Easy Gardening with Hydroponics!

for Teachers, Students, & Home Hobbyists

Serving you since 1961

We here at Foothill Hydroponics have been providing supplies and guidance for hydroponic gardeners since 1961. Today, we are especially pleased and excited to be helping thousands of elementary, middle-school and high school students, and their teachers, with their Hydroponic science projects. In partnership with the state-wide Agricultural Literacy & Fairs Alliance, we are actively bringing the fascinating world of Hydroponics to schools all across California.

We also continue to help the film industry with Hydroponics systems, and with living plants for background effects. In fact, a feature film currently in production will feature an amazing array of Hydroponic systems.

If this booklet whets your appetite for more information about Hydroponics, we have more than 100 free brochures on virtually every aspect of "soilless" growing. We also have a brand-new catalog with 60 pages of systems, equipment, media and nutrient supplies. Whether you are an educator, student or hobbyist, please feel free to call, write or e-mail us with any specific questions you may have. I would also recommend a visit to our Web site, at: www.foothill-hydroponic.com.

I would also like to mention three dear friends who were devoted to Hydroponics, and who have since passed on. **Jim McCaskill** was an inspiration to anyone who likes growing plants. As a professional lecturer, he taught classes on Hydroponics and plant nutrients at more than a dozen community colleges, universities and garden clubs in Southern California. His widow, Gallena McCaskill, has graciously granted us permission to publish Jim's work, carrying on the tradition of humanity and caring that were Mr. James McCaskill's trademarks.

Buck Isham was the founder and previous owner of Foothill Hydroponics, and worked with us for seven years. **Gary Pelland** was very helpful over the 10 years we knew him. They are missed.

Thank you for your interest in Hydroponics, and welcome, friend, welcome!

Mohsen Daha and Colleagues
Foothill Hydroponics

Contents

Introduction

Hydroponics is a method of growing plants without soil. In nature, the soil provides nutrients and is a means of physical support for the plant. In hydroponics, soil is replaced by inert media such as perlite, vermiculite, horticultural rockwool, sand, or fired clay pebbles to which the necessary elements for growth are added in the form of a nutrient solution. By incorporating a study of hydroponics into the school curricula, students at all levels will be able to appreciate the different ways in which plant life can be sustained.

For many centuries, people have endeavored to increase yields and improve crop quality against nature's inconsistency. The basic techniques of hydroponics have been known for some time, but it is only since the beginning of this century that the techniques have been refined to the point where they could be applied commercially. Dr. Gericke of the University of California at Los Angeles successfully grew tomatoes in water culture before 1936, arousing great interest in hydroponics as an alternative method of horticulture.

The commercial and hobby production of vegetables and cut flowers hydroponically is becoming more popular. If optimum growing conditions and nutritional requirements are applied, combined with sound horticultural management, hydroponics can offer an alternative means of food production. Good quality, high yielding crops may be produced in areas where climate or location may previously have hampered the production of crops by soil cultivation.

This booklet is intended to help people of all ages—students, teachers and home gardeners—gain enough knowledge of hydroponics to be able to successfully and satisfactorily grow plants by this modern procedure. Many students and teachers like using hydroponics as a learning tool because it is a “hands on“ method. It brings the disciplines of chemistry, biology, and physics together.

Objectives

1. To be able to set up one or more of the various hydroponic systems.
2. To be able to maintain the hydroponic system(s).
3. To be aware of the advantages and disadvantages of the various hydroponic systems.
4. To be aware of the different media used in hydroponics.
5. To understand nutrient elements and solution pH.

Hydroponic fundamentals

The word "hydroponics" was coined in the U.S.A., in the early 1930s, when Professor Gericke at U.C.L.A. coined the name to describe the growing of plants with their roots suspended in water containing mineral nutrients. The name comes from two Greek words: "hydro" (water) and "ponos" (to work, labor), and literally means "water works."

The definition of hydroponics has gradually been broadened. Today it is used to describe all ways of growing plants without soil. It is synonymous with the term "soilless culture," and both terms are restricted to the growing of plants without soil. All systems except hydroculture can be used for the commercial production of vegetables and cut flowers.

Commercial hydroponics is a relatively recent development. However, the art of hydroponics is believed to date back to the Aztec Indians of ancient America, who grew their plants on rafts on shallow lakes where cultivation in soil was not possible. These rafts were covered with soil removed from the lake bed, and the plant roots grew through the soil down into the water of the lake. A few of these "floating gardens" still exist near Mexico City.

Professor D. Hoagland of U.C. Berkeley verified many of the Gericke experiments during the 1930s. Commercial hydroponics was really first started in 1936, when gravel culture was used. Robert and Alice Withrow at Purdue University developed the "Nutriculture*" system of gravel culture in 1940, which was used by the U.S. Army well into the 1950s to supply troops in Japan and Korea.

Activities

There are many ways in which hydroponic systems may be established. The manner chosen largely depends upon the availability of space, the preferred media, financial concerns and the type of crops desired.

The hydroponic systems which follow may be classified under eight headings:

- Surface Watering Technique
- Subirrigation
- Wick System
- Grow Bag Technique
- Soak and Drain
- Rockwool Technique
- Drip Feed Technique
- Nutrient Film Technique

Each system may be modified or expanded to suit individual requirements while, similarly, the medium used may be varied from that suggested here. There is abundant scope for imagination and initiative in the design of an installation which would suit your particular needs.

Advantages

A number of advantages can be identified when growing crops hydroponically, compared with growing plants in soil.

- The labor input is less than if soil is used, once the unit is established.
- The work involved is generally light. Heavy manual operations associated with normal cultivation practice, such as digging weeding, and ploughing, are eliminated.
- No crop rotation is necessary as the growing medium can be reused continually, or replaced.
- Because plants do not have to compete for moisture and nutrients, production in hydroponics compared with soil cultivation in a comparable area may be increased approximately two times.
- Plants are usually uniform in growth and maturity.
- There is minimum wastage of water.
- There are virtually no weeds—and no gophers!
- As the nutrient requirement of plants varies according to the seasons, hydroponic gardening can provide plants with optimum quantities of the necessary nutrients during the different seasons. This will enable maximum growth to be achieved.
- The need for dangerous pesticides is largely eliminated if the plants are grown in a controlled environment. Root diseases are controlled to a greater extent.
- Disabled people are not excluded from participating in hydroponics, as benches or units may be adapted to their requirements.

