.2 dS/cm above the background level of salts. Untreated water can be used but the buffering capacity of most water makes pH and nutrient management extremely difficult. This system endeavors to use nutrient solution for long periods of time (years) without total solution replacement.

Construction



Figure 4 Empty pond with liner.



Figure 5. Edge of pond detail. The inside edges of two separate ponds made of wood and separated by structural members is shown on left. The right hand picture shows a concrete pond.

There are three main options for pond construction.

- The pond may be sunken in the greenhouse floor, with the pond surface just above the floor (not pictured).
- A containerized pond with concrete or wooden walls (Figure 5) can be constructed on top of the floor of the greenhouse.
- The pond can be built on an island of fill with the ponds built into the fill so that the water level is closer to waist level to lessen the amount of bending that must be performed when working with the crop. An important note is that a greenhouse that uses this system must be sufficiently tall so that supplemental lighting is not too close to the plants (not pictured).

In any case, the pond floor can be layered with sand to cushion any sharp edges from puncturing the polyethylene lining. A heavy plastic (for example, 0.5 mm poly) liner is then installed as the major barrier for leak protection. Proper precautions should be taken to avoid leaks.

Design

Each crop will be harvested 14 days after planting. The pond should be deep enough so that the roots do not drag on the bottom and tear. We have found that around 10 or 11 inches is an optimum depth.

Lighting

Configuration and Intensity of Supplemental Lighting

The total light integral received by spinach once plants are floated in the ponds should be at least 17 mol/m²/d. Supplemental light must be used if this amount of PAR cannot be obtained with sunlight only (because of the time of year, light reduction due to shading by greenhouse components, or decreased light transmission because of greenhouse covering).

Lamps should be configured for a uniform distribution of light over the entire growing area. Light intensity is maintained at no less than 50 $\mu\text{mol}/\text{m}^2/\text{s}^1$ of PAR during the first 24 hours the seeds are kept in the germination area. This level of illumination prevented stretching of the seedlings while minimizing the tendency of supplemental lighting to dry out the surface of the medium. Instantaneous light intensity can be measured with a PAR meter, see Chapter 3 under ‘monitoring’.

The following calculation may be used for determination of hourly PAR. Substitute your actual instantaneous PAR measurement for the ‘100 μmol ’ below:

$$\text{Hourly PAR} = \left(\frac{100 \mu\text{mol}}{\text{m}^2\text{s}} \right) \left(\frac{60 \text{ s}}{1 \text{ min}} \right) \left(\frac{60 \text{ min}}{1 \text{ hour}} \right) \left(\frac{1 \text{ mol}}{1 \times 10^6 \mu\text{mol}} \right) = 0.36 \frac{\text{mol}}{\text{m}^2\text{hour}}$$

Sum the accumulated hourly PAR values for a daily PAR value which is called the Daily Light Integral or DLI.

For the remaining 10 days, the light intensity is maintained at no less than 200 $\mu\text{mol}/\text{m}^2/\text{s}^1$. The photoperiod (or day length) may be up to 24 hours. Shorter photoperiods are acceptable if the light intensity is increased to provide the same total daily accumulated light ($\sim 17 \text{ mol}/\text{m}^2/\text{d}^1$).

Note for germination rooms: Light output of cool white fluorescent (CWF) lamps decays over time. Thus, it is important to measure the light output of the lamps regularly. If the light intensity drops below an acceptable level (e.g. 200 $\mu\text{mol}/\text{m}^2/\text{s}^1$), new lamps should be installed. A quantum sensor can be used to measure the amount of PAR.

