HYDROPONIC SYSTEMS

By
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Many people think of hydroponics as growing plants in water, but hydroponic production actually is defined as growing plants without soil. This production system may use a wide variety of organic and inorganic materials. The nutrient solution, rather than the media in which the plants are growing, always supplies most of the plant nutrient requirements. This method of growing has also been referred to as *nutrient-solution culture, soilless culture, water culture, gravel culture* and *nutriculture.*

Hydroponic culture is not new. One of the first experiments in water culture was made by Woodward in England in 1699. By the mid-19th century, Sachs and Knop, the real pioneers in the field, had developed a method of growing plants without soil.

The term “hydroponics” was first used by Dr. W. F. Gericks in the late 1930s to describe a method of growing plants with roots immersed in an aerated, dilute solution of nutrients. Today, hydroponics is used in commercial greenhouse vegetable production around the world.

There are several **advantages** to hydroponic culture. Some of the problems associated with conventional soil culture such as poor soil structure, poor drainage and non-uniform texture, as well as weeds and soil-borne pathogens, are eliminated. In automated hydroponic culture, some of the watering and fertilizer additions can be computerized, reducing labor input.

There are also **disadvantages** to hydroponic culture, such as the responsibility of the grower to maintain the proper level and balance of chemicals in the solution and to provide the proper biological environment for good plant growth. Hydroponic culture provides little or no buffering action to maintain the pH and nutrient concentration of the solution. In a conventional soil system, clay soil particles and organic matter bind and gradually release plant nutrients. These particles also can absorb potentially toxic elements and, therefore, offer plants some protection against toxicity. In a hydroponic system, water must be provided constantly to the plant roots; a malfunction in the pump, especially on a hot day, can result in rapid wilting, serious plant stress and death. Although hydroponic systems initially are free of diseases they can be infected readily because they lack the wide range of micro-organisms found in a soil system that act as antagonists to suppress soil-borne pathogens. Finally, hydroponic culture is more costly than conventional soil systems.

Many newspaper and magazine articles give the impression that plant growth and crop yields will be much greater in hydroponic culture compared to conventional soil growing. Under favorable growing conditions and optimal management,

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Above: Nutrient film technique (NFT) channels are covered with plastic for tomato production in K-State greenhouses.

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however, plant growth and crop yields are similar in the two systems. It is also untrue that plants can be spaced closer together when grown hydroponically; the same amount of light generally is required for optimum growth regardless of the system used. Finally, the nutritional value of a crop grown hydroponically is not superior to a crop grown by conventional culture methods.

LIQUID (NON-AGGREGATE) HYDROPONIC SYSTEMS

In this system, no rigid supporting medium for the plant roots is used. Liquid systems are, by their nature, closed systems; the plant roots are exposed to the nutrient solution, without any type of growing medium, and the solution is recirculated and reused.

Nutrient Film Technique (NFT)

This hydroponic system was developed during the late 1960s by Dr. Cooper at the Glasshouse Crops Research Institute, Littlehampton, England.

The principle of the NFT system is to provide a thin film of nutrient solution that flows through either black or white-on-black polyethylene film liners supported on wooden channels (frequently used with tomatoes and cucumbers) or some form of PVC piping (lettuce production) which contain the plant roots. The walls of the polyethylene film liners are flexible, permitting them to be drawn together around the base of each plant, which excludes light and prevents evaporation.

The 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 to determine the need for replenishment of salts and water before it is recycled. A capillary mat in the channel prevents young plants from drying out, and the roots soon grow into a dense, tangled mat.

A principal advantage is that a greatly reduced volume of nutrient solution is required, and this system is more easily heated during winter months or cooled during hot summers to avoid bolting in lettuce and other undesirable plant responses.

A common NFT unit or module size for producing a tomato crop is 0.9 acre, and will contain 12,000 plants, require 3,963 gallons of nutrient solution, and consume water at the rate of 4,000 to 4,300 gallons per day during the summer. NFT, like other closed systems, is vulnerable to poor water quality and toxic ions which can accumulate in the water if the solution is not completely changed periodically. Lettuce is another crop grown successfully in NFT.

The slope of the channels in NFT needs to be approximately 3 inches per 100 feet. Slopes less than that are not sufficient. Depressions in the channel must be avoided, or puddling of the solution will lead to oxygen depletion and growth retardation.

A cold nutrient solution will prevent plant uptake of nutrients. By heating the nutrient solution, tomato and lettuce growers can lower greenhouse night air temperatures without adversely affecting crop yield and total value. Lettuce also benefits from a heated solution, especially when plants are small and close to the solution.