Hydroponic culture types

At the 4th International Congress of Soilless Culture in 1976, the various systems of hydroponics were classified and defined as follows.

Water Culture: Roots of plants submerged in the nutrient solution with little or no growing media. The Nutrient Film Technique (NFT) is an example.

Sand Culture: Roots of plants growing in a solid aggregate of particles with a diameter less than 3 mm. Fine perlite, plastic beads, and washed river sand have all been used. Beach sand is too fine, giving inadequate aeration of the roots.

Gravel Culture: Roots of plants growing in a solid aggregate composed of particles with a diameter more than 3 mm. Gravel, basalt, scoria, pumice, plastic, and other inorganic material. Used in the 1970s in subirrigation systems in the U.S.A.. The size of most gravel used is between 5 to 10 mm in diameter, with rounded edges preferred.

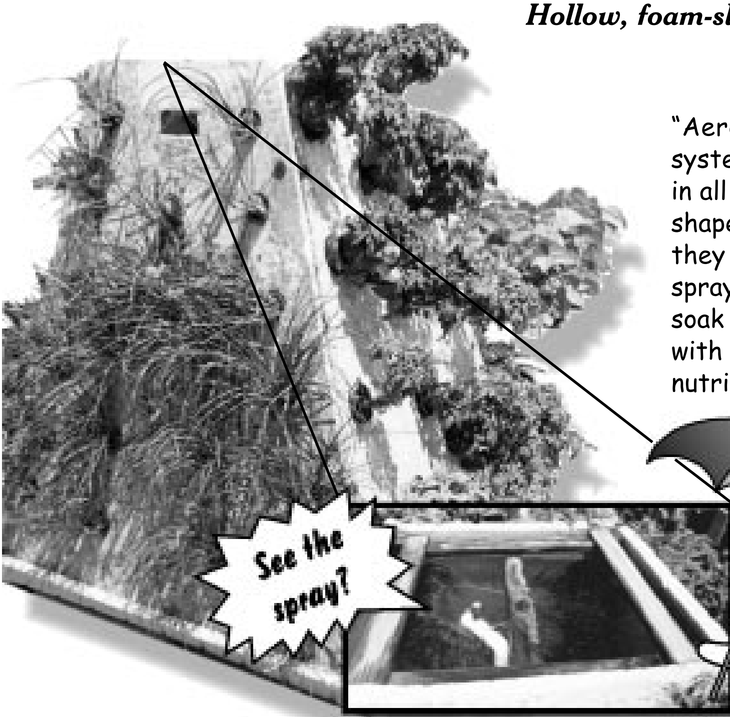
Vermiculaponics: Roots of plants growing in vermiculite, or a mixture of vermiculite with any other organic material. This works very well for small experimental systems.

Horticultural Rockwool Culture: Roots of plants growing in horticultural rockwool or any similar material. This method really came into it's own during the 1980s, after research in the 1970s.

Hydroculture: All systems or methods of hydroponics, if used especially for growing ornamentals in the home or office. It usually means using fired clay pebbles in a passive system with no pump. Excellent for slow growing house plants like ferns or orchids.

Aeroponics: This system uses a spray of nutrient solution that is aimed at the plants roots, which are supported in a chamber filled with moist air. Very high growth rates have been observed.

Hollow, foam-slab system



"Aeroponic systems come in all sizes and shapes. But they all use a spray or mist to soak bare roots with water and nutrient."

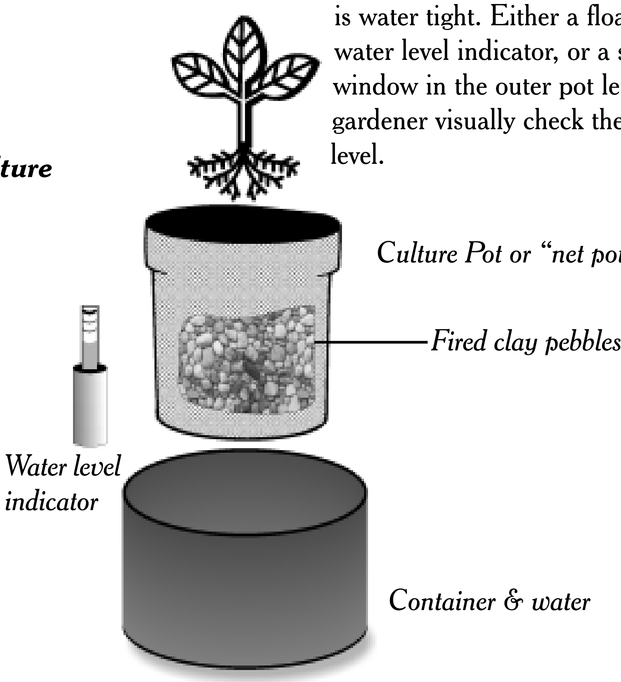
Small, portable system

Wick System

In the wick system, the roots are moistened by the nutrient solution passing up a wick made of nylon, rayon or polyester, or by using a lamp wick. Stand a pot, supported above the nutrient solution, in a tray. Soak the wick thoroughly before passing it through the drainage hole into the nutrient solution, leaving 10 cm of wick in the pot. Unravel the upper end of the wick to give better distribution of the nutrient solution throughout the medium. The growing medium must also be thoroughly soaked to enable the wick to draw up the nutrient solution. Vermiculite, perlite, or fired clay pebbles are the most commonly used growing media for wick systems. Rockwool could also be used, but it may hold too much water for many plants.

Hydroculture is a special type of wick system that uses the high capillary action of fired clay pebbles. No actual wick is required. The inner pot looks like a coarse net type of structure. It holds the clay pebbles and the plant itself. This "culture pot" or "net pot" fits inside another container which is water tight. Either a float type water level indicator, or a see through window in the outer pot lets the gardener visually check the water level.

Hydroculture system



Grow Bag Technique

Using grow bags is a simple and cheap way to grow plants hydroponically. Fill a large clean opaque polyethylene bag with the growing medium of your choice and seal the open end with freezer bag ties or insulation tape. Lie the grow bag on a firm surface. To ensure good hygiene, place polyethylene sheeting underneath the bag. Cut 3 or 4 drainage slits around the outside edges of the bag, approximately 10 mm from the base to allow drainage of excess nutrient solution. Cut holes in the top of the grow bag to allow plants to be inserted. Four to six plants per bag is usually sufficient, but the number will vary according to the type of plant grown or the size of the bag.