Uniform light distribution is required in the Pond Growing Area. A supplemental light intensity within the range of 100-200 $\mu\text{mol}/\text{m}^2/\text{s}^1$ (for a total of 17 moles $\text{m}^{-2}\text{d}^{-1}$ of both natural and supplemental lighting) at the plant level is recommended. It should be noted that we did not experimentally optimize daily light integral. High pressure sodium (HPS) lamps are a type of High Intensity Discharge (HID) lamp, and are used to supply light. These lamps are relatively efficient, have a long life ($\sim 25,000$ hours, generally these lamps lose 1% output for every 1000 hours), and slowly decay in output over time. There is a recent development in the manufacturing process for metal halide lamps that gives them a lifetime similar to high pressure sodium lamps. Metal halide lamps have a spectrum that is slightly more efficient for plant growth than high pressure sodium lamps. A new bulb produced by the Philips Corporation has exaggerated the benefits of metal halide lamps including shifting more light production to the blue and red portions of the spectrum and decreasing the heat output of the luminare. Independent lighting consultants have specialized software to determine proper number and placement of lamps needed for a specific and uniform light intensity. It is critical to have the correct lighting system installation.

Because the CEA spinach program is production-intensive, lighting and electrical power usage is high. Local utility companies should have information on special rates and rebate programs for new industries and Controlled Environment Agriculture facilities.

Lighting Configuration and High Intensity Discharge (HID) Lamps

The number and position of the lamps are determined using a specialized lighting configuration computer program.



Figure 6. High Pressure Sodium lamp for supplemental lighting.

Figure 6 shows a high pressure sodium (HPS) lamp and luminaire used for supplemental lighting. These lamps provide the recommended PAR needed to supplement natural light. The computer control program records the irradiance and adjusts (on and off) the supplemental lighting system to achieve a predetermined total light level each day. For the spinach production the recommended level is $17 \mu\text{mol}/\text{m}^2/\text{s}^1$ though a higher DLI can be tolerated. If given less PAR than the target DLI, the crop will take longer to mature and the *pythium* pathogen may have enough time to destroy the crop.

Temperature Monitoring/Aspirated Box



Figure 7. Aspirated box with digital output screen in greenhouse (left). The picture on the right shows the opening for the box that allows the fan in the bottom of the box to draw air over the sensors for a more accurate temperature reading.

This is an example of an aspirated box (Figure 7) which houses and protects the sensors the computer uses to make control decisions from light or localized temperature fluxes. Most greenhouse control systems supply their own aspirated boxes with sensors included that will be used for environmental monitoring. Aspirated boxes can be home-made but care must be taken so that the air is drawn over the sensors so that heat is not added to the air from the fans. The

position of the box should be close to the plant canopy to measure the environmental parameters at the plant level. This may not be possible in all germination areas. The box is equipped with a small fan which draws air past the sensors. Sensors are located upstream from the fan.

Sensors

See "Sensors" under Chapter 3: Computer Technology for full details.

Chapter 2: System Components

System Component Information

Note: References to company and brand names are used for identification purposes only and do not necessarily constitute endorsements over similar products made by other companies.

2.1 Dissolved Oxygen Sensor

Most manufacturers recommend that dissolved oxygen sensors be calibrated daily. Modern sensors are fairly stable and will probably not go out of calibration in such a short time period. Remember that your data is only as good as your calibration, so be sure to calibrate all sensors on a regular basis.

A hand-held sensor (~\$600 in 2013) is always an essential trouble-shooting tool and should always be available. If the facility is one acre or larger, an in-line sensor may be a worthwhile investment.

Model: Orion 820, hand held, battery operated

Manufacturer: Orion Research Inc., Boston, MA

Some other manufacturers that make this same quality meter are YSI, Oakton and Extech

2.2 Flow Meters



Figure 8. Flow meter for monitoring oxygen addition to ponds.

Model: H-03216-04: 65 mm variable area aluminum flow meter with valve and glass float for O₂
Manufacturer: Cole Parmer Instrument Co., Niles, IL

Specifications: Max. flow rate for O₂ = 46 ml/min

Chapter 3: Computer Technology and Monitoring

Computer technology is an integral part in the production of hydroponic spinach. A computer control system (example: Argus, Hortimax, Priva) should be used to control the abiotic environment. Different sensors are used to monitor greenhouse environment parameters. These parameters include temperature of greenhouse air and nutrient solution, relative humidity and carbon dioxide concentration of greenhouse air, light intensities from both sunlight and supplemental lighting. Nutrient solution parameters such as pH, Dissolved Oxygen (DO) levels, and Electrical Conductivity (EC) can be monitored and controlled with a computer control system but are often managed manually. Sensors will communicate the environmental conditions to the control computer which will activate environmental control measures such as heating, ventilation, shade, and lighting.

