



GROWING HYDROPONIC TOMATOES

Growing Tomatoes Hydroponically (Part One)

By Dr. Merle Jensen

Overview of Hydroponics

Consumption of tomatoes in the United States has reached 4.3 billion pounds each year. When consumers are willing to pay double or triple standard prices for a great tasting, blemish free product, buyers and sellers alike can smile at the possibilities. Repeated pricing studies have shown that only high-quality, garden vegetables, such as tomatoes, cucumbers, salad crops and culinary herbs, can provide break even or better revenues in hydro systems.

Hydroponics is a technology for growing plants in nutrient solutions (water and fertilizers) with or without the use of artificial medium (e.g., sand, gravel, vermiculite, rockwool, peat, coir, sawdust) to provide mechanical support. Liquid hydroponic systems have no other supporting medium for the plant roots: aggregate systems have a solid medium of support. Hydroponic systems are further categorized as open, where after the nutrient solution has been delivered to the plant roots, it is not reused; or closed where surplus solution is recovered, replenished, and recycled. The definition of hydroponics has been confined to liquid systems only, which blurs statistical data and leads to underestimation of the extent of the technology and its economic implications. All hydroponic systems in temperate regions of the world are enclosed in greenhouse-type structures to provide temperature control, reduce evaporative water loss, and to reduce disease and pest infestations.

The principal advantages of hydroponic controlled environment agriculture (CEA) include high-density maximum crop yield, crop production where no suitable soil exists, a virtual indifference to ambient temperature and seasonality, more efficient use of water and fertilizers, minimal use of land area, and suitability for mechanization, disease and pest control. The major advantage of hydroponic (CEA) compared to field grown produce is the isolation of the crop from the soil, which often has problems of diseases, pests, salinity, poor structure and/or drainage.

The principal disadvantages of hydroponics, relative to conventional open-field agriculture, are the high costs of capital and energy inputs, and the high degree of management skills required for successful production. Capital costs may be especially excessive if the structures are artificially heated and cooled. This is why appropriate crops are limited to those with high economic value such as tomatoes.

History of Hydroponics

The earliest food production in greenhouses was possibly the growing of off-season cucumbers under "transparent stone" for the Roman Emperor Tiberius during the 1st century. The technology was rarely used, if at all, during the following 1500 years.

During the 1600s several techniques were used to protect horticultural crops against the cold. These included glass lanterns, bell jars, cold frames and hot beds covered with glass. In the 17th century, low portable wooden frames covered with an oiled translucent paper were used to warm the plant environment much as plastic row covers do today. In Japan, straw mats were used in combination with oil paper to protect crops from the severe natural environment. Greenhouses in France and England during the same century were heated by manure and covered with glass panes. The first glass house built in the 1700s, used glass on one side only as a sloping roof. Later in the century, glass was used on both sides. The glasshouse was used for fruit crops such as melons, grapes, peaches and strawberries and only rarely for vegetable production. The developers of this new technology kept market profitability in mind: they produced crops which appealed to the wealthy and privileged, the only people who could afford the luxury of fresh fruit produced out of season in greenhouses.

Greenhouse food production was not fully established until the introduction of polyethylene. In the U.S., the first use of polyethylene as a greenhouse cover was in 1948, when Professor Emery Myers Emmert at the University of

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Kentucky, used the less expensive material in place of more expensive glass. Professor Emmert is considered the father of plastics in the U.S. because he developed many principles of plastic technology for agricultural purposes through his research on greenhouses, plastic mulches and row covers.

The development of hydroponics has not been rapid. In the U.S., interest began to develop in the possible use of complete nutrient solutions about 1925. Greenhouse soils had to be replaced at frequent intervals or be maintained from year to year by adding large quantities of commercial fertilizers. As a result of these difficulties, research workers in certain U.S. agricultural experiment stations turned to nutrient solution culture methods as a means of replacing the natural soil system with either an aerated nutrient solution or an artificial soil composed of chemically inert aggregates moistened with nutrient solution.

Between 1925 and 1935, extensive development took place in modifying the methods of the plant physiologists to large scale crop production. Workers at the New Jersey Agricultural Experiment Station improved the sand culture method. The water and sand culture methods were used for large scale production by investigators at the California Agricultural Experiment Station. Each of these methods involved certain fundamental limitations for commercial crop production which were partially overcome with the introduction of the subirrigation system initiated in 1934 at the New Jersey and Indiana Agricultural Experiment Station. While there was commercial interest in the use of such systems, hydroponics was not widely accepted due to the high cost in construction of the concrete growing beds. In the post-W.W.II years, there was a bloom of interest in the Southwest US in gravel culture of tomatoes and cucumbers. However, the systems were not perfected and were eventually abandoned.

After a period of approximately 20 years, interest in hydroponics was renewed with the advent of plastics. Plastics were used not only in the glazing of greenhouses, but also in lining the growing beds rather than beds made of concrete. Plastics were also important in the introduction of drip irrigation. Again, numerous promotional schemes involving hydroponics became common with huge investments made in hydroponic growing systems. Escalating oil prices, starting in 1973, substantially increased the costs of CEA heating and cooling. This along with fewer chemicals registered for pest control caused many bankruptcies and a decreasing interest in hydroponics.

Almost another 20 years have passed since the last real interest in hydroponics, but growers are once again establishing CEA/hydroponic systems. This is especially true in regions where there are environmental concerns in controlling any pollution of groundwater with nutrient wastes or soil sterilants. Today growers appear to be much more critical in regard to site selection, structures, the growing system, pest control and markets.

Future of Hydroponics

Hydroponics is a relatively new technology, evolving rapidly since its inception 70 years ago. From its origins in academic research, to its utilization in industry and government, hydroponics has found many new applications. It is a versatile technology, appropriate for both developing countries and high-tech space stations. Hydroponic technology can efficiently generate food crops from barren desert sand and desalinated ocean water, in mountainous regions too steep to farm, on city rooftops and concrete schoolyards and in arctic communities. In highly populated tourist areas where skyrocketing land prices have driven out traditional agriculture, hydroponics can provide locally grown high-value specialty crops such as fresh salad greens, herbs and cut flowers.

Like manufacturing, agriculture tends to move toward higher-technology, more capital-intensive solutions to problems. Hydroponics is highly productive and suitable for automation. However, the future growth of controlled environment agriculture and hydroponics depends greatly on the development of systems of production that are cost-competitive with those of open field agriculture. Improvements in associated technologies such as artificial lighting and agricultural plastics, and new cultivars with better pest and disease resistance will increase crop yields and reduce unit costs of production. Cogeneration projects, where hydroponic greenhouses utilize waste heat from industry and power plants, are already a reality and could expand in the next few years. Geothermal heat could support large expanses of greenhouses in appropriate locations.

It has been proposed that glasshouses located in deserts of the world could one day serve a dual purpose, where antenna could be embedded into the glass to receive energy radiation from an array of energy collectors in space, while at the same time facilitate hydroponic tomato production.