Thoroughly soak the medium in the grow bag with dilute nutrient solution, before inserting the plants. Plants should receive nutrient when required. Use a plastic watering can or drippers to apply the nutrient solution. The drippers could be automated by using a timer and a pump.

Subirrigation

This system is based on the capillary action of the growing medium which carries the nutrient solution up to the root growing zone. In this particular method a pot is permanently left to sit in nutrient solution. When river sand is used as the growing medium, the nutrient will rise approximately 15 cm above the level of the solution. This level will differ according to the particle size of the river sand used. Of the 15 cm of growing medium available, only 10 cm is suitable for root growth. The first 5 cm above the level of the nutrient solution is saturated and therefore unsuitable for root development.

Regular flooding of the nutrient solution in the tray to the 5 cm mark will alleviate drying out of the media. Rockwool will draw up even more water than sand, due to it's very high capillary action. Rockwool must have a drainage area below it, so that water has somewhere to drain. Otherwise standing water may become anaerobic at the root area. Fired clay pebbles are an excellent media for cooler climates.

Flood and Drain
(Ebb & Flow)

A waterproof growing container is placed on a bench and sloped to an outlet to which a hose is connected. The other end of the hose is connected to a bucket or drum which contains the nutrient solution.

When the container is held above the level of the growing container, the nutrient solution will flow out and soak the growing medium. When the bucket or drum is lowered, the excess nutrient solution will drain out of the medium back into the bucket. The size of the container should be limited to approximately 18 liters, as any larger will make lifting difficult for students.

The container is then topped off with water for the next irrigation. Completely renew the solution every 1-2 weeks. The medium must not be left totally flooded during hot weather because this will cause rapid root death. It is advisable to retain a small reservoir of solution in the bottom of the container to carry plants over a weekend or during periods of hot weather A pump and timer could be used to automate this system. The normal recommendation is to water every 2 hours during daylight. The tray should fully drain within 30 minutes after the pump shuts off.

"Flood and drain is super simple. You raise the container to feed, and lower it to drain."

Rockwool Technique

Horticultural rockwool can be used as a soilless growing medium. The rockwool referred to is a horticultural grade of rockwool capable of absorbing water and made to a specific density. Beware of using standard thermal rockwool products as these are water repellent, and may have toxic fire retardants. The rockwool hydroponic system depends upon using:

- Rockwool propagation blocks, or small cubes
- Rockwool 75 mm wrapped cubes (or 100 mm)
- 900 mm x 300 mm x 75 mm rockwool growing slabs

The advantage of using rockwool as a growing medium lies in the fact that the plants at no point need to be removed from the rockwool. Plants are propagated in rockwool propagation blocks, which are then transplanted into rockwool 75 mm wrapped cubes, which are then directly placed onto the rockwool growing slab when plants are at an advanced stage. Most plants may be grown to maturity in the wrapped cubes. The large slabs are only needed for crops with a very long life like tomatoes or cucumbers. Both of those crops could keep bearing for six to nine months.

Propagation

Rockwool propagation blocks are used with the uncut surface uppermost. Cuts in the block help prevent roots from growing from one block to another and also make the blocks easier to separate at the end of the propagation period. Blocks are placed in seed trays or placed directly onto propagation benches lined with polyethylene sheeting. Looking at the underside of the propagation block the air gaps are readily observed.

How are seeds sown in Rockwool?

A hole is made in the propagating block into which a seed is sown. DO NOT push the rockwool fibers together to cover the seed. The blocks must be completely wet before the seeds are sown. This can be achieved by submersing the blocks in nutrient solution. Once the seeds have germinated, water them with nutrient solution. Plants that can be direct-seeded into cubes are cucumber, zucchini, legumes, tomato and lettuce. Keep the rockwool moist, but not soggy.

The vertically-arranged fibers in rockwool allow most softwood and semi-hardwood cuttings to be inserted directly into wet propagation blocks. Bottom heating, if available, should be used. Plants suitable for cuttings are carnations, chrysanthemums, begonias, indoor plants, roses and fuchsias.

Mist propagation can be used, but waterlogging and plant diseases can develop from frequent misting. To improve drainage, stand blocks in seed trays or on a coarse aggregate. Increased humidity can be achieved by using a small polyethylene tent which will aid the establishment of plants.

Growing On

Tear away the rockwool propagation blocks with the struck cuttings or seedlings. Separation of blocks is easier when wet. Individual blocks can be removed easily. Air gaps reduce rooting into adjacent blocks. When roots are visible on the outside of the propagation block they are ready to transplant into the larger blocks. The propagation blocks are then directly placed into rockwool (75 mm or 100 mm) cubes. The propagation blocks fit neatly into the holes in the larger cubes.

Safety Note: If the grower suffers from skin allergies it is advisable to cover the arms and wear leather gloves while working with dry horticultural rockwool. Once the rockwool has been moistened it has no irritating effects on skin.

Rockwool Slabs for crops that grow over 6 months

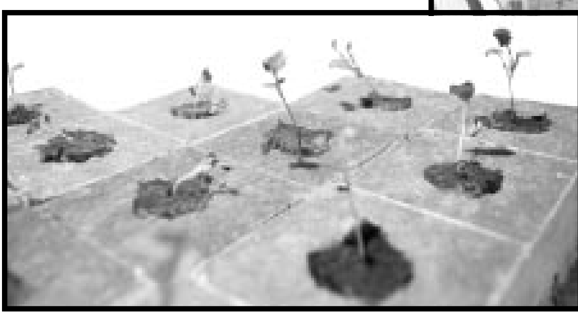
Soak the rockwool-wrapped cubes (75 mm or 100 mm) with nutrient solution before inserting the propagation blocks. Again, place the cubes on a well-drained surface. The cubes must be watered daily with nutrient solution.

When the plants in the rockwool cubes are at an advanced stage, the cubes containing plants can be placed directly onto the rockwool growing slabs. The roots should grow into the slab from the rockwool-wrapped cube in 3-7 days.

It is necessary to prepare the rockwool growing slabs prior to placing the cubes on the slabs. Arrange the 750 mm x 300 mm x 100 mm rockwool growing slabs in beds approximately 300 mm apart. A drainage channel will be required to remove any excess solution, so the slabs must be tilted slightly toward the drainage channel.