3.1 Biological Significance of Environmental Parameters

Temperature

Temperature controls the rate of plant growth. Generally, as temperatures increase, chemical processes proceed at faster rates. Most chemical processes in plants are regulated by enzymes which, in turn, perform at their best within narrow temperature ranges. Above and below these temperature ranges, enzyme activity starts to deteriorate and as a result chemical processes slow down or are stopped. At this point, plants are stressed, growth is reduced, and, eventually, the plant may die. The temperature of the plant environment should be kept at optimum levels for fast and successful maturation. Both the air and the nutrient solution temperature must be monitored and controlled. *A chiller must be purchased* to maintain the water temperature at a sufficiently cool level. Water temperature should be maintained at 50-68 F (15-20 C). Temperature control of the nutrient solution is critical to controlling the pathogen population so that the entire crop is not lost to disease (See Chapter 1).

Relative Humidity

The relative humidity (RH) of the greenhouse air influences the transpiration rate of plants. High RH of the greenhouse air causes less water to transpire from the plants, which causes less transport of nutrients from roots to leaves and less cooling of the leaf surfaces. High humidities can also cause disease problems in some cases.

Carbon Dioxide or CO₂

The CO₂ concentration of the greenhouse air directly influences the amount of photosynthesis (growth) of plants. Normal outdoor CO₂ concentration is around 390 parts per million (ppm). Plants in a closed greenhouse during a bright day can deplete the CO₂ concentration to 100 ppm, which severely reduces the rate of photosynthesis. In greenhouses, increasing CO₂ concentrations to 1000-1500 ppm speeds growth. We have conducted experiments with CO₂ concentrations ranging from 400-1600 ppm and can confirm that spinach is consistently responsive to increased CO₂ concentrations even with the short crop cycles associated with this spinach production protocol. CO₂ is supplied to the greenhouse by adding liquid CO₂. Heaters that provide carbon dioxide as a by-product exist but we do not recommend these because they often provide air contaminants that slow the growth of the spinach.

Lights

Light measurements are taken with a quantum sensor, which PAR in the units $\mu\text{mol}/\text{m}^2/\text{s}$. PAR is the light which is useful to plants for the process of photosynthesis. Measurements of PAR give an indication of the possible amount of photosynthesis and growth being performed by the plant. Foot-candle sensors and lux meters are inappropriate because they do not directly measure light used for photosynthesis.

Dissolved Oxygen

Dissolved oxygen (DO) measurements indicate the amount of oxygen available in the pond nutrient solution for the roots to use in respiration. Spinach will grow satisfactorily at a DO level of at least 4 ppm. If no oxygen is added to the pond, DO levels will drop to nearly 0 ppm. The absence of oxygen in the nutrient solution will stop the process of respiration and seriously damage and kill the plant. Pure oxygen is added to the recirculation system in the ponds. Usually the level is maintained at 8 ppm (between 7-10, no advantage to raising to 20). For sufficiently small systems, it is possible to add air to the solution through an air pump and aquarium air stone but the dissolved oxygen level achieved will not be as high as can be achieved with pure oxygen.

pH

The pH of a solution is a measure of the concentration of hydrogen ions. The pH of a solution can range between 0 and 14. A neutral solution has a pH of 7. That is, there are an equal number of hydrogen ions (H^+) and hydroxide ions (OH^-). Solutions ranging from pH 0 - 6.9 are considered acidic and have a greater concentration of H^+ . Solutions with pH 7.1 - 14 are basic or alkaline and have a greater concentration of OH^- . This is important because a laboratory test of the nutrient solution may show that the micro and macroelements required by the crop are within the appropriate concentration range but if the pH is not correct then the nutrients are unavailable to the crop.