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The economic prospects for controlled environmental agriculture and hydroponics may improve if governmental bodies determined that there are politically desirable effects of hydroponics that merit subsidy for the public good. Such beneficial effects may include the conservation of water in regions of scarcity or food production in hostile environments; governmental support for these reasons has occurred in the Middle East. Another desirable societal effect could be the provision of income-producing employment for chronically disadvantaged segments of the population entrapped in economically depressed regions; such employment produces tax revenues as well as personal incomes, reducing the impact on welfare rolls and improving the quality of life.

Hydroponics is a technical reality. Such production systems are producing horticultural crops where fresh vegetables and ornamentals are unavailable for much of the year. The development and use of controlled environment agriculture and hydroponics have enhanced the economic well being of many communities throughout the world.

Tomato Timeline

700 A.D.

Tomatoes were cultivated by the Incas, thus making tomatoes an authentic American native crop. Centuries later, tomatoes traveled from Peru where they grew wild in the Andes mountains, eventually migrating into Mexico, where they were known as "tomatis".

16th, 17th, and 18th Centuries

Conquistadors carried tomato seeds from the Americas to Spain and Portugal. Most of these early fruits were yellow-skinned, and picked up such names as "manzanas" (apples) and "pomi d'oro" (apple of gold). They were considered poisonous but appreciated for their beauty. Some considered the fruit a potent aphrodisiac. Eventually the Spanish, Portuguese and Italians experimented with tomatoes in recipes.

After the French Alliance, Colonial Americans adopted tomatoes into their pantries, although seed catalogs still listed tomatoes under "annual and ornamental flowers".

Early 1800s

Tomatoes were first quoted on the stock market around 1812. Breeding work was begun to develop improved varieties. Two gentlemen advocates ate tomatoes publicly to dispel the fear of toxicity. In 1818, an edition of American Gardener lists the earliest known recipe for tomato ketchup.

Late 1800s

The first greenhouse tomatoes were produced for the market by farmers in Cleveland, Ohio. Although botanically a fruit, the U.S. Supreme Court decided that the tomato would legally be considered a vegetable because it is usually served with the main part of the meal (an import duty case was involved).

Early 1900s

A glut of tomatoes, plus a boycott by independent brokers and other users broke up a potential "tomato trust" when there was an attempt to corner the canned market. "Tomato clubs" were formed by young farm girls who cultivated and canned tomatoes on their own.

The nutritive properties of tomatoes, along with fruits and greens were recognized and publicized. The tomato is considered a valuable source of Vitamins A and C, retaining C even through cooking and aeration. They offer minerals as well, and are low in sodium.

Today

The tomato is now a food of worldwide importance. The hydroponic tomato research and development programs at the University of Arizona, starting in the mid 1960s, have led the way to the development of the most modern hydroponic systems in the United States. Early in these programs, it was learned that light is the most important factor in locating the best site for hydroponic tomato production. The highest winter light conditions in the world are in the southwestern desert region of the United States. This is when the tomato prices are at their highest. Today, Arizona is center to the most rapid growth of hydroponics in the United States. The future for hydroponics has never appeared more positive.

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Greenhouses

There are many factors to consider in determining the amount of greenhouse space you will need. Amount of investment capital, training, the type of business, environmental requirements, market, labor requirements and personal preferences must all be evaluated. You should also be aware of factors which are important in choosing a good building site, such as drainage, accessibility, available utilities and amount of sun exposure.

There are companies who sell greenhouse packages which contain everything needed for turnkey operation. Greenhouse tomatoes with indeterminate growth habits are best managed in houses with high roofs. The structural design of a greenhouse must provide protection from wind, rain, heat and cold. The structural supports must be of minimal size to permit maximum light transmission to the crop while still supporting the structure itself, heating and ventilation units and the weight of the crop which is trained to grow up a support system carried by the greenhouse frame.

There are a variety of types of greenhouse covers. Glass is still a common glazing material. Large panes reduce the shading of the crop from the support frame. While shading may seem minimal in traditional greenhouses, it is estimated that every 1% decrease in light will result in a 1% decrease in yield.

Despite the common use of glass as a covering for greenhouses in Northwest Europe, glass remains inflexible, heavy, and expensive. Consequently, the hectarage of glasshouses on a world basis has remained static, (approximately 30,000 ha.) during the last 25 years. In contrast, the quantity of plastic used for greenhouses is increasing rapidly. Since polyethylene sheet film was first developed in England in 1938, it has been used widely in greenhouses because it is easy to work with and inexpensive. Worldwide, there are nearly 300,000 ha. of plastic greenhouses for growing high value horticultural crops.

Several other plastics have also been used for greenhouse glazings. Polyvinylchloride (PVC) has a very high emissivity for long wave radiation (similar to glass), which creates slightly higher air temperatures in the greenhouse during the night. The Japanese consider this improvement in thermal environment a benefit that outweighs the price advantage offered by the less expensive polyethylene (PE). The disadvantage of PVC is its narrow width as compared to PE, which may be manufactured in widths of up to 15 meters. The narrow PVC sheets can be heat-welded together to form a large sheet, but this adds to the cost of the glazing material.

The large sheets of PE can be applied as an air-inflated "blanket" over a greenhouse: two sheets of PE are separated by air pressure maintained by a small continuously running fan. This arrangement provides approximately 30-40% heat savings during winter. The double-layer, air-inflated roof has also proven valuable in regions with high winds or typhoons. It offers stability during these conditions, saving the greenhouse and the crop during times when structures covered only with one layer of plastic are often lost and the crops damaged or destroyed. PVC film is not suitable for air-inflated roofs because the air pressure stretches the film and reduces its structural strength. Because PVC film is not photodegradable, as is PE, environmental concerns about disposal may diminish the use of PVC in Japan in favor of PE, which is the predominant cover for greenhouses worldwide.

New materials such as double-skinned panels made of polycarbonate and acrylic are becoming increasingly popular. Unfortunately, their technical merit is offset by high costs, making them affordable only in the industrial nations of the world rather than in developing agricultural communities.

The ideal greenhouse "selective film" should do the following:

Transmit the visible light portion of the solar radiation spectrum, the only portion utilized by plants for photosynthesis.
Absorb the small amount of ultraviolet radiation in the spectrum and cause some of it to fluoresce into visible light, useful to plants.

Reflect or absorb infrared radiation , which plants cannot use and which cause greenhouse interiors to overheat.
Minimize costs, and have at least a 10 to 20 year useable life.

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Light

Photosynthesis is the key to good growth and high yields. If photosynthesis is decreased, due to low light conditions, high humidity (which closes stomates and reduces gas exchange), or water stress, then the production of sugars will decline and the fruit quality, shelf life, and size will all diminish.

Because of the critical role of photosynthesis in plant growth, a one-percent decrease in light can translate to a one-percent decrease in yield. Shading from outside topography and trees, the greenhouse structure itself, or taller plants in the greenhouse can significantly reduce the amount of light reaching the crop. Both the greenhouses and the rows of plants in the greenhouse should be oriented north and south so the light is evenly distributed across each plant. Some growers reflect light back into the crop using white floorcoverings or paint. Clean white paint is more reflective than metallic or foil, although there is some indication that foil tends to "confuse" insects and slightly decrease insect pest damage.