Lay sheets of black polyethylene on the ground, along which the growing slabs are laid in rows. Then cut 3-4 tiny slits on each side of the growing slabs, approximately 10 mm from the base to allow for the drainage of excess solution. Thoroughly soak the growing slabs with nutrient solution before the wrapped cubes are placed on the slabs.

Drippers are used to provide each plant with nutrient solution. It is necessary to have appropriate timing mechanisms in order to irrigate for the required time. Seasonal variation and the different needs of plants will influence how often the system is irrigated. Irrigation must be sufficient to prevent the rockwool from dehydrating and to prevent the development of dry spots and areas of salt accumulation. Set the dripper in the top of the 75 mm cubes. Pump the nutrient solution from a large tank using a submersible pump. Extra solution should be pumped at each watering, to ensure at least a 10% drainage of fluid through the slab. The extra amount ensures that nutrient buildup doesn't happen too quickly.



Aeroponics

The ultimate method is growing the roots in an enclosed space that is misted or sprayed with droplets of nutrient solution. First tried in Israel, then in Arizona, the systems were effective, but were very expensive to build and maintain. We at Foothill developed the "Superstarter" Aeroponic System in 1997, and have been refining it. The system uses a low-pressure, high-efficiency submersible pump. The pump forces water through a special nozzle that develops a flat circular spray of water. The plants are held by a "netpot" that in turn holds a small rockwool cube, just to give the cutting or seedling something to grab onto. The roots grow past the rockwool and into the air and water spray. Kids are amazed by the visible root structure. U.S. patent protection has been applied for and is currently pending.

Seedlings or cuttings planted in our Superstarter aeroponic kit are usually ready to transplant after 3 or 4 weeks, although some plants may be ready in just two weeks. Then they may be placed into larger rockwool cubes, or into containers of fired clay pebbles.

"We have grown cherry tomatoes and even lettuce to maturity in the Super Starter (spaced every other hole)."

Recycled Pump Feeding (PVC tube system)

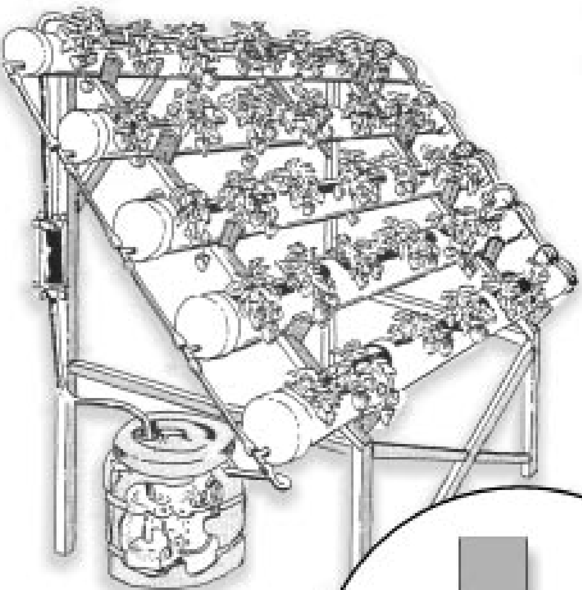
Designed to recycle the nutrient solution, the recycled pump feeding PVC tubes uses a submersible pump and therefore does not require as much attention as do some of the other systems mentioned. The growing tubes are made from 100-150 mm PVC drainage pipes. Caps are fitted to each end with a tee piece or elbow, as needed to assemble the system.

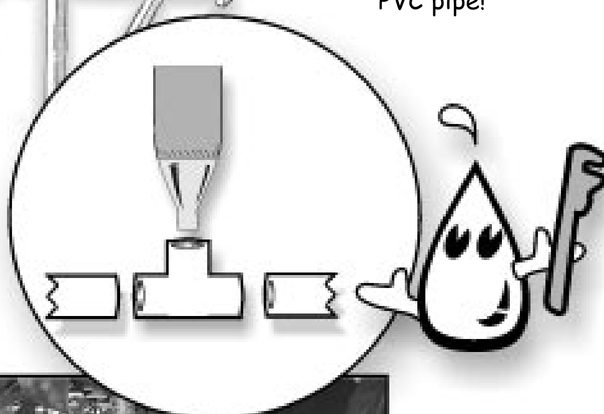
A 50 mm (2“) diameter hole saw can be used to cut out the PVC pipes so that plants can be inserted. Plants should be spaced 6 to 12 inches apart, depending on how large they will grow. A small 50 mm “netpot“ is used to hold a small piece of rockwool. The plants roots grow out past the rockwool into the PVC tubing. Another option is using a tee fitting with the open end facing upwards. The neck of a 2 liter soda bottle will fit right into it. Cut off the bottom of the soda bottle, and insert a 100 mm netpot into it. The growing media is then placed inside the netpot.

To construct a supporting frame various materials can be used, including wood, aluminum, steel pipes or angle iron. Black ½-inch (12 mm) poly tubing is used for connection to the submersible pump. A hose can be connected directly to the tank from a tap to maintain a constant level of nutrient solution in the reservoir, using a float valve. Otherwise, manually top-off the nutrient solution with fresh water as needed. Change the nutrient to a fresh nutrient solution every 7-14 days.

Make certain power to the submersible pump has been turned OFF before the tank is emptied. The whole system must be flushed out with water every 2-4 weeks.

