HYDROPONICS

Principles and Guidelines

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Hydroponic Culture

HYDROPONICS is the science and art of growing plants in water without the use of soil. The science is in knowing what essential nutrients to add to the water. The art is in knowing when and how much to add for healthy plant growth. A more general term for this method of growing plants is nutri-culture, a term applied to all methods of growing plants in some media other than natural soil. Of principal interest in this paper are hydroponics (often called either water nutrient or solution culture), sand culture and aggregate culture. Basically, these methods are the same. They all provide the essential nutrients in the form of a dilute salt solution and differ only in the way in which the plants are supported in an upright position. In pure hydroponics, the tops of the plants are supported, and the roots are allowed to hang free into a nutrient solution. In both sand and aggregate culture the plants grow normally and are supported by their roots which are anchored in some inert material, such as sand or gravel, and which are regularly irrigated with nutrient solution. Sand culture consists of growing the plants in inert sand—usually quartz sand washed free of all contaminates—and watered frequently with nutrient solution. In aggregate culture, coarser materials, such as gravel, cinders, or crushed granite, are used in place of sand.

The nutrient solution used to irrigate plants supported by inert media such as sand and gravel must have the same nutritional value as that used for pure hydroponics (Hewitt 1966).

These three hydroponic systems can also differ by being either a "closed" or "open" system in respect to the nutrient solution. In a closed system the same nutrient solution is maintained in the plant beds, or is periodically recirculated through the plant beds to supply water and nutrients to the plants. In open systems fresh nutrient solution is applied to the plant beds each time they are irrigated, and the nutrient solution not used by the plant is discarded and allowed to drain away. The open system is much less susceptible to plant toxicity problems than the closed system but does pose some problems in disposal of the excess without polluting the environment.

The science of hydroponics is neither new nor simple. It is an alternative method of supplying mineral nutrients and water to growing plants. It has been used for scientific purposes since the middle of the nineteenth century. Much of our knowledge about the micronutrients essential for life come from experiments using this technique. It should be pointed out that there is no magic in hydroponics. Plants grown in soil, soil mixes, or water, can produce equal yields of equal quality provided that each media is managed appropriately. The taste of tomatoes grown in water will vary to some degree, just as the taste of tomatoes grown in soil will vary from one section of the country to another. The important thing is that the correct root environment must be maintained in each media and growing system to insure good plant growth.

The necessary environmental conditions which the root must be provided are water, oxygen and the essential mineral nutrients, plus support under natural conditions. Fortunately, many of the common horticultural and agronomic plants are very similar in their nutritional requirements. This allows us to concentrate primarily on the general techniques of hydroponics rather than compiling a list of anomalies associated with the particular requirements of individual plants.

Advantages and Disadvantages

The principal advantage of growing plans hydroponically is the precise control the method offers over the growing conditions. For example, such matters as the kind and amount of essential nutrients can be controlled in a water medium to a degree not possible in soil. This control makes possible the maximization of such qualities as plant size, leaf color, fruit yield, or oil production. Further, any or all of these qualities, determined by the set of conditions chosen, can be repeatedly and uniformly reproduced. Control over growing conditions and, by extension, reproduction, can be a very desirable advantage any time that the timing and yield of a particular high-value product needs to be known in advance. In a different context, it should be mentioned here that by reason of this high degree of control, hydroponics is a very valuable and versatile research tool.

The disadvantages of growing plants hydroponically are the large amount of equipment and care required and the need to know more about the physiology of the plant in order to provide the right growing conditions. The amount of care can be reduced somewhat by the use of additional automatic equipment.

When plants are grown hydroponically there are many more parts of the root environment that are possible to control and need to be controlled than are either possible or feasible when plants are grown in soil. Although such things as temperature, nutrient replacement, and oxygen must be considered, it is the mineral nutrition that is most amiable to manipulation and most likely to be mismanaged. Deficiencies of one or more essential mineral nutrients, or toxicity of a wide variety of substances including the essential nutrients, can and does occur. Hydroponics primarily differs from other plant growing systems in the way in which the nutrients are supplied. Therefore, the differences required in the cultural management of hydroponically grown plants are in relation to their nutrition. All other cultural practices such as light, temperature, season, and so on, are managed in the same way as for soil-grown plants. The amount of nutrients required by a plant is a function of the plant's growth rate. If the growth of the plant is slow due to low temperature, low light or other conditions, then only a limited amount of nutrients is required. If these conditions are improved, and the growth rate of the plant is increased correspondingly, then both the amount and frequency of the nutrient additions will have to be increased.