During long periods of cloudy weather, tomato leaves become low in sugars, and may become pale and thin. Excess nitrogen at that time can be detrimental.

Some growers prefer to shade tomatoes, while others do not. Theoretically, shading will reduce photosynthesis, and therefore total yield, however, this has not always been shown in controlled studies. In fact, in some studies, total yield was improved using 30% shadecloth. Shading can improve fruit quality, since direct sunlight on fruit can cause yellow or green shoulders, cracking, and russetting. Alternatively, older leaves can be left in place to shade the individual fruit trusses. In areas of high summer temperatures and humidity, shading may be necessary to keep temperatures within a reasonable range. Ultimately, the decision to shade or not depends on the location of the greenhouse, the cultivar of tomato grown, the season and the overall management system employed by the grower.

Historically, the greenhouse industry has traditionally measured light in foot-candles and lumens. Foot-candles are the amount of light received on the surface and lumens are the measure of light emitted by a light source. Natural sunlight and artificial light falling on a plant are measured in foot-candles (f.c.) while the light emitted by sources such as the sun and electric lamps are rated in lumens. A clear, sunny day may measure 10,000 f.c. and an overall winter day as low as 500 f.c. To read comfortably requires about 20 f.c. The light of the full moon measures less than 1 f.c. A light meter with a scale in direct foot-candle readings is manufactured by the General Electric Company and is sold by most greenhouse supply companies.

Supplementary artificial light, from cool white, high output fluorescent or high intensity discharge sodium vapor lamps is beneficial to plants when sunlight is unavailable but is not a complete substitution. Intensity of supplementary lighting should be about 800-1000 foot-candles at the plant surface.

Today, plant scientists are primarily interested in that light which is responsible for photosynthesis. The portion of the light band most responsible for photosynthesis measures 400-700 nanometers. This band is often termed the Photosynthetically Active Radiation (PAR). Within this range, intensity is the most critical factor along with light period. Within the PAR region light is measured as the Photosynthetic Photon Flux (PPF) and is expressed in $\mu\text{mol}/\text{m}^2/\text{s}$. Daily total of PPF, expressed in mol/m^2 have been shown to relate to total photosynthesis for the day.

In the southwestern region of the United States, the winter light readings are three times higher than in the northern regions such as the states of New York and Ohio. This is why the greenhouse tomato industry is growing so rapidly in Arizona and surrounding states.

Supplemental lighting is generally not economical for vegetable crops, with the exception of seedling production. However, for backyard or hobby situations, full-spectrum lighting can be effective in increasing yields by increasing the daylength to 18 hours during winter months.

Temperature

Both day and night temperatures influence plant vigor, leaf size, leaf expansion rate, and time to fruit development. Under low night temperatures, the rate of leaf growth is slower, and leaf size is reduced in young plants. Day and

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night temperatures should be carefully monitored. A general rule of thumb for most horticultural crops is for night temperatures to be approximately 5.5° C (10° F) lower than day temperatures. For tomatoes, day temperatures should be 21° -26° C (70° -79° F) and night temperatures around 16° -18.5° C (61° -65° F), although many new varieties do best with little difference between day and night temperature (check with your seed company for recommended growing temperatures). For seedlings, the temperatures should be constant, 20° -22° C (68° -72° F), then gradually acclimate the plants to the diurnal temperatures before transplanting.

High temps in excess of 30° C to 35° C will cause many different types of damage to the plants, such as inhibition of growth and even death. The physiological nature of heat damage is thought to involve a denaturation of some protein component of plant cells. Fruit abortion may occur at these temperatures as well. Temperatures lower than optimum will alter the plant metabolic systems to slow growth and again hinder fruit set.

Fogging systems can be an alternative to evaporative pad cooling. They depend on absolutely clean water, free of any soluble salt, in order to prevent plugging of the mist nozzles. Like fan and pad cooling, fog cooling is only really efficient in low humidity environments.

In hobby greenhouses, temperatures can be measured easily with a minimum/maximum thermometer. Several thermometers should be placed throughout the greenhouse, and should be calibrated against each other and a quality thermometer at least twice per year. In large commercial operations, computer controlled systems are common. Such systems can provide fully-integrated control of temperature, humidity, irrigation and fertilization, carbon dioxide, light and shade levels.

Air Circulation and Ventilation

Good circulation is necessary for proper cooling, heating, CO₂ replenishment, and removal of undesirable gases, such as ethylene. Your circulation system must work together with your heating, cooling, and CO₂ systems in order to obtain peak efficiency.

Many different methods of circulating air have been developed. The vent-tube system is used quite a bit, and consists of a fan-jet connected to a perforated plastic tube running the length of the greenhouse at ceiling height. The fan forces air through the tube, which moves the warm air in the roof space downward to displace the cooler air at the floor level. This design is not very efficient. A horizontal airflow system is more efficient, and can move a larger amount of air around the plants. Large fans, hanging above the crop, are set up facing one direction in one section of the greenhouse, and in the opposite direction in the adjacent section of the greenhouse. A more complicated system is a vertical airflow system, which uses fan-jets to move air along the roof, downward at the end walls, then along the floor through the crop. This system provides the best mixing of air and brings warm air down into the plants. Various types of alternative ventilation systems have been proposed, such as up-draft and down-draft chimneys. However, it will be some time before these systems are thoroughly tested and refined.

In the tropics, natural air exchange to the outside of the greenhouse can be achieved simply through the sides of the greenhouse structure. For active or mechanical ventilation, low-pressure propeller blade fans are used for greenhouse ventilation. They are placed on the end of the greenhouse opposite the air intake, which is often covered by evaporative cooling pads and louvers. The cooling pads used in combination with fans (fan and pad cooling) can be made from a number of materials. Most often they are made of a cellulose material, usually aspen wood, or a multi-celled/honeycombed material called "kool-cel". The ventilation fans for larger greenhouses (100-120 feet in length) are normally sized to allow a maximum air exchange once per minute. Small hobby greenhouses, which have a large greenhouse surface area to floor area ratio, may require an air exchange of up to 2.5 times per minute.

Humidity

In order for a plant to actively grow, it must be allowed to transpire freely during photosynthesis; this means plenty of available water, low to moderate humidity, and good air circulation. Humidity influences calcium uptake and hormonal distribution by controlling transpiration, ion pumping, and stomatal opening and closing. High humidity coupled with low air movement reduces transpirational cooling, and can lead to heat overload for the plant.

People tend to think of humidity in terms of relative humidity, which is the ratio of the amount of water vapor in

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the air to the amount of water vapor the air could hold at that temperature, expressed as a percent. Plants, on the other hand, perceive humidity in terms of vapor pressure deficit (VPD). VPD is the difference between the vapor pressure in the air and the vapor pressure inside the leaf. Water moves by diffusion from the roots through the plant and out the leaves as transpired vapor, thereby being “pumped” up the plant as the vapor moves from the higher pressure inside the leaf to the lower pressure in the surrounding air. Low VPD (high humidity, greater than 90%) is often responsible for nutrient deficiency symptoms, such as blossom end rot (calcium deficiency) because the plant is not transpiring, therefore it is not drawing water, or nutrients, into the roots. High VPD (low humidity, less than 50%) can also lead to the same symptoms, because water and nutrients are pumped too quickly through the plants, depositing nutrient ions in the leaves rather than properly in the fruit.