Drip feed technique with recycled pump feeding



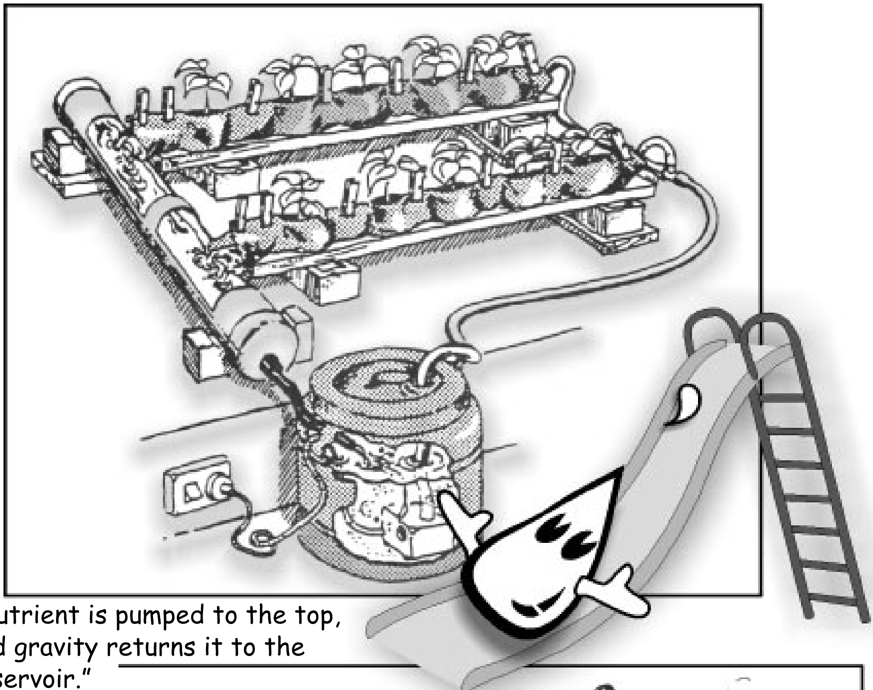


Nutrient Film Technique (NFT)

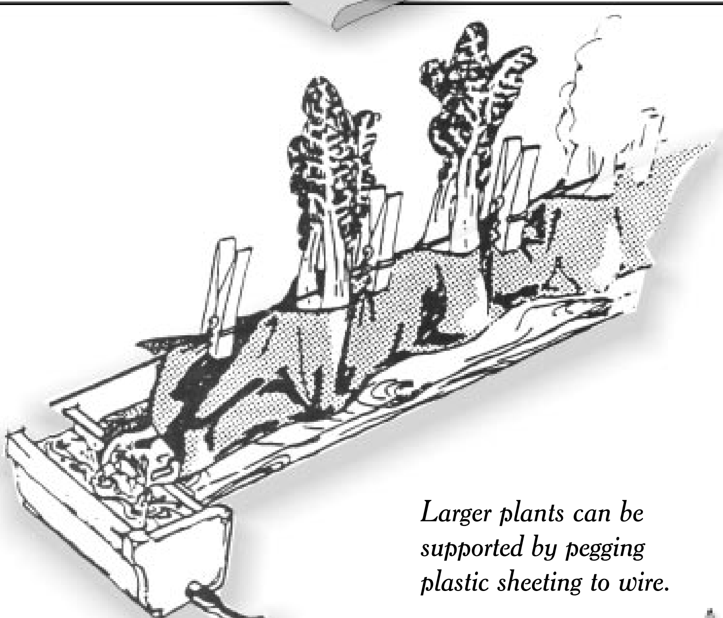
The Nutrient Film Technique is based on the principle that a constantly flowing stream (film) of nutrient will supply the growing plant with its requirements. In order to have the roots in contact with the nutrient, it is necessary to have the solution running along channels, preferably constructed from black polyethylene. Light must be prevented from reaching the roots of the plant as this will prevent growth. It is important to check nutrient levels regularly. This can be minimized by replacing the nutrient solution on a regular basis. No growing medium is required for this particular system, although some type of support for plants may be necessary.

One example of an NFT system is made of strips of polyethylene laid out on a slope with the sides folded up to make a channel. The bottom of the plastic should be placed upon a very flat surface, to ensure correct drainage. The nutrient solution runs along the channel and upon reaching the end, is collected and returned to the top of the channel by means of a continuously running pump. Some growers use off-cycles of up to 30 minutes to let the channels drain out completely back to the reservoir. Any period without irrigation of more than 30 minutes may result in water stress, or plant death. In the 1980s, we built NFT systems using PVC tubing. These systems were easy to build, but hard to clean and even harder to sterilize.

Nutrient Film Technique



"Nutrient is pumped to the top, and gravity returns it to the reservoir."



Larger plants can be supported by pegging plastic sheeting to wire.

Growing media

Many types of media and combinations of media may be used to grow plants hydroponically. Choice is largely dependent upon availability, the type of system in use and the plants to be grown.

Crushed granite: In hydroponics, screened crushed granite of approximate particle size of 2 mm should be used. The medium is totally inert, but has a relatively low water retention capacity. The medium can be reused over a period of time.

Sand: Coarse washed river sand is a mixture of fine and coarse particles. Sand in the 0.5 mm to 2.5 mm range is most suitable, allowing drainage and good aeration. Between 20-25 per cent by volume of peat moss may be added to improve moisture retention. Builders sand may be used as long as it does not contain large quantities of fine broken shell which will increase the alkalinity of the medium.

Scoria: Scoria is a relatively porous volcanic rock which is very good as a medium. Generally a mixture of fine and coarse scoria is used, being heavy enough to support plants yet having good aeration. It is sold as "lava rock" in many hardware stores.

Perlite: Perlite is a volcanic rock, which when heated in excess of 1000 C, expands into lightweight particles. In hydroponics approximately 3 mm particle size should be used. The medium is inert and sterile and is used as a lightweight support medium. It does not have a high capacity for water retention and has no nutrient holding capacity. Perlite can be used on its own or with vermiculite, depending upon specific plant needs. The medium must be pre-wetted before use. Avoid inhalation of the dust.

Vermiculite: An expanded mica, vermiculite is light and has a very high capacity for water retention. Because of its flaky structure, vermiculite eventually breaks down and requires replacement every 2-4 years. Works well in warm climates.

GROWING MEDIA (continued)

Mixes: A 50/50 mix of perlite/vermiculite makes an ideal growing medium. It is advisable not to mix sand, scoria or crushed granite with Perlite or vermiculite, as they will separate when wet due to differences in densities.

Rockwool: Horticultural rockwool consists of a mat of long, fine fibers, spun from molten natural rock. It is inorganic and inert, very light when dry, sterile, is not biodegradable and has a very high water and air holding capacity. It is sold in Australia under the trade name of Growool. In Canada, the United States and Europe the product is marketed under the brand name of Grodan Rockwool.

Fired Clay Pebbles: This is a high performance growing media. The clay pebbles are either formed from clay and fired, or milled form shale rock, and then fired. In either case the end result is a porous interior surrounded by a less porous hard shell. The less porous hard shell prevents the media from degrading in the presence of water. The capillary action is very high. Three sizes are available.

Coconut Fiber "Coir": Not used much in the United States, but due to the low cost it is used in tropical countries. Not recommended for recirculating systems due to leaching of organics into the water.