The pH of a solution is important because it controls the availability of the fertilizer salts. A pH of 5.8 is considered optimum for the described spinach growing system, however a range of 5.6-6.0 is acceptable. Nutrient deficiencies may occur at ranges above or below the acceptable range.

Electrical Conductivity

Electrical conductivity (EC) is a measure of the dissolved salts in a solution. As nutrients are taken up by a plant, the EC level is lowered since there are fewer salts in the solution. Alternately, the EC of the solution is increased when water is removed from the solution through the processes of evaporation and transpiration. If the EC of the solution increases, it can be lowered by adding pure water, e.g., reverse osmosis water). If the EC decreases, it can be increased by adding a small quantity of a concentrated nutrient stock solution. When monitoring the EC concentration, be sure to subtract the base EC of your source water from the level detected by your sensor.

Monitoring

The following parameters should be monitored. Specific sensor recommendations will not be made here.

Temperature, see Figure 7.

Relative Humidity, see Figure 7.

Carbon Dioxide Concentration (Infra Red Carbon Dioxide Sensor)

Light (Quantum PAR sensor), see Figure 12.

Dissolved Oxygen

pH

Electrical Conductivity (EC)



Figure 9. PAR meter for measuring instantaneous PAR and calculating DLI.



Figure 10. Dissolved oxygen sensor. DO levels should be greater than 4 ppm to prevent growth inhibition. Visible signs of stress may be observed at 3 ppm.

3.3 Set-points

Air Temperature	24 C Day/19 C Night (75 F/65 F)
Water Temperature	No higher than 25C, cool at 26C, heat at 24C
Relative Humidity	minimum 50 and no higher than 70%
Carbon Dioxide	1000-1500 ppm if light is available, ambient (~390 ppm) if not
Light	17 - 22 mol/m ² /d combination of solar and supplemental light
D O	7 mg/L or ppm, crop failure if less than 3 ppm
pH	5.6-6
EC	1300 +/- 100 μ S/cm above the source water

Chapter 4: Spinach Production

Spinach Production

This handbook is directed toward baby leaf spinach. The production of the spinach crop is separated into two growing areas. Seeds are started in a germination area where they germinate for 2 days. They should be shaded from full sun on the first day after germination, but can then be exposed to full light ($17 \text{ mol/m}^2/\text{d}$) or slightly greater. On Day 14 the plants are harvested by shearing the crop above the media. Do not attempt a second harvest with the same plants as this will eventually allow pathogens in the nutrient solution to build to a lethal level and destroy both the plant material in the pond and future plant material placed in the same solution.

Germination Area Stage

Germination Area stage is scheduled for production days 0-2 and may occur in a growth chamber or nursery area in the greenhouse.

Sowing

Production begins with the making of the germination media. Media should be moistened to an optimal moisture before sowing occurs. Cornell mix or a commercial product that approximates the mixture of peat/perlite in CU mix should be used. Fill the flat with media. Use a dibble to compress media (Figure 11). Place seed on top of media by hand or with automatic seeder (vacuum seeder, Figure 12). Add additional media and compact. Place in humid environment for germination.



Figure 11. Underside of dibble on left and dibble compressing soil on right.



Figure 12. Pelleted seed being spread on a vacuum seeder.



Figure 13. Seed adhered to vacuum seeder plate being inverted over flat.



Figure 14. Pelleted seed on dibbled media ready for additional media to be added.

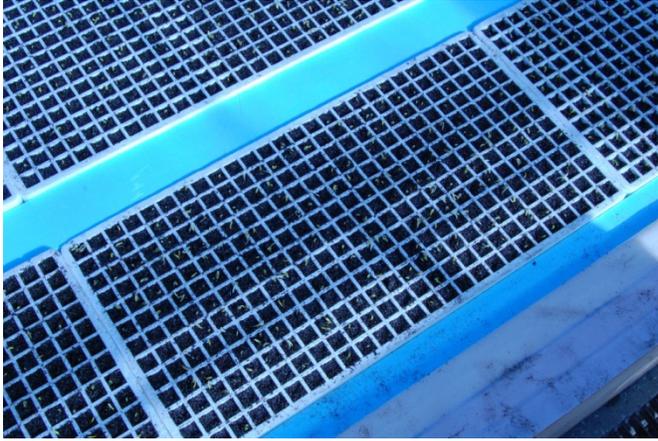


Figure 15. Newly germinated seedlings just after floating in the pond. Note the cotyledons just poking through media.