Lettuce growing in nutrient film technique (NFT) channels.

The NFT system also allows for economical cooling of plant roots, avoiding more expensive cooling of the entire greenhouse. Problems do occur in hydroponics when the temperature of the nutrient solution exceeds 95°F (less with lettuce, which begins to bolt at root temperatures above 68°F). Cooling the nutrient solution for lettuce production not only reduces bolting but lessens the incidence of "damping off." Damping off is caused by the fungus *Pythium aphanidermatum*, which also affects establishment and yield of tomato and cucumber crops.

Capital costs of an NFT hydroponic growing system are estimated to be about $33,000 per acre exclusive of construction labor (and of the greenhouse structure), with annual operating costs of approximately $8,906 per acre.

AGGREGATE HYDROPONIC SYSTEMS

Aggregate systems such as vertical (5 gallon) or flat plastic bags are "open" and the solution is not recirculated, while porous horticultural grade rockwool may be "open" or "closed." In a "closed" rockwool system the excess solution is contained and recirculated through the system. Not reusing the nutrient solution means there is less sensitivity to the composition of the medium used, or to the salinity of the water.

Bag Culture

In bag culture, the growing mix is placed in plastic bags in lines on the greenhouse floor. The bags may be used for at least two years, and are much easier and less costly to steam-sterilize than soil.

Bags are typically made of UV-resistant polyethylene, with a black interior, and generally last for two years. The exterior of the bag should be white in regions of high light intensity levels, to reflect radiation and inhibit heating the growing medium. Conversely, a darker exterior color is recommended in northern, low-light latitudes to absorb winter heat. Most Kansas producers use black bags. Growing media for bag culture may include peat, vermiculite, or a combination, with perlite sometimes added to reduce cost. Examples of lay-flat bags are Plant-in-Bags and Fertile-Bags.

Tomato plant in bag culture system.

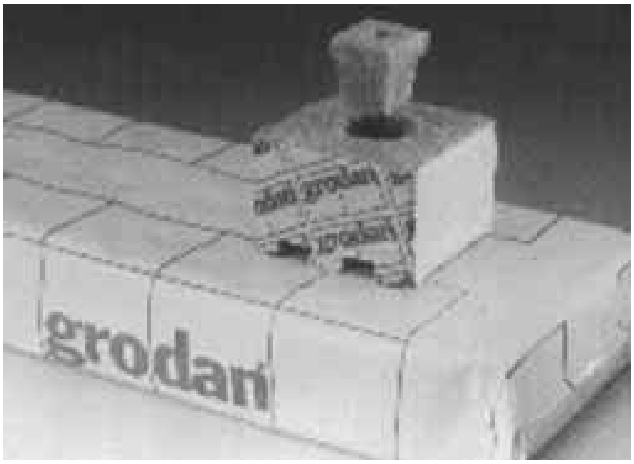
Bags are placed on the greenhouse floor at a normal row spacing for the crop. It is beneficial to first cover the entire floor with white polyethylene film, increasing the amount of light reflected back into the plant canopy. A covering may also reduce relative humidity and the incidence of some fungal pathogens.

Paired rows of bags are usually placed flat, about 5 feet apart (from center to center), with some separation between bags. Holes are made in the upper surface of each lay-flat bag for transplants, and two small slits are made low on each side for drainage or leaching. The soil in the bag is moistened before planting.

Drip irrigation with nutrient solution is recommended. A capillary tube should run from the main supply line to each plant. Plants growing in high light or high temperature regimes may require up to ½ gallon of nutrient solution per day. Moisture conditions near the bottom of the bagged medium should be examined frequently. It is normally best to be on the wet side, rather than dry.

The crops most commonly grown in bag culture are tomatoes and cucumbers. Tomato bags may be used for two crops per year (fall and spring) for at least two years.

The cost of bags is fairly high, and is one of the primary reasons for the limited use of bag technology to date.



A small seed-starting block is inserted into a larger block, to be inserted into a long rockwool ”bat."

Rockwool Culture

The use of horticultural rockwool as a growing medium in open hydroponic systems has been increasing rapidly. Cucumbers and tomatoes are the principal crops grown in rockwool. This technology is the primary cause of rapid expansion of hydroponic systems in Holland and Denmark.

Rockwool was first developed as an acoustical and insulation material. It is made from a mixture of diabase, limestone and coke, melted at a high temperature, extruded in small threads, and pressed into lightweight sheets. Insulation rockwool and fiberglass batting are not appropriate for use in horticulture. For use as a growing medium, rockwool must first be modified by a special proprietary process.