Shredded Fir Bark (or coarse fir sawdust): Again, low in cost but not recommended for recirculating systems due to the leaching of large amounts of tannic acid into the water. Canadian tomato growers used to use non-recirculating drip systems with coarse sawdust with good results. The sawdust must be replaced each season. Orchid growers use fir bark, as it simulates the natural way they grow on trees, and doesn't hold excess water.

Care and maintenance of hydroponic systems

Recirculating Systems: As the level in the supply tank falls in hydroponic systems which recirculate the nutrient solution, it should be topped off to its original level with water. This can be achieved manually, or automatically by the use of a float valve placed in the nutrient tank. Do not top off the tank with nutrient solution, otherwise you will have no idea of its strength.

After a while, the nutrient solution will need replacing. As a rough guide this should be done about every 1-2 weeks in summer, every two weeks in spring and autumn, and in winter every four weeks. As a more accurate method of determining when to replace the nutrient solution, a conductivity meter can be used. This instrument measures the electrical conductivity of freshly prepared nutrient solution, so when the conductivity falls to two-thirds of the original reading, the solution needs to be replaced or topped off with nutrients.

Non-Recirculating Systems: In systems where the nutrient solution is not recovered and reused, the supply tank is simply topped off with nutrient solution at any convenient time. Make sure that the supply tank is big enough to hold sufficient nutrient solution to last a number of days. Try to keep wastage to a minimum by learning how much is required under various conditions and efficiently applying the correct amount.

Moisture Content: The nutrient solution should be applied at a rate to fully wet the growing medium and cause some drainage. Do not keep the growing medium flooded with solution as this will force the exclusion of air and have detrimental effects.

Flushing: Over a long period of time, deposition of nutrient salts in the growing medium occurs, which may cause an imbalance in the nutrient supply. Every 1-4 weeks flush the whole system out with plain water.

High Temperature: If the temperature becomes too hot in summer then some protection will be needed. The plants may need some shelter such as shade cloth if grown outdoors. If grown inside a greenhouse, shade cloth or the application of whitewash may be needed. In greenhouses, good air movement is essential and will assist growth and reduce the incidence of fungal diseases on the foliage.

Low Temperatures: Complete protection from low temperatures can only be achieved with a heated and regulated greenhouse. Very little protection can be given to plants grown in the open. Covering plants with a plastic sheet can protect against light frosts, and advance their growth slightly.

Containers: When building any hydroponic systems, use inert materials like plastic or fiberglass. Some materials corrode and cause a nutrient imbalance. For example, if galvanized iron is used, zinc toxicity in plants will occur.

CROPS

When trying to decide the type of crop to grow in your hydroponic system, a number of factors need to be considered. These include: The availability of space, the yielding capacity of the crop, density of planting, and the cost of purchasing the crop locally. These factors can influence your choice greatly and restrict the variety of crops to a few. Vegetables worth considering are tomatoes, eggplant, capsicums, lettuce, cucumbers, zucchini and celery, all of which are much more palatable when fresh and also yield well.

Another popular crop would be strawberries, which are easy to manage and will produce for at least three years. Herbs are another alternative, especially grown in individual containers which are easily portable. Cut flower production is worth trying as another experiment. Carnations, roses, gladioli and chrysanthemums are suitable. The management of crops, whether they be grown hydroponically or in soil, must be similar. Care must be taken to provide optimal growth conditions for the plant variety chosen. Using a hydroponic system in no way increases your chances of success, if you fail to observe normal management procedures.

Nutrient solution and the elements it contains

Once a nutrient solution comes in contact with plant roots, its composition is immediately changed by plant uptake. Plants have the ability to actively select nutrients according to their need, and this can be totally independent of the ratio between nutrients in the solution. With repeated usage not only does the nutrient level fall in the solution, but changes also occur in the nutrient balance. Some nutrients are rapidly taken up by the plant (nitrogen, potassium) and others relatively slowly (magnesium, calcium). If the solution is used for a long time without renewal, it begins to run short of some nutrients. Generally, nitrogen is the first to become depleted and the appearance of nitrogen deficiency symptoms is a good indicator that the solution is exhausted. Another problem encountered with old solutions is that some nutrients gradually become unavailable to the plant like iron, or phosphorous. This may become apparent with the development of foliar symptoms. Iron deficiency causes the youngest tissue on the plant to become very yellow.

There are numerous nutrient solution formulations described in scientific papers on plant nutrition, and in books and articles on hydroponics. Some are designed for general use (like Hoagland's solution), and others for specific plants. They all differ in composition, but this is not surprising when the optimum nutrient ranges in Table 1 are studied. The number of nutrient concentration combinations available are almost unlimited.

16 elements are required for optimum plant growth:

Oxygen, hydrogen, and carbon (from carbon dioxide), all from the air. The rest must come from the solution, which includes nitrogen, phosphorous, potassium, calcium, magnesium, and sulfur, which are all "macro elements" used in large quantity. Manganese, iron, boron, copper, zinc, silicon and chlorine are all called trace elements, and are used in micro amounts. Cobalt and sodium are also used by some plants.

One advantage of a hydroponic system is the nutrient composition of the solution can be varied to cater to a plant's seasonal and developmental needs. Table 1 illustrates seasonal variation of the major nutrients. It is common practice to increase the potassium/nitrogen ratio of the nutrient solution during winter months. This reduces plant succulence and makes for hardier winter growth. In other words add more potassium, and less nitrogen during cool or cloudy weather

Nutrient	*Winter ppm*	*Spring/Autumn ppm*	*Summer ppm*
Nitrogen	150	200	260
Phosphorus	70	70	70
Potassium	350	300	260
Calcium	120	160	160
Magnesium	50	50	50

Table 1. As an example, seasonal variation in the concentration of major nutrients in the solutions.

Nitrogen plays an important role in hydroponics. It is very important to know a crop-specific requirement for this nutrient. As a general rule, vegetable root crops grown in hydroponics have a much lower nitrogen requirement than leafy crops. Potassium levels are generally increased for flowering plants.

Plants have two methods of uptake. There is a high nutrient mode and a low nutrient mode. Plants take some time to switch back and forth. This area is ripe for further research. High rates of growth have been reported at only a few PPM of the macro nutrients.