Greenhouse humidity is measured with sling psychrometer. Other equipment such as a humidistat can measure relative humidity to an accuracy within 4%. Most greenhouse supply companies sell equipment to measure humidity.

Most plants can function adequately in relative humidities of between 55 and 95%, which corresponds to VPD's of 1.0 to 0.2 kPa. For tomatoes, the ideal humidity should be between 65 and 75% during the night and 80 to 90% during the day. Tomato yields and fruit quality are lower at lower VPDs (higher humidity). Leaf size can also be reduced, and flower and fruit abortion can be significantly increased under high humidity conditions. Glassiness and “gold fleck” in tomato fruit is also attributed to high atmospheric humidity.

Misting and fogging systems are used by some growers to increase humidity and decrease temperatures. However, if used improperly, these systems can greatly increase the incidence of mildews and plant diseases, not to mention corrode metal greenhouse structures.

Seeds

Several tomato varieties have been specifically developed for hydroponic production in controlled environments. All varieties have indeterminate morphology; meaning vegetative growth of the plant is continual and does not stop once flowering begins. This creates long tomato “vines” which must be trained up strings hanging from the greenhouse structures to maximize space and manage the crop. Some of the more popular varieties are Apollo, Belmondo, Caruso, Dombito, Larma, Perfecto, Trend and Trust. These are hybrid varieties, and the seed can be rather expensive. This may lead some novice growers to consider germinating seed from mature fruit, but those successive generations will not necessarily have the same characteristics of the parent plants. Some hobbyists prefer to grow successive generations from vegetative cuttings, producing genetic clones from the original plants. This is okay on a small scale, however, the high risk of perpetuating a latent disease or pest problem on a large scale outweighs the cost of new seed.

Starting Media and Nutrients

Any propagation medium must be thoroughly soaked before seeds are sown to assure uniform distribution of moisture. There are many different propagation media available.

Seeding trays can be filled with a soilless mix, such as peat and perlite. Peat pellets are also popular starters. Seedlings grown in a soilless mix may have enough nutrients available to them from the media that they would not need additional nutrients for the 1st few weeks of growth, and therefore could be watered with fresh water only. However, seedlings in an inert medium, such as rockwool or oasis, will definitely require nutrients at all times.

Rockwool blocks are available in several sizes, and are designed so that seeds can be placed directly into seeding cubes, then, as the plants develop, the cubes can be nested inside larger blocks, for a “pot in a pot” system. This minimizes transplant shock, since the larger block consists of the same material as the germination cube. Oasis horticubes are similar to rockwool cubes in that they are inert, sterile blocks with excellent drainage. Other cubes made of urethane foam and paper fiber are also available.

Tomato seeds should be sown 1/4 to 3/8 inch (0.6 to 1 cm) deep. Sprinkle a thin layer of vermiculite over the seeds or cover the germination cubes or pots with a large piece of clear plastic to conserve moisture at the surface. Avoid the use of plastic if the cubes receive direct sunlight, as the temperature may get too hot for good germination. The plastic must be removed as soon as emergence begins.

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Seedling System Design

Overhead watering is the most common method used for germinating seedlings. It is important for the seedlings to be in full sun and at the proper temperature as soon as germination occurs. When watering, the water must be sprinkled uniformly over all seedlings to avoid uneven growth. The plants must be checked often.

Flood and drain (ebb and flow) systems can also be very effective for germinating seedlings. Nutrient solution or water floods a shallow tray containing the sown cubes or pots, providing moisture from the bottom, which will diffuse throughout the propagation block by capillary action. Once the blocks are evenly moist, the tray is drained, which allows the cubes or pots to drain and assure aeration of the roots. This process will need to be repeated often throughout the day, but may not need to be done at all during the night. The advantages of this system are even moisture, no physical beating of the leaves and tender plants, and low labor costs (especially if timers are used).

In any event, the temperature of the irrigation solution should be at least 18° C (64° F). Irrigating seedlings with colder water will result in slower growth. During winter months, especially in Northern latitudes, supplemental light may be required for strong growth of seedlings. The lights should operate 14 to 18 hours per day.

Transplanting

The three stages of early development are germination, post-emergence, and transplant. Germination should occur within one week of seeding, post-emergence is generally five to 12 days, and transplanting should be done between 12 and 14 days from seeding. Once true leaves appear (during post-emergence), seedlings should be transferred into larger growing blocks (pots) from the original seedling cubes, then evenly spaced to maximize light to each plant, without any crowding or shading. The transplants must be spaced so as not to touch one another, and may need to be spread several times during their growth. If crowded, the plants will become spindly. A good transplant is one that is as wide as it is tall. If plants are somewhat "leggy", with long stems, they can be transferred into the larger blocks with their stems bent 180° so the original cube is upside-down inside the larger block, and the main stem forms a "U" shape, emerging vertically upward from the block. Tomato plants readily grow adventitious roots from the stems if given the opportunity, producing a stronger plant with more roots. Adventitious roots will grow from the bent stem inside the block.

Transplanting into the final growing media should be done before any flowering. The final growing media should be properly leached and moistened and be at the proper temperatures before plants are brought in. Plants should be irrigated with nutrient solution immediately after moving.

The spacing of tomatoes in hydroponic systems can be much denser than in soil. As little as two square feet per plant (0.2 square meters per plant) have been used with good yields and quality under high light conditions. Spacing is a function of sunlight, so in areas of lower light wider spacing should be applied.

Indeterminate tomatoes must be trained up support strings immediately after transplanting. The strings should be hung from horizontal wires, which are connected to the frame of the greenhouse. These wires will need to support hundreds of pounds of weight, as each mature plant with fruit may weigh 20 to 30 pounds (7 to 14 kilograms). Additional vertical poles can be added to help support the horizontal wires. The wires and strings should be put in place before any other paraphernalia is brought into the greenhouse, and should be at least 10 feet (three meters) above the ground. The strings should not be re-used, however, a variety of clips are available which can be sterilized and re-used. As the plants grow, the strings are unwound from their hangers and moved along the horizontal wire, effectively "lowering" the plants without breaking them. Mature indeterminate tomato plants may be 40 feet (12 meters) in length, and can grow much more.

Double Cropping

Some growers prefer to grow two crops of tomatoes in the growing media before tearing the system down, cleaning and sterilizing, and starting again. In this management system, young plants would be planted in the media between the older plants, just as the older plants are reaching their maximum economic life span. This effectively overlaps the crops, increasing total annual yield. However, the older plants must still be completely removed to prevent buildup of disease and excessive shading of the new crop, and care must be taken to work around the younger plants. In high light regions of the world, such as deserts and equatorial latitudes, the first crop is generally planted in midsummer and lasts through to the end of the year. The second crop can be planted in January and continue through the end of June. Alternatively, one long crop planted in late summer or fall can be grown until July.