As a growing medium, rockwool is not only relatively inexpensive, but is also inert, biologically non-degradable, takes up water easily, is approximately 96 percent “pores,” or air spaces, has evenly sized pores (important for water retention), lends itself to simplified and lower-cost drainage systems, and is easy to heat during winter. It is so versatile that rockwool is used in plant propagation and potting mixes, as well as in hydroponics.

In “open” rockwool hydroponic systems, plants are usually propagated by direct seeding in small rockwool cubes with a hole punched in the top. The cubes are saturated with nutrient solution and are usually transplanted into larger rockwool cubes manufactured specifically to receive the germinating cubes, and side-wrapped with black plastic film. The large cubes are then placed atop rockwool slabs on the greenhouse floor. The slabs are usually 6 to 12 inches wide, 29 to 39 inches long, and 3 inches thick.

The greenhouse floor is covered with white polyethylene film for sanitation and light reflection. A bed normally consists of two rows of rockwool slabs, each wrapped in white film, in rows spaced 12 inches apart. The slabs should have a slight inward tilt toward a central drainage channel. If bottom heat is required, the slabs are placed on polystyrene sheets, grooved in the upper surface to accommodate hot water pipes. Due to the porosity of the rockwool, and given an appropriately modest irrigation schedule, almost all the solution remains in the slab for plant use. If there is a surplus, it will drain out of the slab and into the shallow channel.

Before transplanting, the rockwool slabs are soaked with nutrient solution. The plant remains in the small rockwool cubes in which it was established. Plants are set along the slabs through holes cut in the plastic film. If a root system is well developed in the cubes, roots will move into the slab within two or three days. Each plant receives nutrient solution through individual drippers, with irrigation rates varying by plant demand and environmental conditions.

The advantages of the rockwool system are:

- Rockwool is lightweight when dry, and is easily handled.
- It is simple to bottom-heat.
- It permits accurate and uniform delivery of the nutrient solution.
- It uses less equipment and has lower fabrication and installation costs; and there is less risk of crop failure due to the breakdown of pumps and recycling equipment.

The disadvantage is that rockwool may be relatively costly, unless manufactured nearby.

NUTRIENT SOLUTION

Although there are many “recipes” for hydroponic nutrient solutions (Hoagland’s, Johnson’s, Jensen’s, Larsen’s and Cooper’s), they all are similar, differing mostly in the ratio of nitrogen to potassium. The N-K rates differ because the plants need less nitrogen during short or dark days, more nitrogen during long days, bright sunlight and higher temperatures. There can be a significant difference in the cost, purity and solubility of the chemicals used. Chemicals may be of pure grade, technical grade, food grade or fertilizer grade.

Smaller operators often buy ready-mixed chemicals to prepare a nutrient solution. Larger facilities prepare their own solution to standard or slightly modified formulas. Commonly used components of nutrient solutions are listed in Table 1. It is necessary only to multiply the factor for a chemical by the ppm desired in the formula to obtain the number of grams to be weighed out.

Typical nutrient solutions for tomato and cucumber culture (in open or closed hydroponic system) are given in Table 2, with a typical micronutrient formula (for open or closed system) given in Table 3.

Closed Systems

Closed systems (such as NFT) are economical in the use of nutrients, but require frequent monitoring and adjustments of the nutrient solution. Measuring electrical conductivity (EC) is a convenient check of total salt concentration, but provides no data on the concentration of major elements, and it is virtually unaffected by the amounts of trace elements present. Periodic chemical analyses are required, usually every two or three weeks for major elements (N, P, K, Ca, Mg) and every four to six weeks for trace elements (Na, B, Cu, Fe, Mn, Mv, Zn). It is essential to add fertilizer concentrations to the nutrient solution at levels equaling those taken up by the crop; otherwise, some nutrients accumulate while others are depleted. Chemical additions may be required weekly or even daily.

Small operators commonly practice this regime: Begin with a new solution; at the end of a week add one-half of the original formula to the solution. At the end of the second week, dump the remaining mixture from the tanks or sumps and start all over again.

Open System

Because the solution is not recovered and recycled in open systems, it does not require monitoring and adjustment. Once mixed, it is generally used until depleted. In addition, the quality of the irrigation water is less critical. A content of up to 500 ppm of extraneous salts is easily tolerated, and for some crops (tomatoes, for example) even higher salinities are permissible, although not desirable.