Preparation of the nutrient solution

The method described below is used to prepare Hoagland's solution, and has been used for the various hydroponic systems described earlier, including the Nutrient Film Technique. Only soluble salts are used.

Step 1. Make up four separate stock solutions of each major nutrient salt (these are molar concentrations). This is achieved by weighing out:

(a) 115g ammonium dihydrogen phosphate-NH4H2PO4
(b) 101g potassium nitrate-KNO3
(c) 236g calcium nitrate-Ca(NO3)2.4H2O
(d) 246g magnesium sulfate-MgSO4.7H2O

Place the weighed-out amounts into separate containers and bring the volume of each up to one liter.

Step 2. Make up an iron stock solution. Iron is prepared separately by dissolving 5g of sodium ferric ethylene diamine tetra acetic acid (iron EDTA) in 1 liter of distilled water.

Step 3. Make up a stock solution of the other trace elements. For ease of handling, all trace elements are added together. Weigh out, and then dissolve in 1 liter of distilled water:

(a) 0.38g boric acid-H3BO3
(b) 1.02g manganese sulfate-MnSO4*4H2O
(c) 0.22g zinc sulfate-ZnSO4*7H2O
(d) 0.08g copper sulfate-CuSO45SH2O
(e) 0.02g ammonium molybdate-(NH4)6Mo,024*4H2O

Step 4. Make up the nutrient solution.

Add so many ml of each stock solution to a given volume of water. For example, to make up 100 liters of Hoagland's solution, to 80 liters of water add:

100ml ammonium dihydrogen phosphate
600ml potassium nitrate
400ml calcium nitrate
200ml magnesium sulfate
150ml iron solution
100ml trace element solution

Top off with tap water to make 100 liters.

If smaller or larger quantities of nutrient solution are required, then the amount of stock solution is adjusted accordingly.

For further study, we have a brochure called "Observing Nutrient Deficiencies: A Science Project," put together by professional agricultural engineer Pat Sano (now retired). We also have the book "Plant Nutrients for Hydrorenics & How to Make Your Own Fully Formulated Plant Nutrient," by Jim McCaskill.

Pre-mixed Plant Foods

Pre-mixed hydroponic plant foods are now available at the local market. These are dry mixtures of salts blended together in the correct proportions so as to provide a balanced nutrient solution when added to water at the recommended rate. These proportions are ideally suited for the hobbyist or those with small hydroponic gardens.

A word of warning: For many years soluble plant foods have been on the market designed primarily as foliar feeds. These should never be used for hydroponics because they make imbalanced nutrient solutions, even after being modified by the addition of calcium and magnesium salts. Growth of plants on solutions made from these preparations is unpredictable. To be safe, use only those plant foods which are specifically formulated for hydroponic use.

The Nutrient Solution In Use

To maintain active growth, it is imperative that the plants at all times have a good level of nutrition. If, for some reason, the plants fail to receive an adequate nutrient supply by failure to renew or supplement the nutrient solution, growth will be slow. Reduction in growth rate can often go unnoticed because in the early stages there may be no other symptoms. The result is an overall loss of potential production.

In the growing medium (sand, gravel and vermiculite cultures) the nutrient solution must be applied at such a frequency that the medium never dries out or remains excessively wet or waterlogged for long periods. This latter situation can result in poor aeration and root death. Therefore there is a need to vary irrigation frequency and rate according to plant usage. Rockwool is more forgiving than most other media, due to it's huge water storage capacity.

Changing the Solution

A nutrient solution which is recycled through a hydroponic garden must be renewed on average every 4-14 days, or should receive regular nutrient supplements. The life of a solution varies with the nutrient demand of the plants. A solution feeding a bed of seedlings may have a practical life of 3-4 weeks because of the small nutrient usage. By the time the plants reach full maturity and maximum production potential, the solution may need renewing every 4-7 days.

In all hydroponic systems it is important that water loss from solutions by evaporation and/or plant transpiration is replaced daily. This can be done manually or automatically with a ball float valve in the nutrient tank. During hot weather, water usage is extremely high and, if not replaced daily, the volume of the remaining solution may become inadequate to maintain the moisture level in the growing medium.

Also, the nutrients become concentrated, and in extreme situations could induce a temporary salinity problem and adversely affect plant growth.

All hydroponic units using a growing media need to be flushed out with water every so often (1-4 weeks). This practice prevents the possible build up of unused salts in the medium to toxic levels.

The changing of the old nutrient also removes root exudates that are naturally produced. In soil, the roots are always seeking a new growing area, so exudates do not build up. Fresh water also helps prevent harmful fungi from growing on the plants roots.

Nutrient Solution pH

The term "pH" stands for "potential hydrogen," and is a logarithmic scale with a range of 0 to 14. A pH value of 7.0 is neutral, while less than 7 is acidic, and above 7 is basic (alkaline). The pH of a solution can be determined electrically with a pH meter, or colorimetrically with either universal indicator papers or solutions. The maximum range of pH values in nutrient solutions is from 5 to 8. Plants grown beyond either end of the range make poor growth and may have nutritional problems.

Most plants grow best at a pH range of 6-6.5. However, provided that the pH lies between 5.5 and 7.5, plants should remain healthy and continue to grow. Plants can tolerate a wider pH range in a nutrient solution than in soil. In most hydroponic solutions, pH will rise with time as plants remove nutrients. The major danger arising from this pH drift is that once pH exceeds 7.5, some of the nutrients may precipitate out of the solution and become unavailable (like iron and calcium phosphates). This problem with iron is overcome by using iron chelate instead of iron sulfate in the solution. An upward pH drift in solutions is corrected back to 6.5 by the careful addition of either dilute phosphoric, nitric or sulfuric acids. Citric and acetic acids are also useful organic acids that lower the pH.

The E. C. of the Nutrient Solution

E.C. is short for "electrical conductivity," which provides a measure of the total amount of dissolved salts in the solution. It does not tell how much of each nutrient is present. For this information, chemical analysis is necessary and costly. Electrical conductivity is measured by a conductivity meter. These are now available, giving direct readings in microsiemens (uS/cm) or millisiemens (ms/cm). These meters enable changes in the total nutrient level of a solution to be routinely monitored, and indicate when the solution needs to be replenished with nutrients or renewed.

As a guide for the NFT systems, when the conductivity falls below 2000 uS/cm (or 2 ms/cm), nutrients are added to maintain a value between 2000-3000 uS/cm (2-3 ms/cm). In taking conductivity readings it is important to keep the nutrient solution topped off to its correct volume, otherwise false readings will occur.