We recommend an expanded polystyrene plug tray for baby spinach production. These roughly 0.52 square meter trays come in many different densities (for example, arrays of 12 x 24, 14 x 28, 13 x 26) and we have trialed densities between 1000-3000 plants per square meter. We find that a plug tray that allows 1500 plants per square meter is optimal. The two companies whose trays we have experience are Speedling (1.75" deep) and Beaver Plastics (2.5" deep). Custom trays can be ordered and manufactured such that every other cell is Styrofoam so that only half the media is needed and cells would be double seeded. Please note that if trays are double seeded they need to be harvested when a little smaller or plants become brittle.

Trays are filled with a peat/perlite mixture, we use Sungro Redi-Earth seedling germination mix. The moisture content of this media is critical to seedling germination. Please note that media CANNOT be re-used because of the risk of disease. Also note that media cannot be autoclaved to reduce disease risk because that process damages the physical properties of the media. Media should be moistened before seeding (3:1 water: media for peat-based) to ensure proper moisture content and consistent and predictable germination. Both the moisture and air content of the media are critical for uniform and consistent germination. Attempting to add moisture to the top or bottom of the flats will often result in uneven germination.

Trays must be kept in a high-humidity environment until plants emerge from the soil. Roots will exit the bottom of the flat before the shoots emerge from the top. The time this takes can change based on the temperature the trays are kept in. We suggest a temperature range between 22 and 26C and humidity as close to 100% as possible. Many different ways may be used to create the high humidity condition including putting plastic sheeting on top of stacked floats or adding humidity to the germination chamber.

Seeding depth



Figure 16. Comparative size of seeds: Basil, pelleted basil, spinach (left to right).

Spinach seed is large which makes it easy to handle (Figure 16). Seeds must be planted at least ½” deep so that the outer covering of the seed (called the pericarp) is removed by the friction of the media as the hypocotyl emerges.

When trays are placed into a temperature controlled chamber until seedling emergence careful attention should be given so that temperature stratification (ex. Warmer at top and bottom of rack, see Figure 3) does not occur. To help avoid this issue, allow all trays to arrive at an even temperature before placing in the germination chamber.

Light should be provided at a minimum intensity of 100 $\mu\text{mol}/\text{m}^2/\text{s}$ to prevent stretching after 24 hours.

Float the flats in the pond after cotyledons appear (Figure 15). We recommend a two pond system so that the growth of the product is faster than the reproduction of the pathogen. If the spinach is allowed to remain in the same pond for the entire crop cycle, the asexual form of the pathogen can reproduce and spread to the younger plants. Because the nutrient solution is not changed regularly, eventually concentrations of the pathogen will be large enough to infect young plants and kill them before they reach maturity.

Monitor pH and EC daily and DO not less than once per week. Harvesting is conducted on day 16 and is often performed manually with scissors or an automatic knife. Commercial harvesting machines are not widely available.

Chapter 5: Packaging and Post-Harvest Storage

Packaging can be a significant cost and many grocery stores are requesting clamshell style hard plastic packaging. The type of packaging will affect the shelf life of the product. Re-sealable bags are the most inexpensive packaging option.

After being packaged, the spinach should be stored at 40F (4C). Penn State researchers have performed experiments investigating the

Chapter 6: Crop Health

Disease

As mentioned previously, hydroponic spinach is particularly susceptible to a water-borne pathogen called *Pythium aphanadermatum* that will attack the crop roots slowing growth and eventually killing the plants. A review of the life cycle of this pathogen is beyond the scope of this handbook but an excellent and classic resource is Plant Pathology by G.N. Agrios. We feel that hydroponic spinach can be grown successfully by following the protocol outlined above that includes controlling the temperature of the pond water, duration of the crop in each pond, and daily light integral. You must keep the crop rapidly growing by providing adequate light, nutrients, and other environmental conditions at all times.