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By Dr. Merle Jensen

Growing Media

Various growing media are used in hydroponic systems. However, any system must have the following 4 qualities:

- sufficient support for the plants
- appropriate distribution of air, since roots need oxygen and respire other gasses, such as carbon dioxide
- maximum water availability for the plant roots
- accessible nutrient solution with consistent chemical characteristics
- Liquid (non-aggregate) Hydroponic Systems

Deep Flow Hydroponics

The classic hydroponic system, where plants are supported so that their roots hang into a nutrient solution, is generally called “deep flow hydroponics.”

This system is appropriate for hobbyists and large scale production of leafy vegetable crops. The system consists of horizontal, rectangular-shaped tanks lined with plastic. The nutrient solution is monitored, replenished, recalculated, and aerated. Commercial facilities are now quite popular in Japan. The rectangular pools act as frictionless conveyor belts where large, moveable floats of plants (lettuce) can be transported from transplant to harvest.

Nutrient Film Technique

A modification of the deep flow system is called “nutrient film technique”, where a thin film of nutrient solution flows through plastic lined channels, which contain the plant roots. The walls of the channels are flexible; this permits them to be drawn together around the base of each plant, excluding light and preventing evaporation. For lettuce production, the plants are planted through holes in a flexible plastic material that covers each trough. Nutrient solution is pumped to the higher end of each channel and flows by gravity past the plant roots to catchment pipes and a sump. The solution is monitored for replenishment of salts and water before it is recycled.

Capillary material in the channel prevents young plants from drying out, and the roots soon grow into a tangled mat. This method is mainly used for tomatoes.

Aeroponics

Aeroponics is another technique, where nutrient solution is sprayed as a fine mist in sealed root chambers. The plants are grown in holes in panels of expanded polystyrene or other material. The plant roots are suspended in midair beneath the panel and enclosed in a spraying box. The box is sealed so that the roots are in darkness (to inhibit algae growth) and in saturation humidity. A misting system sprays the nutrient solution over the roots periodically. The system is normally turned on for only a few seconds every two to three minutes. This is sufficient to keep roots moist and the nutrient solution aerated. Systems were developed by Dr. Merle Jensen at the University of Arizona, for lettuce, spinach, and even tomatoes, although the latter was judged not to be economically viable. In fact, there are no known large-scale commercial aeroponic operations in the United States, although several small companies market systems for home use.

Aggregate Hydroponics

In aggregate hydroponic systems, a solid, inert medium provides support for the plants. As in liquid systems, the nutrient solution is delivered directly to the plant roots. Aggregate systems may be either open or closed, depending on whether surplus amounts of the solution are to be recovered and reused. Open systems do not recycle the nutrient solutions; closed systems do.

In most open hydroponic systems, excess nutrient solution is recovered; however the surplus is not recycled to the plants, but is disposed of in evaporation ponds or used to irrigate adjacent landscape plantings or wind breaks. Because the nutrient solutions are not recycled, such open systems are less sensitive to the composition of the medium used or to the salinity of the water. These factors have generated experiments with a wide range of growing media and the development of more cost-efficient designs for containing them.

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There are numerous types of media used in aggregate hydroponic systems. They include peat, vermiculite, or a combination of both, to which may be added polystyrene beads, small waste pieces of polystyrene beads, or perlite to reduce the total cost. Other media such as coconut coir, sand or rock are also common in some regions of the world.

For growing row crops such as tomato, cucumber, and pepper, the two most popular artificial growing media are rockwool and perlite. Both of these media can be used in either closed or open systems (gravel is not recommended as an aggregate in either system). Both media are lightweight when dry, easily handled and easier to steam-sterilize than many other types of aggregate materials. Both can be incorporated as a soil amendment after crops have been grown in it.

Rockwool, or stonewool, is produced from basalt rock, and can come as spun wool, resembling fiberglass, or it can be granulated, offering an alternative to perlite and vermiculite in terms of water holding capacity and aeration. Stonewool has a high pH, generally greater than 8.0, however, it has essentially no buffering capacity, meaning it will not affect the pH of the nutrient solution nor will it affect any other media it is mixed with, such as peat moss (which has a pH of 3.8 to 4.5). Stonewool can be purchased in prepackaged "slabs" (commonly 15 x 7.5 x 100 cm long), ready to use, or as bulk granules for those growers who wish to mix their own soilless media.

Perlite is usually bagged in opaque white bags with drip irrigation tubes at each plant and drainage slits in the bags. Perlite is an inert media providing excellent aeration and water holding capacity. As in rockwool, it can be steam sterilized, rebagged and reused several times.

When both perlite and rockwool are used as closed systems, great care must be taken to avoid the buildup of toxic salts and to keep the system free of nematodes and soilborn diseases. Once certain diseases are introduced, the infested nutrient solution will contaminate the entire planting. In addition to the common practice of sterilizing the recirculating solution, there is current research exploring the use of surfactants to control certain root diseases. Such systems can be capital intensive because they require leak proof growing beds as well as subgrade mechanical systems and nutrient storage tanks.

Water Quality

Good, consistent water quality is essential for hydroponics. Fresh water free from pesticide runoff, microbial contamination, algae, or high levels of salts must be available throughout the year. The levels of pH and alkalinity (measured as carbonates and bicarbonates) of the raw water affects the absorption of certain nutrients by the roots. Water pH levels above the desirable range (5.0 to 7.0) may hinder absorption of some plant nutrients; pH levels below this range permit excessive absorption of some nutrients, which may lead to toxic levels of those elements.

In arid areas, or areas near salt water, the concentration of sodium chloride (NaCl) may be too high for optimal plant growth (greater than 50 parts per million or 1.5 mmol/liter). The hardness of the incoming water will also have an effect on the nutrient solution. Hardness is a measure of the concentrations of calcium and magnesium carbonates, which are often quite high in areas of limestone rock. The naturally occurring concentrations of these minerals in hard water must be taken into consideration when calculating the amount of nutrient salts to add to the nutrient solution, and may interfere with the availability of other essential nutrients, such as iron. Similarly, concentrations of other essential elements may be found in very high levels in poor quality water. For example, water may carry high levels of iron, selenium, boron, or sulfur; and municipal water may have undesirably high levels of chlorine.

The electrical conductivity of good quality raw water should be below 0.5 mS/cm or mmhos/cm. It is advisable to invest in a complete analysis of the water quality, including all major and minor elements, microbial contamination and pesticide residues before any further work is done.

For more information on desirable ranges for specific elements in irrigation water, see Jensen and Malter, 1995, referenced in the Links and References section of this website.

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Nutrient Solution Recipes

There are sixteen elements which are generally considered to be essential for good plant growth. The macro elements are those required in "high" concentrations: Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Sulfur (S), and Magnesium (Mg). Carbon must be supplied to the plant as carbon dioxide gas (CO₂). In a small operation or one with large amounts of fresh air movement, additional CO₂ may not be required. Larger operations, or ones with high density plantings will need a CO₂ generator (See CO₂ enrichment, detailed below). Hydrogen is available in sufficient quantities from the atmosphere and oxygen is supplied from well-aerated nutrient solutions. Nitrogen, phosphorus, potassium, calcium, sulfur and magnesium must all be supplied by the nutrient solution.