Nutrient Requirements

Plant nutritionalists generally accept 16 elements as being essential for the normal growth and development of higher plants ,Steward 1963). Three of these elements are normally obtained from air and water (carbon, hydrogen and oxygen). The other 13 elements are generally obtained directly from the soil by way of the plant roots. These elements are called the mineral nutrients and are divided into the macronutrients and micronutrients depending on the amount of each nutrient required by the plant (see Table 1). The macronutrients are present in dry plant material in the percent range, while the micronutrients are present at the level of only a few parts per million.

Although in theory the growing of plants in water is relatively simple, some experience in both the fields of chemistry and botany is desirable. Further, the equipment required for growing plants hydroponically is not the same as that normally associated with backyard gardening. However, the pleasure derived from hand-feeding the plant the required essential elements and from learning to recognize the deficiency symptoms can be very rewarding for the extra effort and study involved.

Many factors, such as concentration, pH, total amount of nutrient present, plant growth, plant requirements and their interactions, are all interdependent and have to be considered simultaneously. Solution culture does offer the grower the greatest control over the growth of the plant. But, at the same time, it implies that the grower will have to monitor and control more variables to obtain normal plant growth than would be necessary if the plants were grown in soil.

In hydroponic culture the required mineral nutrients are supplied as a dilute solution of their salts, and oxygen availability is maintained by constant aeration of the nutrient solution or by repeated flooding and draining in aggregate culture. The preparation of the hydroponic solution is relatively simple and easy if the water and salts are pure. However, if pure water and salts are not available, the actual composition of these materials will have to be considered and in some cases adjustments made. The preparation of nutrient solutions should be done under conditions of extreme cleanliness. When plants are grown in hydroponic culture, in contrast to soil, there is relatively little buffering capacity or resistance to change in the system and very small amounts of biotoxic materials will result in plant growth reduction. The hydroponic solution given in Table 2 was developed for tomatoes, but has been found adequate to satisfy the nutrient requirements of many types of plants. Silght modifications of this solution may prove better depending upon the plant species being grown and the type of growth desired. That is, whether top growth, root growth, fruit or some other aspect of growth or yield is being encouraged. For example, if corn and certain other grass-type plants are grown in this nutrient solution, the amount of added iron should be increased 2 to 4 times. Researchers in plant nutrition will recognize the formula presented in Table 2 as a minor modification of half - strength Hoaglands solution (Hoagland and Arnon 1950). Concentrated stock solutions are prepared so that routine nutrient additions can be done by simple dilutions without the need to weigh and dissolve numerous salts each time. The stock solutions can be stored successfully, preferably in a cool and dark place. It will be necessary to prepare the two concentrates (#1 and #2) in separate containers in order to avoid a precipitate of calcium phosphate. Fiberglas or plastic-lined containers are recommended. These containers should be opaque to light because these solutions are excellent for the growth of green algae in the presence of light. Once the nutrient solution is prepared, most of the tedious work is done and it is then possible to concentrate on growing the plants.

Nutrient Preparation

The chemicals needed to prepare the stock concentrations are generally available from agricultural fertilizer companies. In some areas, nurseries sell premixed salts to prepare the nutrient solution, which vastly simplifies nutrient preparation. Molybodic acid is somewhat less available than the other chemicals but its omission in many instances will not be deleterious because impurities in the other salts will supply the very small amount required. The exact amount of each salt should be weighed out on a scale that reads at least in fractions of an ounce.

Recipe For Preparation Of Nutrient Solution:

Supplies needed:

1. A scale that reads in fractions of an ounce.
2. Three (5 gallon) containers
3. Salts listed in Table 2.

Stock concentrate #1

This contains the majority of macronutrients and all the micronutrients needed.

1. Weigh out the appropriate amounts of the macronutrients, salts, potassium nitrate, potassium phosphate, magnesium sulfate and sodium chloride. Place these in a 5-gallon container, add 4 gallons of water and mix until all salts are completely dissolved.

2. Weigh out the appropriate amounts of the micronutrients, boric acid, manganese sulfate, zinc sulfate, copper sulfate and molybdic acid. Place these in a separate 5-gallon container and mix with warm water 60°C (140°F) to volume. Without the warm water the boric acid may not dissolve easily.

4. Add one-half gallon of the dissolved micronutrient solution to concentrate I and make to volume.

Stock concentrate #2

1. Weigh out the appropriate amount of calcium nitrate and place in a 5-gallon container.

2. Add 4 gallons of water and mix until dissolved.

3. Weigh out the appropriate amount of iron chelate (sequestrene 330 Fe) in a small container. Mix to a slurry with a small amount of water.

