HYDROPONICS AS A HOBBY

growing plants without soil
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URING THE PAST SEVERAL DECADES, many amateur and commercial gardeners have become interested in growing plants with their roots in an artificial medium instead of soil. This method of growing plants is commonly known as "hydroponics." It is also sometimes referred to as nutrient-solution culture, soilless culture, water culture, gravel culture, and nutriculture.

Soilless culture of plants is not new. One of the first experiments in water culture was made by Woodward in England in 1699. He was trying to determine whether water or the solid portion of the soil was responsible for plant growth. By the mid-nineteenth century, Sachs and Knop, the real pioneers in this field, had developed a method of growing plants without soil.

In the late 1920's and early 1930's, Dr. W. F. Gericke was able to grow plants successfully on a large scale through the laboratory technique of solution culture. Dr. Gericke used the term "hydroponics" to describe this method of growing plants. Today, hydroponics is used in commercial production, but it is employed mostly in those areas where soil is lacking or unsuitable for plant growth. Hydroponics is also a tool in plant research as well as a fascinating hobby.

REQUIREMENTS FOR PLANT GROWTH

The requirements for plant growth in soil culture and nutriculture are the same. The only fundamental difference between the two methods is the manner in which the inorganic nutrients required for growth are supplied to the roots.

Temperature. There is an optimum temperature range for plant growth. Above or below this range, plants will not do well. Warm-season crops usually do well between 60° and 75° or 80° F., with 60° F. the night temperature. Cool-season crops do well between 50° and 70° F., with 50° F. the night temperature. Temperatures for best growth should be maintained whenever possible.

Light. Most cultivated plants need large amounts of sunlight. When plants are grown indoors, additional artificial light is sometimes needed. If plants are grown entirely under artificial light, the intensity of the light must be very high without causing the temperature to rise above the optimum range.

Water. Water should be available in adequate amounts in the soil or in soilless culture for proper growth. Too little or too much water will not give optimum growth.
**Oxygen.** In soil that is not waterlogged, adequate oxygen should be available. In hydroponic systems for growing plants, there may not be sufficient oxygen in the nutrient medium. To provide enough oxygen, it is often necessary to bubble air through the solution surrounding the roots.

**Carbon Dioxide.** Carbon dioxide, a gas, is taken up through the surface of the leaf and furnishes carbon and oxygen. These elements are required, along with hydrogen, in the manufacture of carbohydrates. Carbohydrates are used by the plants as food.

**Mineral Nutrients.** The plant must absorb certain minerals through its roots to survive. The minerals required in relatively large amounts are nitrogen, potassium, phosphorus, calcium, magnesium, and sulfur. Those required in small amounts are iron, manganese, boron, zinc, and copper. Molybdenum and chlorine are also useful to plants, but the quantities required are so minute that they are usually supplied in the water or along with the other mineral nutrients as impurities.

**SYSTEMS OF SOILLESS CULTURE**

**Water Culture**

In the water-culture method, plants are supplied with mineral nutrients directly from a water solution. The chief advantage of this method over aggregate culture is that a large volume of solution is always in contact with the root system, providing an adequate water and nutrient supply.

The major disadvantages are the difficulties of providing an air supply (oxygen) for the plant roots and proper support and root anchorage for the plants.

**Materials and Equipment**

The cost of growing plants through hydroponics depends upon the cost of chemicals and water used in the preparation of the nutrient solutions, the size of the operation, and the amount of mechanization. The cost may be quite low if you have a small setup and use available materials.

For a large setup, you will need a tank or trough constructed of concrete or wood. A depth of 6 to 18 inches and a width of 2 to 3 feet are the most common sizes for the larger tanks. If you use wood, be sure that it is free of knots and sealed with asphalt that does not contain creosote or tars. Do not use asphalt that leaves an oil film on
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the surface of the water. If the system is small, you can use glass jars, earthenware crocks, or metal containers. Metal containers should be well painted on the inside with an asphalt-base paint. Glass jars must be painted on the outside with dark paint to keep out light. A narrow strip should be left unpainted so that the level of the solution can be seen in the glass container.

The seedbed or plant bed should be 3 or more inches deep and large enough to completely cover the trough or tank. To support the litter, cover the bottom of the bed with chicken wire or ½-inch-mesh hardware cloth painted with an asphalt-base paint. Fill the bed with litter. The litter may be of wood shavings, excelsior, sphagnum moss, peat, or some other organic material fairly resistant to decay. Germinate the seed in sand or vermiculite and transplant to the water-culture bed. Keep the bed moist until the plants get their roots down into the nutrient solution.