The micro elements are also essential for growth, but required in smaller concentrations. There is still some disagreement, but generally the micro elements are thought to be: Iron (Fe), Chlorine (Cl), Manganese (Mn), Boron (B), Zinc (Zn), Copper (Cu), and Molybdenum (Mo). Certain plant species may need others for good growth: Silica (Si), Aluminum (Al), Cobalt (Co), Vanadium (V), and Selenium (Se).

Small greenhouse operations often buy ready-made nutrient formulations; only water need be added to prepare the nutrient solution. Larger facilities prepare their own solutions. The commonly used salts and the required amounts to make 1000 liters of 1 ppm solution are given in Table 1. Multiplying the value for a salt by the number of ppm desired in the formula will yield the number of grams to be used per 1000 liters.

Nutrient solutions need to be adjusted during the growing cycle of the crop and are different for each crop grown. Leaf crops generally need higher N, root crops need higher K, and fruit crops such as tomatoes or cucumbers should maintain relatively low N levels.

The nutrient solution for tomatoes is generally made in two or three levels for the various stages of growth (see Table 2, below). Only the macro nutrients change, becoming progressively more concentrated as the crop matures. The micronutrients remain the same throughout the growth cycle. The first stage of growth (Level A formula) is for seedlings from the first true leaf until the plants are 24 inches (62 cm) tall, when initial fruit is 1/4 - 1/2 inches (1 to 1.5 cm) in diameter. After that, Level B formula is used. While the formula in Table 2 has been standard for many years, some new tomato varieties may require much higher nitrogen and potassium. It is advisable for commercial growers to consult their seed company for the recommended nutrient formulas for the tomato variety grown. Optimizing the N:K ratio is important as the crop matures and as the available light and day length changes. Under high light conditions, plants use more N. High K during the fall and early winter months improves fruit quality. It is common practice to double the ratio of K:N during winter months when plants receive less light. The optimum pH of the nutrient solution should be 5.5-6.0. The pH of the nutrient solution can be lowered with phosphoric acid.

The micronutrients should remain at the same concentration throughout the life of the crop. Optimum concentrations for tomatoes are: Boron 0.44, Copper 0.05, Chlorine 0.85, Manganese 0.62, Molybdenum 0.06, Zinc 0.09, Iron 2.5 ppm (mg/L).

If a concentrated stock solution is used for the macronutrients, then the calcium salts should be kept apart from the other salts in a separate solution. Nitric or phosphoric acid can be used to lower the pH if necessary; concentrated acid should always be carefully diluted before it is added to the stock solutions.

Symptoms of Nutrient Deficiencies and Toxicities

Nutritional disorders can be very complex, involving temperature, humidity, day length and disease as well as nutrient levels. Multiple disorders can produce a syndrome which does not resemble any single disorder. Some growers feel that relying on plant disorder symptoms is a reactive, not a pro-active approach, since by the time symptoms appear, the yields will already have been adversely affected.

Symptoms of nutritional disorders should never be ignored, however, and excellent sources of information are available to key out specific problems.

Professional growers should keep such sources and horticultural experts near at hand, and have their nutrient solutions analyzed routinely. Table 4 outlines some common nutrient disorder symptoms in tomatoes.

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As soon as any deficiency is confirmed, the nutrient solution should be changed with the concentration of the deficient element increased 25 to 30%. After the deficiency is rectified, the concentration should be lowered back down to slightly higher than normal levels. Foliar sprays can be applied for a faster response, however burning of the plants may result. It is best to test a foliar spray on a few plants and wait several days to observe the effects before spraying a whole crop.

Sampling (Nutrient Solution and Plant Tissue)

Nutrient solution analysis is absolutely necessary in a closed system, where the solution is re-used, and recommended in an open system to verify concentrations of macro and microelements. Plants take up nutrients in varying amounts depending on their needs. Although monitoring pH and EC will give an indication of changes in the nutrient solution, it cannot indicate changes in preferential uptake of particular ions. In a closed system, if no analysis is possible, then the nutrient solution should be completely changed every two weeks.

Plant tissue analysis can provide other information about the growing system. That is, tissue analysis can indicate any problems the plants may be having in absorbing nutrients which are present in the solution. For example, fluctuating pH levels, high cation exchange capacity of the media, high humidity, or diseases and nematodes can prevent nutrient uptake by a plant.

On a commercial scale, nutrient solution and plant tissue analysis is absolutely required. Plant tissue analysis allows the grower to detect a problem in the uptake/assimilation of nutrients which may not be apparent in a nutrient solution analysis. Consult with the testing laboratory for information on sampling and sample prep. For more information on expected levels of individual elements in tomato tissue analysis, see Hydroponic Food Production by Howard Resh, 1995, (cited in the Links and References page of this website).

Electrical Conductivity (EC) is a convenient estimation of Total Dissolved Solutes or Total Dissolved Salts (TDS) in the solution. However, although EC is a function of the salts in the solution, it does not indicate the relative concentration of the major nutrients, or the quantity of trace elements (micro nutrients) present. For example, high levels of calcium can give a lower EC reading than the equivalent concentration of sodium ions. A grower would not be able to detect these changes by monitoring EC alone. Although changes in TDS and EC can indicate a change in the nutrient solution, they should not be relied on exclusively.

Carbon Dioxide Enrichment

Carbon dioxide is necessary for growth, and optimal levels for tomatoes may be two to five times the normal atmospheric levels (1000 to 1500 ppm CO₂ versus ambient levels of 350 ppm). Plants can deplete the CO₂ in a closed greenhouse in a matter of hours, significantly reducing growth rates. Growers using CO₂ enrichment have claimed to see a 20 to 30% increase in tomato yields, and accelerating flowering and fruiting by as much as 10 days.

Specially designed CO₂ generators are natural gas or propane burners hooked up to sensors. Large commercial growers often use the flue gases from a hot water boiler burning natural gas as a source of CO₂, or they will use bottled CO₂. It is important that the CO₂ be free of contaminant gases, as tomatoes are extremely sensitive to many gases, especially ethylene. Plants enjoying elevated levels of CO₂ can be expected to increase fertilizer and water requirements.

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Growing Tomatoes Hydroponically (Part Four)

By Dr. Merle Jensen

Pollination

Tomato flowers are normally wind pollinated, however there is not enough air movement in a crowded greenhouse to ensure good pollination. Therefore, growers have two options for pollinating their crop: mechanically pollinate or maintain hives of bumblebees in the greenhouse.

Mechanical pollination entails shaking or vibrating each flower cluster at least every two days when humidity and temperature conditions are best. Generally, midday and early afternoon during sunny conditions when humidity is about 70% is best. Greenhouse temperatures should be kept above 65° F (15° C) at night and below 85° F (29° C) during the day. Even if conditions are not ideal, pollination should be attempted. Although tapping or shaking the entire vine will move some pollen, the best approach is to use an electric vibrator on each truss. Commercially available pollinators have a very forceful action; battery operated toothbrushes also work well.