It is advisable to monitor the growing medium, particularly if the irrigation water is relatively saline or if the operation is located in a warm, high-sunlight region. To avoid salt accumulation in the medium, enough irrigation water is used to allow a small amount of drainage or “leaching” from the bags. This drainage should be collected and tested periodically for total dissolved salts. If salinity of the drainage reaches 3,000 ppm or above, the bags must be leached free using plain water in the irrigating system.

FERTILIZER PROPORTIONERS

An automatically controlled system uses fertilizer proportioners which inject specific amounts of nutrient solution into the irrigation water. The highly concentrated nutrient solution is prepared in two separate mixtures, one containing calcium nitrate and iron, the other containing the balance of the dissolved chemicals. (This avoids combining calcium nitrate and magnesium sulfate in concentration, forming a precipitate of calcium sulfate). This arrangement requires the use of a twin or triple head proportioner. The rate of injection by the proportioner heads determines the concentration of the nutrient solution. For example, if each head injects 1 quart of concentrated stock solution into each 53 gallons of water passing through the irrigation system, the stock solution must be 200 times the concentration listed in Table 2.

It is necessary to monitor the total dissolved salts of the nutrient solution actually delivered to the plants twice each week. It is also important to check the proportioner pumps separately, to be sure they are working correctly.

NUTRITIONAL DISORDERS

Nutritional disorders are plant symptoms or responses that result from too much or too little of specific nutrient elements.

Generally, there are no nutritional disorders unique to hydroponics. Plants are more likely to experience nutritional disorders in a closed hydroponic system than in an open system. In a closed system, the levels of impurities or unwanted ions in the recycled liquid, or from the chemicals used, may more easily destroy the balance of the formulation and accumulate to toxic levels.

The most common nutritional disorders in hydroponic systems are caused by:

1. High levels of ammonium (NH_4). This causes various physiological disorders in tomatoes, and is avoided by supplying no more than 10 percent of the necessary nitrogen from ammonium.
2. Low levels of potassium (less than 100 ppm in the nutrient solution) can affect tomato acidity and reduce the percentage of high-quality fruit.
3. Low levels of calcium. This induces blossom-end rot in tomatoes and tip-burn on lettuce.
4. Zinc toxicity, caused by dissolution of the elements from galvanized piping used in the irrigating system. It is avoided by using plastic or other non-corrosive materials.

SYMPTOMS OF PLANT-NUTRIENT DEFICIENCIES

Plants usually display characteristic symptoms if nutrients are not present in adequate amounts. Below is a guide to the symptoms that may occur if the level of one mineral nutrient is below the range needed for best plant growth. There may be other reasons, such as ratio of nutrients, that may cause a plant to display a definite symptom. If one of the deficiency symptoms occurs, however, a lack of the proper nutrient may be suspected, and the amount of that nutrient increased. Nutrient-related disorders of crop plants can be avoided if crops are closely observed and the composition of the nutrient solution adjusted, particularly in closed systems.

Deficient nutrient	Symptoms
Nitrogen	Leaves are small, light green; lower leaves lighter than upper; weak stems.
Phosphorus	Dark-green foliage; lower leaves sometimes yellow between veins; purplish color on leaves or petioles.
Potassium	Lower leaves may be mottled (light to dark blotches); dead areas near tips and margins of leaves; yellowing at leaf margins continuing toward center.
Calcium	Tips of shoot die; tips of young leaves die; leaf tips are hook-shaped.
Magnesium	Lower leaves are yellow between veins (veins remain green); leaf margins may curl up or down or leaves may pucker; leaves die in later stages.
Sulfur	Tip of the shoot stays alive; light-green upper leaves; leaf veins lighter than surrounding areas.
Iron	Tip of shoot stays alive; new upper leaves turn yellow between veins (large veins remain green); edges and tips of leaves may die.
Manganese	Tip of the shoot stays alive; new upper leaves have dead spots over surface; leaf may appear netted because small veins remain green.
Boron	Tip of shoot dies; stems and petioles are brittle.

Table 1. Calculations for nutrient solutions. Amount of chemicals, in grams, used to make 1000 liters of nutrient solution (265 gallons).