A simple method for growing plants in solution.

Cross-section of a simple water-culture system.
Aeration

The water-culture method often fails because of inadequate aeration of the solution. The space between the seed bed and the nutrient solution may provide enough air for the roots of certain plants. But you must make special provision to allow an exchange of air between this space and the air outside. Prop up the seed bed a fraction of an inch or drill holes in the container or tank just above the highest solution level.

If you have trouble aerating the roots, use an aquarium air pump. Do not stir the solution too vigorously. You may damage the tender roots and cause poor plant growth. Pumping the air through an air stone, a perforated pipe, a porous glass tube, or a hose covered with a fine screen will reduce root damage by breaking down the air bubbles.

Water Supply

An adequate supply of pure water is essential for this system of hydroponics. The mineral content of water varies from place to place. In some areas, water is softened by replacing the calcium and magnesium with sodium. Sodium is toxic to certain plants when present at high levels. Boron and copper may be toxic at very low levels in the water, even though these elements are required in minute quantities for plant growth. Usually the minerals in water are not detrimental to plant growth. Calcium and magnesium, which are often present in water, are beneficial to plants.

Applying Nutrient Solution

Nutrient solution may be added by hand, by means of a gravity-feed system, or mechanically.

In a small setup, the nutrient solution can be mixed in small containers and added by hand as needed.

In a large setup, the gravity-feed system can be used effectively. The nutrient solution is mixed in a vat and tapped from the vat as needed. A large earthen jar or barrel will serve as the vat. If you use a metal barrel or container, paint the inside with an asphalt-base paint.

A pump can be used to transfer the material from the mixing vats to the growing tanks. Use a special non-rusting pump, or wash the pump carefully after each use. This precaution is necessary because the chemicals used in the nutrient solution will corrode metal.

The time to add nutrient solution depends upon the temperature and the growth of the plants. When the plants are young, the space between the seedbed and the nutrient solution may be quite small (sometimes one-half inch is sufficient). As the plant roots grow, lower the nutrient level slowly, keeping the level of the solution as constant as possible.
When the temperature is high and evaporation rapid, the plants may need additional solution every day. *Keep the roots at the correct level in the water.* The roots will die if allowed to dry out.

The container or tank should be drained completely every two weeks and the nutrient solution renewed from the mixing vats. This operation should be arranged so that it can be accomplished in a short time. If more than a few minutes elapse between the time of draining the tanks and refilling them, the roots will dry out. To delay the drying of the roots, change the solutions on a cloudy day or after the sun has gone down.

Transplanting seedlings or seeding directly into the seedbed will get the plants growing under the solution-culture system. The litter must be kept moist until the roots become established in the nutrient solution. Transplant seedlings carefully. Work the roots through the support netting into the nutrient solution; then build up the litter around the plant to support it.

**Aggregate Culture**

This method is often referred to as “sand culture” or “gravel culture.” Aggregates are used much as soil is used in conventional plantings—to provide anchorage and support for the plants.

The aggregate in the tank or container is flooded with a nutrient solution as required. The advantages of this system of hydroponics over the water-culture method are lack of trouble in aerating the roots, ease of transplanting seedlings into the gravel or other aggregate medium, and less expense.

**Materials and Equipment**

The tank or container should be *watertight* to conserve the nutrient solution. Construction materials will depend upon the size of tank or container. Large tanks can be built of wood, asphalt paper, concrete, or metal. The wood should be free of knots, and cracks should be sealed against leakage with asphalt. Asphalt paper can be used with wood framing to make a workable tank. A metal tank should be painted on the inside with an asphalt-base paint.

Metal, earthen, and glass containers can be used quite successfully for a small-scale operation. Ground beds, flower pots, baskets, and even bean hampers have been used in aggregate culture. Since they are not watertight, however, some of the solution is lost. Metal containers should be painted on the inside with an asphalt paint, and glass containers should be painted on the outside with a dark-colored paint.

The aggregate material may differ greatly in composition. Well-washed silica sand makes one of the better materials. But any sand,
Cross-section of plants growing in aggregate culture.

preferably of coarse texture, that does not contain lime may be used. Sand is a desirable medium because of its ability to hold moisture, and because plants may be easily transplanted to it.

A mixture of sand and gravel makes a very good medium if the sand or gravel does not contain much lime. Well-washed cinders may be used, provided that they are not high in toxic materials. Other materials such as peat moss, vermiculite, wood shavings, etc. are also satisfactory. You can obtain aggregate materials from local lumber yards, garden centers, or garden-supply houses.