The more efficient method of pollinating large greenhouses of tomatoes is through the use of bumblebees. However, maintaining a healthy hive requires an integrated management approach. It is imperative that there is a proper balance of tomato flowers and bees. One hive will work approximately one half acre (0.2 hectare) of tomatoes. Bumblebee hives cost several hundred dollars each, and may only last a few months. The hives are housed in cardboard boxes with a sugar water solution to supply a balanced diet for the bees. The bees pose no threat to people working in the greenhouse, but will be devastated by any insecticides used on the crop. Therefore, bumblebee pollination works well in pesticide-free greenhouses, assuring efficient, complete pollination.

A quote from the Penn State University program perspectives sums up the use of bumblebees well:

"Tomato growers who eliminate pesticides in the greenhouse can use bumblebee hives to pollinate their crops, saving 15 hours of labor per acre [per day] required for manual pollination. Research indicated that bumblebees pollinate more efficiently, leading to yield increases of as much as 25 percent."

Harvest

Flavor is the ultimate test of a good quality hydroponic tomato. However, there are other factors that determine overall quality: color, texture, firmness, shelf life, and nutrient levels are all important quality indicators. The single most important factor in all these issues (especially flavor) is the genetic makeup of the plant, so careful selection of the proper cultivar for the growing conditions is absolutely necessary.

The level of maturity at the time of harvest is another important factor affecting final fruit quality. For commercial trade, tomatoes are harvested mature but unripe, often called the "mature green" stage. U.S. standards for grades of vegetables define a mature tomato as the one in which the contents of two or more seed cavities have developed a jelly-like consistency and the seeds are well developed.

Mature fruit produce large quantities of ethylene, which will hasten ripening, increasing the carotenoids (red and yellow colors) and decreasing the chlorophyll (green color). Therefore, harvested fruit should be stored in well-ventilated areas, or in a low oxygen or high carbon dioxide atmosphere. The fruit should never be exposed to temperatures below 54° F (12.5° C) or chilling injury may result. In tomatoes, chilling injury can appear as pitting, shriveling, softening, uneven ripening, seed discoloration, or increased susceptibility to rot. Optimum ripening temperatures for tomatoes are 68-72° F (20-22° C), and an ethylene treatment of 100 ppm for 24 to 48 hours can be effective in producing evenly ripe fruit.

The major cause of postharvest losses in tomato is physical damage. To prevent puncture wounds from stems, the calyx and stem should be removed from the fruit immediately at harvest, although many growers will leave the calyx on the fruit in order for the consumer to recognize the fruit as greenhouse grown. Tomato picking crews must be well trained in placing the harvested fruit in the picking boxes. Many large greenhouse facilities have an extensive system of canals to float the fruit from the growing areas to the packing rooms, thereby minimizing physical damage to the fruit. Another cause for postharvest loss is desiccation. In tomatoes, about 65% of the water loss occurs through the stem scar. Optimum relative humidity levels for harvested tomato fruit is high, in the 90-95% range.

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Insects

It is commonly assumed that hydroponic agriculture systems are relatively free of insect pests and plant diseases because the technology is mostly enclosed. Unfortunately, this is not true. Pest populations can increase with alarming speed in greenhouses because of the lack of natural environmental checks.

The frightening ability of some insects to develop resistance to pesticides has revived worldwide interest in the concept of biological control: the deliberate introduction of natural enemies of pest insects, particularly when used in association with horticultural practices, plant genetics and other central mechanisms.

While there are many pests and diseases which attack tomatoes, below is a list of a few of the major pests associated with hydroponic tomato production and their control.

Whiteflies

There are about 1,200 different species of whiteflies. They are pests in many important agricultural and horticultural crops, both inside and outside the greenhouse environment.

Trialeurodes Vaporariorum

The greenhouse whitefly (*Trialeurodes vaporariorum*) has been a problem for greenhouse tomatoes in the U.S. since 1870. Originally from tropical or subtropical America, probably Brazil or Mexico.

Life cycle of the greenhouse whitefly:

Females lay eggs on the undersides of new leaves. Eggs are white at first, oval shaped, and about 0.25mm in diameter. After one or two days, the eggs turn brown to black. The larvae emerge after seven to 10 days.

The larvae are transparent, 0.3mm-0.7mm in size, mobile at first, but become immobile after the first few hours, at which time they begin to feed. They are oval shaped, and deposit much wax at this stage.

At the pupa stage, the red eyes of the growing adult become visible. The pupa is dirty white, and surrounded by much wax and honeydew.

The adult whitefly emerges from the pupa and begins to eat. Adults are 1mm long with two pairs of white wings and a light yellow body. They are generally found at the top of the plant. Females start laying eggs within one to two days, and may lay up to 500 eggs in a lifetime.

Length of the life cycle depends on temperature, ranging from four weeks at 27 ° C to over eight weeks at 14° C degrees. Damage is caused by flies and larvae sucking the leaf sap, which can cause stunting, leaf drop, and reduced yield. Honeydew deposits on fruit are sticky and can mold, making the fruit unmarketable. Greenhouse whitefly can transmit viruses. And although whiteflies cannot hibernate, the eggs of the greenhouse whitefly can survive for about five days at temperatures of -6°C.

Bemisia tabaci

Tobacco whitefly, (*Bemisia tabaci*), also known as the sweet potato, silverleaf, or cotton whitefly, first occurred in Greece in 1889 on tobacco. It was discovered in Florida in 1900. It is the predominant pest on cotton in the United States due to the insects' increased resistance to insecticides. It resembles the greenhouse whitefly except it is slightly smaller and more yellowish, and holds its wings closer to its body. The lifecycles of the two species are quite similar. The eggs are easy to distinguish from each other - *B.tabaci* are yellowish green and do not change to brown. Longevity depends on temperature, at high temperatures the female lives 10-15 days, at lower temperatures they can live up to two months. Adults can live for an extensive time even without host plants in an empty greenhouse, however, they cannot survive temperatures below freezing. *B. tabaci* can transmit many viruses, including Tomato Yellow Leaf Curl Virus (TYLCV).

Natural Enemies of Whiteflies

There are several natural predators of whiteflies, however they tend to be very specific to particular species of whitefly hosts, therefore correct identification of the pest is critical. Any pesticide residues may adversely affect the predator population, so careful attention to integrated pest management practices are essential to the success of any biological control effort.

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Encarsia formosa

Encarsia formosa is a tiny parasitic wasp of *T. vaporariorum* (greenhouse whitefly). The larvae of this wasp develop inside the whitefly larvae or pupae. The parasitized greenhouse whitefly larvae are easy to recognize because they become black after about 10 days as the young wasp develops inside. Although Encarsia prefer greenhouse whitefly, they can also parasitize *B. tabaci*, in which case the parasitized larvae become transparent to brown in color. Adult wasps emerge from the whitefly pupa approximately 21 days after parasitization through a neat, round hole. The female adult wasp is about 0.6mm long, with a black head and thorax and a yellow abdomen. The adult wasps feed on the honeydew and body fluids of whitefly larvae. Encarsia develop faster than whiteflies, with lifecycles ranging from three weeks at 27°C to two months at 14°C . The population of Encarsia is almost 98% female and mating is not necessary for reproduction. The female can lay about 300 eggs in a lifetime, most of which will be more females (this is called parthenogenetic reproduction).