If root disease does occur, the ponds and solution tanks should be drained and the crop sacrificed. The ponds and tanks should be cleaned with a 2% bleach solution. It is possible the disease started in the Germination Area, and that area, including the benches and solution tanks, should be cleaned, as well.

Wash the Styrofoam floats, trays, and other equipment with a 2% bleach solution (sodium hypochlorite). The equipment should be washed between each use, to prevent the spread of disease.

Do not bring other plant material or soil into the greenhouse. This material may contain pests and pathogens likely to infect your crop. **Keep visitors to the greenhouse to a minimum** or allow them to view the production area from the outside of the greenhouse only.

Keep the solution tanks shaded in some manner. Algae flourish in wet, well-lit locations, and the solution tank is ideal for algal growth. Shading the tanks, input and output pipes, and other "wet" equipment will inhibit algal growth. The algae will not harm the crop directly, but may act to weaken the crop to potential disease.

Pests

Pests in hydroponic spinach production have not been a major problem. Fast plant growth rates make pest population establishment difficult. With continuous crop production, pest populations may have the opportunity to establish themselves. Precautions can be taken to exclude pests from the facility, such as screening potential entry points (ventilation inlets). Keeping the grass and weeds mowed outside the greenhouse or removing all vegetation entirely can reduce pest pressure inside the greenhouse. Few pesticides have been labeled for use on greenhouse vegetables. Biological insect control is a viable but less used alternative.

Chapter 7: References

Albright, L.D., deVilliers, D.S., Shelford, T.J., Johnson, C.J.2007. Root disease treatment methods for commercial production of hydroponic spinach. Final report for NYSERDA. 127 pp.

Appendix

Stock Solutions

Two stock solutions are prepared which will be added separately to RO water and will supply nutrients to the spinach plants while in the pond area. Two separate stock solutions are prepared to prevent certain chemical reactions. These chemical reactions will cause some of the chemicals to form a precipitate and become inactive. The precipitates will not form if mixed one after another with a large volume of RO water. Note: Some salts have different waters of hydration. If you do not plan to use the salt with the exact formula in this protocol, be sure to adjust the weight accordingly.

STOCK A	
These chemicals are added to 300 L of RO water	
Calcium Nitrate	29160.0 g
Potassium Nitrate	6132.0 g
Ammonium Nitrate	840.0 g
Sprint 330 Iron - DTPA (10% Iron)	562.0 g

STOCK B	
These chemicals are added to 300L of RO water	
Potassium Nitrate	20378.0 g
Monopotassium Phosphate	8160.0 g
Potassium Sulfate	655.0 g
Magnesium Sulfate	7380.0 g
Manganese Sulfate*H ₂ O (25% Mn)	25.6 g
Zinc Sulfate*H ₂ O (35% Zn)	34.4 g
Boric Acid (17.5% B)	55.8 g
Copper Sulfate*5H ₂ O (25% Cu)	5.6 g
Sodium Molybdate*2H ₂ O (39% Mo)	3.6 g

Final Fertilizer Solution Concentrations

Macro-nutrients:			Micro-nutrients:		
N	8.9 millimol l ⁻¹	(125 ppm)	Fe	16.8 micromol l ⁻¹	(0.94 ppm)
P	1.0 millimol l ⁻¹	(31 ppm)	Mn	2.5 micromol l ⁻¹	(0.14 ppm)
K	5.5 millimol l ⁻¹	(215 ppm)	B	15.0 micromol l ⁻¹	(0.16 ppm)
Ca	2.1 millimol l ⁻¹	(84 ppm)	Cu	0.4 micromol l ⁻¹	(0.03 ppm)
Mg	1.0 millimol l ⁻¹	(24 ppm)	Zn	2.0 micromol l ⁻¹	(0.13 ppm)
S	1.1 millimol l ⁻¹	(35 ppm)	Mo	0.3 micromol l ⁻¹	(0.03 ppm)