Aeration

Aeration is much easier in aggregate culture than in the water-culture system. Draining and refilling the tank with nutrient solution causes air to move in and out of the aggregate material, thus supplying adequate oxygen to the roots.

Water Supply

Water requirements for this system are the same as those for the solution-culture methods. The mineral nutrients and the minerals present in the water as impurities accumulate in the aggregate materials as a result of evaporation. To overcome this accumulation of minerals, flood the aggregate material with water every two weeks. Drain off the water to wash out the minerals.
Applying Nutrient Solution

The “slop” or surface method is the simplest for adding the nutrient solution. In this method, the solution is poured over the aggregates by hand. A manual gravity-feed system with buckets or other vats and small growing containers may be used. The vat is attached to the bottom of the tank or container with a flexible hose, and is raised to flood the tank and lowered to drain it. The vat may be lowered and raised by hand or by means of a mechanical device. The vat should be covered to prevent evaporation and filled with new nutrient solution at least once every two weeks.

The gravity drip-feed system also works satisfactorily, and reduces the amount of labor. The vat is higher than the tank in this system, and the solution drips from the vat just fast enough to keep the aggregate moist.

A manual gravity-feed system.

A simple gravity-feed system. The solution flows from vat A into the aggregate material in the growing bed. When the growing bed is flooded, the solution is drained into vat B and then returned to vat A.
A pump can be used to raise the solution to the desired depth for sub-irrigation. Sub-irrigation is a system of supplying the nutrients by raising and lowering the solution level from the bottom. The solution must be raised to a higher level for younger plants than for older plants. A timer may be arranged on the pumping system so that the nutrient solution can be added whenever necessary. If the pump is not a non-rusting pump, it should be washed carefully after each use to prevent rusting. This mechanical system for adding the nutrient solution is practical only for a large setup.

The nutrient material must be added and drained or raised and lowered in the tanks once or twice a day. When the weather is especially hot and dry, the aggregate material may need more than two drenchings. Examine the aggregate material frequently to be sure that it has not dried out around the roots. After a few examinations, you will know about when the nutrient solution should be added. Remember — frequent drenchings will cause little harm, and permanent injury may result if the plant roots dry out.

Do not use the nutrient solution more than two weeks. If the solution is used for longer periods, it will probably build up salts or fertilizer residues that will damage the plants.

Seedlings or rooted cuttings may be used in this system. The aggregate material should be flooded and the solution drained off before planting. This will leave a well-packed, moist seedbed.

Seeds may be planted directly in the aggregate material. Do not plant too deep. Flood or sprinkle the tank with water frequently to prevent the aggregate material from drying out at the surface. If this happens, small seedlings may die. A few days after the seedlings have germinated, start using nutrient solution.

The safest way to get the plants established is by transplanting the seedlings from a germination bed. The seed should be germinated in a medium that is free of soil. Soil on the roots may cause them to rot, and may also cause trouble by getting into the nutrient solution.
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AGGREGATE

DRAIN

A simple mechanical subirrigation system.

Cross-section of a mechanical gravity-feed system.

PREPARING THE NUTRIENT SOLUTION

For proper growth, plants must be supplied with nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, boron, zinc, copper, molybdenum, and chlorine. Within certain limits of composition and total concentrations, there can be a rather wide range in the nutrient solutions suitable for plant growth. Usually the small amount of minerals in the water supply can be ignored. When nutrients are deficient or present in excess in the solution, however, the plants will suffer. For this reason, you must be careful in selecting and adding the minerals that go into the nutrient solution.
Purity of the nutrient materials or chemicals is important in preparing a solution. In some cases, the fertilizer grade of a chemical may be used, and in other cases, a technical-grade or food-grade chemical may be needed. The best grades have few impurities; the lower or fertilizer grades may have more. Sometimes the plants may use the impurities. Because of the low price of the fertilizer-grade chemicals, they should be used whenever possible.

Many formulas have been devised for supplying the nutrient requirements for plant growth. Most of these recommendations will give satisfactory results, but they often require less than one gram of chemicals that are not easy to obtain.

Paint the storage vats and containers used for the nutrient solution to prevent exposure to light, and close the vats and containers to prevent contact with the air. Evaporation of the solution, whether through the atmosphere or through plants, reduces the amount of water and increases the proportion of salt in the solution. Too much salt may be detrimental to the plants.

**Pre-Mixed Chemicals**

The chemicals needed for hydroponic plant growth are now being mixed in the correct proportions. These mixtures may be obtained through catalogs, or from garden-supply stores and reputable fertilizer suppliers. They are relatively inexpensive, and small quantities will go a long way in growing plants. Follow the directions on the container.