Eretomocerus californicus

The tobacco whitefly can be parasitized by Encarsia, but they are controlled better by Eretomocerus species. The Eretomocerus is another tiny parasitic wasp about the same size as the Encarsia, but without the dark head and thorax of the Encarsia species. Abundant in the Southwest U.S., Eretomocerus is reported to be well adapted to extremes of temperature and humidity, and also more resistant to pesticides than some other whitefly parasites. Females lay about three to five eggs per day, but they can also kill whitefly nymphs by repeatedly probing with their ovipositors and feeding on the haemolymph (blood) that exudes from the wounds.

Verticillium lecanii

Verticillium lecanii is a common soil borne fungus which affects several different kinds of insects. It is widespread in temperate and tropical areas, but cannot infect birds, fish, mammals or plants. It was first observed on whitefly in 1915. It has a white to light yellow cotton-like appearance. The whitefly dies from infection before the fungus even becomes visible; the fungal spore germinates and begins to grow on the honeydew secretion on the whitefly body. It can either infect the insect or directly penetrate the insect. Since the fungus is not mobile and cannot seek its host, it is only effective in very high densities of white fly and repeated applications are necessary.

Tomato Fruit Worm

Heliothis armigera - The larva of this insect feeds on a number of plants, including tomato, corn and cotton. It is sometimes called the corn earworm or the cotton bollworm. It burrows in the fruit of the tomatoes. The adult is a moth that is light yellowish in color. Control this insect with sprays of *Bacillus thurengiensis* (B.t.), which is compatible with other biological control agents.

Other pests common to hydroponic tomato production are leaf miner, tomato pinworm, cabbage looper and two-spotted spider mites. Consult your local agricultural experiment station or agricultural university for identification and control. Good sanitation is important in hydroponic tomato production, so weeds and other debris should not be allowed in and around the greenhouse as they can become a harbor in which pests can hide and multiply. A clean strip around the greenhouse, free of any plants and debris, is important.

Bacterial and Viral

Bacterial and viral diseases can spread very quickly throughout a greenhouse, especially if a closed system is being used, where nutrient solution is recirculated. Although UV and ozone water purifiers can be used in hydroponic systems, they can be very expensive and have adverse effects on the minerals in the solution. If raw, incoming water is from a contaminated surface source, UV and ozone treatment may be necessary to assure pathogen-free source water.

Basic sanitation is necessary in hydroponic greenhouses. Workers' clothing and shoes should be free from soil, in fact, some greenhouse operations have shallow trays of bleach solution for workers to clean off their shoes before entering the growing areas. Hands and tools must be cleaned regularly to prevent spread of disease within a greenhouse. Smoking or chewing tobacco must be strictly forbidden in the greenhouse, and workers should wash their hands after handling tobacco to prevent transmittance of tobacco mosaic virus (see below).

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Bacterial canker (*Clavibacter michiganensis*): this is a seedborn disease, which is unlikely to be found in hybrid seeds purchased from a reputable dealer. The disease is first noticed on the lower leaves, which exhibit unilateral wilting on one side of the leaf, then wither and die. Often, the petioles remain on the plant, which helps distinguish bacterial canker from other diseases. Fruit may be affected with small, raised white spots that develop brown centers. Moderate temperatures and high humidity favor disease development. There is no cure, but spread of the disease can be controlled by sterilizing all equipment and media.

Bacterial spot (*Xanthomonas vesicatoria*): First symptoms: small, dark, water-soaked spots on leaves, progressing to dried, cracked lesions surrounded by yellow. Spreads rapidly via wounds, such as pruning or sucking insects. Warm, moist temperatures favor the disease. Copper sprays can provide some control. Destroy all plant residues.

Bacterial wilt (*Burkholderia solanacearum*, also called *Pseudomonas solanacearum* and *Ralstonia solanacearum*): Symptoms begin as wilting of lower leaves, followed by whole plant, without characteristic yellowing caused by other diseases. A quick diagnosis: place a freshly cut infected stem in a glass of water, and a white, milky stream of bacterial ooze will be visible flowing from the cut. Highly contagious, this disease can cause serious damage. No effective controls known.

Tobacco mosaic virus (ToMV) will cause disfigurement of the leaves and stunted growth. Sucking insects or hands and tools of workers in the greenhouse can transmit the virus. Prevent the disease by using resistant cultivars and making sure all workers wash hands with soap and water after handling any tobacco products.

Tomato yellow leaf curl virus (TYLCV): a gemini virus transmitted by the tobacco whitefly, *Bemisia tabaci* - a serious problem in the Middle East. The virus causes leaf edges to curl upward, and interveinal chlorosis. Fruit set is greatly reduced, particularly if young plants are attacked, as very little fruit will be produced. Currently, new, resistant cultivars are being developed. Meanwhile, complete control of whitefly is the best protection.

Other mosaic viruses, such as common mosaic, *Aucuba* mosaic, and cucumber mosaic can all infect tomatoes. Symptoms include mottled areas of the leaves, yellowing, and stunted growth. Prevention includes sanitation, especially the removal of any weeds that may also be susceptible to these diseases. Aphids can transmit viruses, so control of insect pests will reduce the risk of viral problems.

Bemisia transmitted gemini virus on tomato (as yet unidentified). This can be a severe virus on tomatoes growing in the southern latitudes of the United States and in Mexico. The symptoms are often similar to tomato yellow leaf curl virus and the fruit can exhibit off-colored ripening. Again, the best control of this disease is to control the whitefly which spreads it.

Marketing and Distribution

It is imperative that good markets be identified before any investments are made in hydroponic tomato production. The fruit are of high value and perishable. Once harvested the tomato fruit continues to ripen. This process can be delayed only slightly with refrigeration. Disastrous quality losses can occur at any stage in the marketing chain from grower to consumer and the total value of the product may be lost. Every activity in the production and marketing chain must be precisely timed.

The highest prices for hydroponic tomatoes are during the winter, when there is little or no production of open field tomatoes in the U.S. Imports from Europe and Israel present some competition but do not have the taste and quality of greenhouse hydroponic tomatoes produced in high light desert regions of the southwestern part of the U.S.

In the spring, fruit from Mexico and Florida will decrease the wholesale prices received for hydroponic tomatoes, but the hydroponic fruit will still bring two to three times higher wholesale prices.

The distribution of hydroponic tomatoes is throughout North America. The major mode of transportation is by truck. In the future when markets open in the Pacific Rim countries, the tomatoes will be shipped to various regions of the world by air, typically packaged in 15 pound boxes, each with fruit of even size and color. Premium prices are paid for jumbo fruit weighing 225 grams or more.

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