4. Add the iron chelate slurry to the calcium nitrate solution and make to volume.

Working nutrient solution

From the two (1 and 2) stock solutions it is necessary to make a 1 to 200 dilution.

1. Add 3.2 fluid oz. of each stock concentrate and make to 5 gallons.

or, 1 qt. of each concentrate to 50 gallons,

or, 50 ml of each concentrate to 10 liters.

This is the dilute salt solution used to feed plants.

The concentrates can be diluted to make the nutrient solutions either manually or by the use of equipment such as aspirators or proportioners. Aspirators and proportioners introduce small amounts of concentrate into waterline, as a function of flow. Whenever these are used it is wise to make sure that the concentrate is fully mixed with water before it is applied to the plants. A simple check is to add food coloring to the concentrate, then mixing can be checked visually.

Equipment

A number of different containers for plant growth may be used with success in solution culture work. The size of the container is governed by the same criteria that determines container size when using soil mixes. That is, the smaller container the more often it will have to be cared for, and the larger the container the fewer plants that can be placed in a given area. Many times greenhouse space is

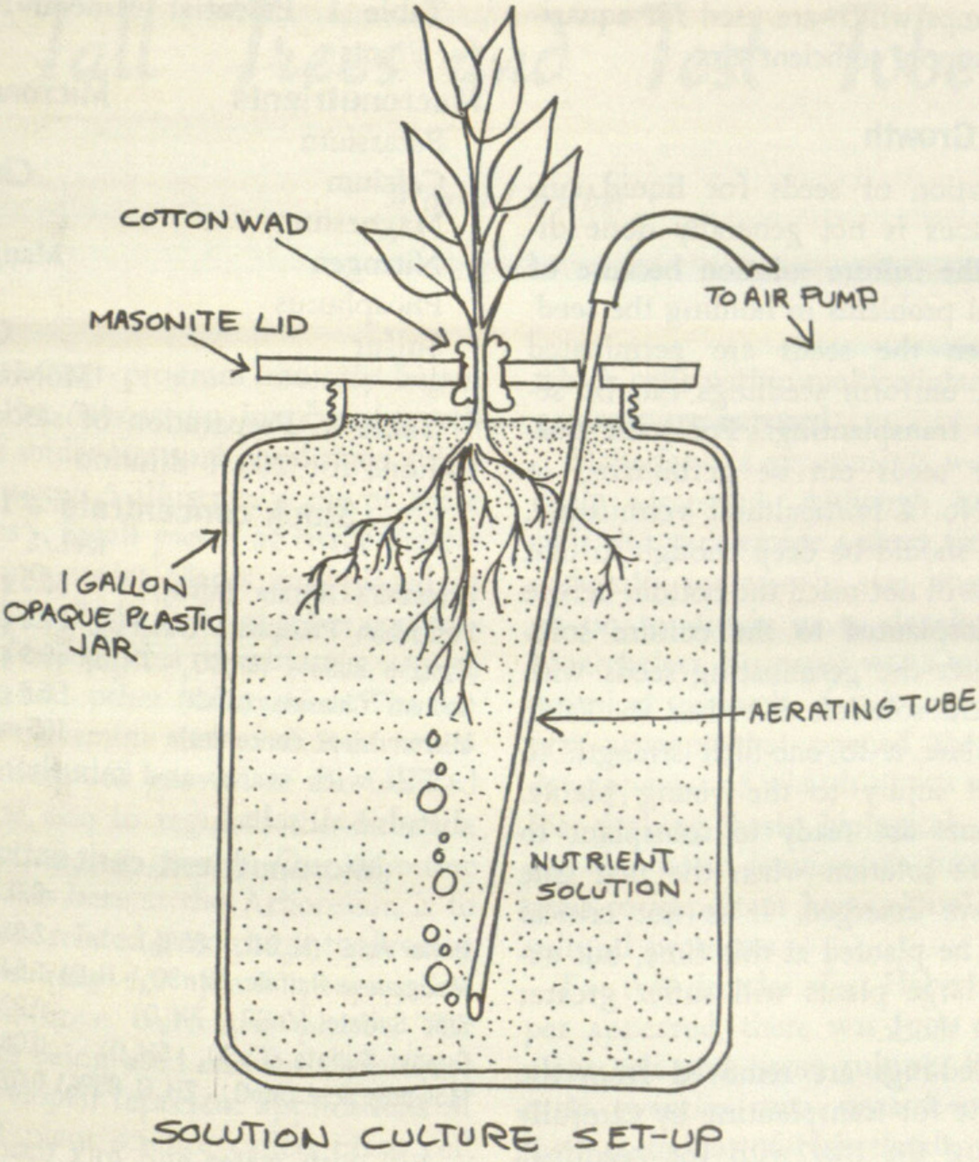

Fig. 1

more important than the amount of care required. Containers of glass, plastic or fiberglass having a capacity of one quart or greater will work well. However, if plants the size of tomatoes are to be grown to maturity and a crop harvested, no container smaller than 5 gallons should be considered. The containers should be opaque, or painted with an opaque paint, to prevent the growth of photosynthetic microorganisms (algae). The lids of the container should also be opaque to light. It has been found to be convenient to construct the lids from sheet plastic or masonite. The lids are cut to size and two holes drilled. One, one-quarter inch hole for the aeration tube is drilled close to the edge and a one and one-half inch hole in the center for the plant (see Fig. 1). Vigorous uniform aeration is necessary to oxygenate, stir and maintain a uniform solution composition and temperature. Without aeration the roots of many plants will drown and die. The aeration can conveniently be done by placing a glass or plastic ¼-inch tube connected to a compressed air supply in the bottom of the container. The compressed and filtered air supply should be adjusted so that a rapid stream of individual bubbles is coming out the end of the tube. For a single container, the air pumps which are used for aquariums will supply sufficient air.

Seedling Growth