**Self-Mixed Chemicals**

You may want to prepare your own nutrient solution. The nutrient solution given below was worked out by the late Dr. D. R. Hoagland of the University of California. This solution supplies the major elements required for plant growth. It is easy to prepare, and usually gives satisfactory results.

<table>
<thead>
<tr>
<th>Salt</th>
<th>Grade</th>
<th>Nutrients</th>
<th>Amount for 25 gallons of solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium phosphate</td>
<td>Technical</td>
<td>Potassium phosphorus</td>
<td>ounces</td>
</tr>
<tr>
<td>(monobasic)</td>
<td></td>
<td></td>
<td>½</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>Fertilizer</td>
<td>Potassium nitrogen</td>
<td>2</td>
</tr>
<tr>
<td>Calcium nitrate</td>
<td>Fertilizer</td>
<td>Calcium nitrogen</td>
<td>3</td>
</tr>
<tr>
<td>Magnesium sulfate</td>
<td>Technical</td>
<td>Magnesium sulfur</td>
<td>1½</td>
</tr>
</tbody>
</table>
The table below can be used as a guide for adding nutrients required in very small amounts. You can obtain the chemicals listed from a garden-supply store or drug store. When you buy manganese chloride, zinc sulfate, or copper sulfate, be sure that the formulas for these salts are the same as those shown in the table. The amounts of solution given may be more than you will need. The amounts of chemical salts and water needed may be reduced by one-half or even more.

<table>
<thead>
<tr>
<th>Salt (all chemical grade)</th>
<th>Nutrients</th>
<th>Amount of water to add to 1 tsp. of salt</th>
<th>Amount to use for 25 gallons of solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boric acid, powdered</td>
<td>Boron</td>
<td>1/2 gallon</td>
<td>1/2 pint</td>
</tr>
<tr>
<td>Manganese chloride (MnCl₂·4H₂O)</td>
<td>Manganese Chlorine</td>
<td>1 1/2 gallons</td>
<td>1/2 pint</td>
</tr>
<tr>
<td>Zinc sulfate (ZnSO₄·7H₂O)</td>
<td>Zinc Sulfur</td>
<td>2 1/2 quarts</td>
<td>1/2 teaspoon</td>
</tr>
<tr>
<td>Copper sulfate (CuSO₄·5H₂O)</td>
<td>Copper Sulfur</td>
<td>1 gallon</td>
<td>1/2 teaspoon</td>
</tr>
<tr>
<td>Iron tartrate</td>
<td>Iron</td>
<td>1 quart</td>
<td>1/2 cup</td>
</tr>
</tbody>
</table>

Zinc sulfate and copper sulfate usually do not need to be added because of their presence as impurities in the water and in the other chemical compounds used in making up a nutrient solution. If you use the water-culture method of growing plants, it may be necessary to add the iron solution once or twice a week. You may want to use the chelated form of iron, since this form will not readily precipitate out of the solution. Mix 1 1/2 ounces of NaFe EEDTA 13 percent Fe₂O₃ in 5 quarts of water. Use 1/4 pint of this solution in 25 gallons of water.

Other sources of nutrients may be substituted for those in the tables as long as they furnish the mineral nutrients needed by the plants. The toxic effects of some chemicals upon plant growth must always be considered when making substitutions.

After all of the chemicals have been mixed into the solution, check the pH (acidity or alkalinity) of the solution on a pH scale. The pH scale runs from 0 to 14. Any solution below 7.0 is acid, and any solution above 7.0 is basic or alkaline. A pH of 7.0 is neutral.

Plants that do well at a low pH (between 4.5 and 5.5) include azaleas, buttercups, gardenias, and roses. Plants that will grow at a pH level between 7.0 and 7.5 include potatoes, zinnias, pumpkins, and myrtle. Usually plants will not grow with any success in solutions below a pH of 4.0 or above a pH of 8.0. For most plants, the solution should be slightly acid within a range of 5.5 to 6.5.

Use an indicator or pH tester to determine the pH of the solution. Indicator papers register pH within different ranges. When dipped into
the solution, the paper will change color at different pH levels. There are other devices for determining pH, and testing kits may be obtained from scientific and chemical supply houses.