Remember, conductivity provides no information on the nutrient balance in the solution. Therefore in systems in which a replenishing solution is added to the nutrient solution to maintain conductivity, the nutrient composition of the solution will gradually change in time, as those nutrients not readily absorbed by the plants are accumulated. It is good practice to have total solution renewal every so often.

TDS meters

TDS meters read conductivity out directly in parts per million (PPM). Because different fertilizer salts ionize at different strengths, one gram of sodium chloride, for example, dissolved in one liter of water, is more conductive than, say, 1 gram per liter of potassium phosphate. To compensate for the low ionization of some salts, TDS meters are corrected to read 0.7 of the uS/cm conductivity value. The accuracy is more than adequate for hydroponic use, and is simpler to relate to in actual usage.

(2000 uS/cm = 1400 PPM)

Water quality

As a general rule, all water suitable to drink or used to irrigate greenhouses is ideal for hydroponics. To be more precise, water suitable for hydroponics should have a conductivity less than 500 uS/cm, or a total salt concentration less than 350 ppm. Harmful amounts of sodium and boron can cause problems in some areas. Very soft water should be used with calcium-containing nutrients. Hard tap water usually works very well, but after pH adjustment may “bounce back” to very high pH values.

The Root Environment

For a plant to thrive and achieve maximum production, it must at all times have an optimum root environment. The criteria which constitute a good root environment are as follows:

1. An adequate supply of water, oxygen and nutrients in, and removal of carbon dioxide from, the root environment. Remember, without oxygen at the roots no nutrients can be absorbed.
2. The establishment of a microbial population in the medium to decompose dead root tissue and root secretions.
3. Insulation of roots against adverse fluctuations in temperature. The temperature at the roots should not go below 68 degrees F (20 degrees C).
4. Provision of anchorage so that roots can physically support the plant. For example, cucumbers will need a trellis to support the weight of the vines and fruit.
5. Be completely free from harmful factors, such as insect pests, root pathogens, toxic chemicals, etc.

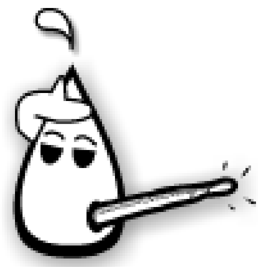
These conditions are relatively easy to achieve in hydroponics. However, it may be necessary in some systems to provide the plants with physical support. Soilless culture systems are extremely versatile and the only limit is one's imagination. A major objection to hydroponics is the initial high capital outlay to establish a system, particularly if it is fully automated. A foremost motivating force is the search for cheaper materials and systems. Initially, the NFT was heralded as a cost-cutting method in which expensive hydroponic beds were replaced by gullies made from plastic sheeting. A soilless system can be tailored to suit a particular need, site or crop. It becomes a personal choice of what you consider to be the most appropriate and economical, to both maintain and establish for your particular situation.

Nutrient deficiency symptoms

Nitrogen: The oldest leaves turn pale green, then yellow. Growth is stunted and slow.

Potassium: Scorched brown leaf edges that curl upwards. The leaves may be glossy blue green of small size. Roots are stunted.

Calcium: New leaves cup backwards, with white spots near the edges that turn brownish.



Magnesium: Leaves look bronze, with yellow patches between the veins.

Sulfur: Older leaves turn purple, the new leaves are very small with yellow between the veins.

Manganese: Very yellow between the leaf veins. Older plants get dead spots on the leaves and stunted roots.

Boron: Deformed roots, and roots with a torn patchy look on the surface. Calcium deficiency may start to develop as a result of lack of Boron!

Iron: Very pale leaves, with new leaves yellow instead of green. The veins stay dark.

Source: "Growing Edge," page 37, volume 9, #2, December, 1997. Radish plants are described, with other plants being similar.

Man is an inquisitive being with an unquenchable thirst for knowledge and the meaning of life. Naturally, he began to explore the mysteries of plant life. One question which must have been raised was how does soil sustain plant growth? The answer gradually emerged over a period of 250 years, and with it the science of hydroponics. Historical highlights can be summarized as follows:

1699 Woodward in England found he could grow plants in water to which soil was added.

1850s Liebig, a German scientist, showed the value of the nutrient solution to study the nutritional requirements of plants.

1860s Sach and Knop of Germany prepared nutrient solutions from mineral salts, thus freeing plants from the need of soil for growth.

1870-1920s There was a gradual increase in knowledge regarding the nutrient requirements of plants.

1929 Professor Gericke of California developed the first commercial hydroponic unit. He grew tomatoes in water culture which aroused much public interest, but enthusiasm waned as problems appeared, such as aeration and iron deficiency.

1936 In the U.S.A., gravel culture for commercial crop production was developed.

1938 Hoagland and Arnon of the University of California at Berkeley developed a nutrient solution which today is widely used in scientific fields and is known as Hoagland's solution.

1939-1945 American forces on the remote and barren Ascension Island grew vegetable crops hydroponically. The system used was the "Nutriculture" system, developed at Purdue University by Robert and Alice Withrow. Gravel was the growing media, and the nutrient solution was made according to the "Nutriculture" specifications.

1946-1970 Initially producing in excess of 40 tons of fresh vegetables hydroponically, the U.S. Army constructed the world's largest hydroponic farm on Chofu Island, Japan (26 x 90 meter-long gravel beds). Many hydroponic farms developed in the southern states of the U.S.A. where climatic extremes and shortage of land hindered the development of normal agricultural practice.

1970-1985 This period witnessed the development of the Nutrient Film Technique and rockwool culture. There has been a sharp rise in world interest for the communal production of vegetables and flower crops. For example, Jersey Channel Islands, in 1979, had six hectares under NFT, increasing rapidly in the 1980s. Cultivation by rockwool culture in the Netherlands has increased from about a half-hectare in 1975, to between 20-25 hectares in 1978, to over 1300 hectares in 1983. Expansion is continuing worldwide.

1990-onward Aeroponic and aquaculture systems lead the way in research, with genetically engineered plants now a reality. Insect control is now done with predator insects, pheromones, and fungal diseases for the bad insects. Research on hormones and auxins has resulted in the mass production of plants using tissue culture techniques.

source: "Home Hydroponics & How To Do It," by Lem Jones, 1977.