Germination of seeds for liquid culture solutions is not generally done directly in the culture solution because of mechanical problems in holding the seed. Also, when the seeds are germinated elsewhere, uniform seedlings can be selected for transplanting. For most purposes, the seeds can be germinated in trays of No. 2 horticultural vermiculite. The trays should be deep enough so that the roots will not reach the bottom before being transplanted to the culture solution. Water the germinating seeds with the nutrient solution described in Table 2, but dilute it to one-fifth strength to avoid salt injury to the young plants. Most plants are ready to transplant to the culture solution when the first true leaves have emerged. It is not critical that they be planted at this time, but excessively large plants will suffer greater transplant shock.

The seedlings are removed from the vermiculite for transplanting by carefully submerging the tray with the seedlings in water and gently floating the seedlings from the vermiculite. Some of the smaller particles of vermiculite may adhere to the root; do not remove these, for doing so might injure the root, and a few particles will cause no harm. Carefully wrap a small wad of Dacron, nonabsorbent cotton, or plastic foam around the stem of the seedling and place it in the hole in the center of the lid of the nutrient solution container. The dacron gives support without bruising the young seedlings. At this time it is extremely important to make sure that the nutrient solution covers the entire root of the seedling. Care should be taken at this time to make sure that the root does in fact hang down into the nutrient solution for often it will adhere to the lid.

Table 1. Essential Mineral Nutrients for Plants

Macronutrients	Micronutrients
Potassium	Iron
Calcium	Chlorine
Magnesium	Boron
Nitrogen	Manganese
Phosphorus	Zinc
Sulfur	Copper
	Molybdenum

Table 2. Preparation of stock concentrations for 200:1 dilution

Stock concentrate #1

	Amt./L	Amt./5 gal.
Potassium Nitrate (KNO_3)	50.5 g	33.8 oz.
Potassium Phosphate (KH_2PO_4)	27.2 g	18.2 oz.
Mgns'm Sulfate ($MgSO_4 \cdot 7H_2O$)	49.3 g	32.9 oz.
Sodium Chloride ($NaCl$)	5.8 g	3.9 oz.
Micronutrient concentrate	100 ml	64fl. oz.

Fill with water and mix thoroughly to dissolve all salts.

Micronutrient concentrate

	G/L	oz./5 gal.
Boric Acid (H_3BO_3 85%)	2.85	1.90
Manganese Sulfate ($MnSO_4 \cdot H_2O$)	1.54	1.03
Zinc Sulfate ($ZnSO_4 \cdot 7H_2O$)	0.22	0.15
Copper Sulfate ($CuSO_4 \cdot 5H_2O$)	0.08	0.05
Molybdic Acid ($MoO_3 \cdot 2H_2O$ 85%)	0.02	0.01

Fill with water and mix thoroughly to dissolve all salts.

Stock concentrate #2

	G/L	oz./5 gal.
*Calcium Nitrate $Ca(NO_3)_2 \cdot 4H_2O$	118.1	78.8
Sequestrene 300 Fe	5.0	3.3

Mix the iron chelate thoroughly in a small amount of water before adding to the calcium nitrate concentrate.

*If commercial agricultural calcium nitrate (Norsk Hydro) is used, add only 88.8 g/L=59.3 oz./5 gal.

Dr. Berry is a soil scientist on the Department research staff with a special interest in the efficiency of nutrient utilization by plants. He is the author of a number of technical publications on the subject.