If the pH is above the desired range, it can be brought down by adding dilute sulfuric acid. Add the acid in very small quantities, stirring the solution at the same time. An eye dropper is useful for this purpose. Count the drops. After a few drops have been added, retest the solution. Continue adding acid and retesting until the solution reaches the desired pH range. If you count the drops of acid, you can put the same number of drops into the solution each time the solution is made up. You will not need to make further pH tests as long as the water and chemicals of the solution remain unchanged.

**SYMPTOMS OF PLANT-NUTRIENT DEFICIENCIES**

Plants will usually display definite deficiencies if the nutrients are not present in adequate amounts. The following symptoms may occur if the level of one mineral nutrient is not high enough to be within the range needed for best plant growth. There may be several reasons other than a nutrient deficiency why a plant will display a definite symptom. But if one of the deficiency symptoms occurs, a lack of the proper nutrient may be suspected, and the amount of that nutrient increased.

<table>
<thead>
<tr>
<th>Deficient nutrient</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>Leaves are small and light green; lower leaves lighter than upper ones; not much leaf drop; weak stalks.</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Dark-green foliage; lower leaves sometimes yellow between veins; purplish color on leaves or petioles.</td>
</tr>
<tr>
<td>Potassium</td>
<td>Lower leaves may be mottled; dead areas near tips and margins of leaves; yellowing at leaf margins continuing toward center.</td>
</tr>
<tr>
<td>Calcium</td>
<td>Tip of the shoot dies; tips of young leaves die; tips of leaves are hook-shaped.</td>
</tr>
<tr>
<td>Magnesium</td>
<td>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.</td>
</tr>
<tr>
<td>Sulfur</td>
<td>Tip of the shoot stays alive; light-green upper leaves; leaf veins lighter than surrounding areas.</td>
</tr>
<tr>
<td>Iron</td>
<td>Tip of the shoot stays alive; new upper leaves turn yellow between veins (large veins remain green); edges and tips of leaves may die.</td>
</tr>
<tr>
<td>Manganese</td>
<td>Tip of the shoot stays alive; new upper leaves have dead spots over surface; leaf may appear netted because of small veins remaining green.</td>
</tr>
<tr>
<td>Boron</td>
<td>Tip of the shoot dies; stems and petioles are brittle.</td>
</tr>
</tbody>
</table>
EXPERIMENTS FOR YOU TO TRY

Many interesting experiments can be performed with soilless culture. Two experiments, the first dealing with pH levels, and the second with nutrient materials, are outlined below. You may want to work out variations of these experiments or try others of your own.

**Experiment 1: pH Levels**

Use the nutrient solution shown in the tables on pages 12 and 13, or a solution prepared from commercial pre-mixed nutrients. Adjust the pH of the solution to between 5.5 and 6.5.

Pour the solution into three containers. Do not change the pH of the solution in the first container. This solution is the "check" or "control." Lower the pH of the solution in the second container to below 4.0 by adding dilute sulfuric acid. Raise the pH of the solution in the third container to 8.0 or above by adding a dilute sodium hydroxide (NaOH) solution. Test the pH of the solutions with an indicator.

The following plants do well at a pH range between 5.5 and 7.0: carrot, coleus, cucumber, geranium, orange, pepper, petunia, strawberry, turnip, and violet. Grow a plant from this list in each of the three solutions. Choose only one kind of plant (pepper, for example), and be sure the plants are about the same size. If you use seeds, plant them all at the same time.

Notice the differences in growth between the plants in the three solutions. You may want to set up various pH ranges to find the best pH in which to grow a particular plant.

**Experiment 2: Nutrient Levels**

You will need to prepare three nutrient solutions for this experiment. The first solution is a pre-mixed nutrient solution or the "stand-
ard” solution listed in the tables on pages 12 and 13. Use twice the recommended amounts of nutrients in the second solution. For the third solution, use one-half the recommended amounts of nutrients. You will probably not want to prepare 25 gallons of each solution. The amounts of salts and water may be reduced by one-half, one-fourth, or even more, as long as you mix the proper proportion of ingredients for each of the three solutions.

Be sure to grow the same kind of plant in each container so that you can compare results between the plants. If you transplant into these containers, choose plants that are uniform in size. By varying the nutrient and pH levels and observing the effects of these changes upon the plants, you can determine the proper pH and nutrient levels for a particular plant.

**FOR FURTHER INFORMATION**


Growing Ornamental Greenhouse Crops in Gravel Culture, D. C. Kiplinger, Ohio Agricultural Experiment Station Special Circular 92, Wooster, 1956. 37 pages.


Nutriculture, Robert B. and Alice P. Withrow, Purdue University, Agricultural Experiment Station Circular 328, Lafayette, Indiana, 1948. 60 pages.