Chemical compound*	Supplied element	Grams for 1 ppm per 1,000 liters
Ammonium sulfate (21-0-0)	Nitrogen	4.76
Calcium nitrate (15.5-0-0)	Nitrogen	6.45
	Calcium	4.70
Potassium nitrate (13.75-0-36.9)	Nitrogen	7.30
	Potassium	2.60**
Sodium nitrate (15.5-0-0)	Nitrogen	6.45
Urea (46-0-0)	Nitrogen	2.17
Nitro phoska (15-6.5-12.5)	Nitrogen	6.60
	Phosphorus	15.00
	Potassium	8.30
Monopotassium phosphate (0-22.5-28)	Potassium	3.53
	Phosphorus	4.45
Potassium sulfate (0-0-43.3)	Potassium	2.50
Potassium chloride (0-0-49.8)	Potassium	2.05
Monocalcium phosphate (triple super) (0-20.8-0) 13 ca	Phosphorus	4.78
Monoammonium phosphate (11-20.8-0)	Phosphorus	4.78
Calcium sulfate (gypsum)	Calcium	4.80
Boric Acid	Boron	5.64
Copper sulfate	Copper	3.91
Ferrous sulfate	Iron	5.54
Chelated iron 9%	Iron	11.10
Manganese sulfate	Manganese	4.05
Magnesium sulfate (Epsom salts)	Magnesium	10.75
Molybdenum trioxide $Mo0_3$	Molybdenum	1.50
Sodium molybdate	Molybdenum	2.56
Zinc sulfate	Zinc	4.42

*Chemical compounds vary in percent of constituents. These figures are within the workable tolerance of most available fertilizers or chemicals listed. Figures in () indicate percentage of N, P, and K.

**2.6 grams $KN0_3$ in 1000 liters of water equals 1 ppm K and .36 ppm N.

Table 2. Nutrient solution formula for closed and open systems.

Salt	Tomato solution				Cucumber solution			
	A		B		C		D	
Fertilizer grade chemical analysis designed as % N-P-K	Seedlings to first fruit set		Fruit set to term. of crop		Seedlings to first fruit set		Fruit set to term. of crop	
	ppm	g/1000 liters	ppm	g/1000 liters	ppm	g/1000 liters	ppm	g/1000 liters
Magnesium Sulfate $MgS0_4 7H_2 0$ (Epsom salt grade)	Mg 50	500	Mg 50	500	Mg 50	500	Mg 50	500
Monopotassium Phosphate KH_2P0_4 (0-22.5-28.0)	K 77 P 62	270	K 77 P 62	270	K 77 P 62	270	K 77 P 62	270
Potassium Nitrate $KN0_3$ (13.75-0-36.9)	K 77 N 28	200	K 77 N 28	200	K 77 N 28	200	K 77 N 28	200
*Potassium Sulfate K_2S0_4 (0-0-43.3)	K 45	100	K 45	100	—	—	—	—
Calcium Nitrate $Ca(N0_3)_2$ (15.5-0-0)	N 85 Ca 122	500	N 116 Ca 165	680	N 116 Ca 165	680	N 232 Ca 330	1357
**Chelated Iron Fe 330	Fe 2.5	25	Fe 2.5	25	Fe 2.5	25	Fe 2.5	25
***Micro-Nutrients	—	150 ml	—	150 ml	—	150 ml	—	150 ml

* The use of K_2S0_4 is optional.

** Up to 5 ppm of iron may be needed if a calcareous growing medium is used.

*** See Table 3 on micro-nutrient preparation.

NOTE: In growing other vegetable crops, use Solution C.

—Leafy vegetables: 200 ppm N.

—There are 454 g / lb, 3785 ml / gal and 28.35 g / oz.

Table 3. Micronutrient formula for closed and open systems.

Salt	Element supplied	ppm of element	Grams of each micronutrient
Boric Acid (H_3BO_3)	B	.44	7.50
Manganous Chloride ($MnC1_2\ 4H_20$)	Mn	.62	6.75
Cupric Chloride ($CuC1_2\ 2H_20$)	Cu	.05	0.37
Molybdenum Trioxide ($Mo0_3$)	Mo	.03	0.15
Zinc Sulfate ($ZnSo_4\ 7H_20$)	Zn	.09	1.18
		Total 15.95	

To the micronutrients (15.95 grams) add enough water to make a 450 ml micronutrient stock solution (heat to dissolve).

Use 150 ml of micronutrient stock solution for each 1000 liters of nutrient solution or 570 ml for each 1000 gallons (or 20 grams of micronutrient powder for each 1000 gallons of solution).

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Commercial Manufacturers/Suppliers

Hydro-Gardens, Inc. P.O. Box 9707, Colorado Springs, CO 80932. 800-634-6362

Clover Greenhouses, 200 Weakley Lane, P.O. Box 789, Smyrna, TN 37167. 800-251-1206.

Agro Dynamics, 12 Elkins Rd., East Brunswick, NJ 08816. (Rockwool.).

Crop King, Inc., P.O. Box 3106, Medina, OH 44258. 216-725-5656.

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