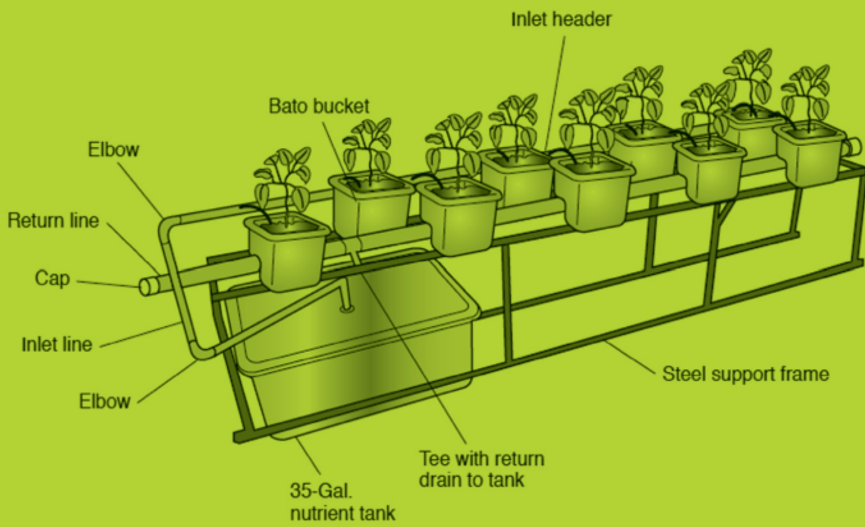
Hydroponics for the HOME GROWER



CRC Press
Taylor & Francis Group

Howard M. Resh

Hydroponics for the
HOME GROWER

Hydroponics for the HOME GROWER

Howard M. Resh, PhD

CuisinArt Golf Resort & Spa
Anguilla, British West Indies

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Version Date: 20141124

International Standard Book Number-13: 978-1-4822-3926-3 (eBook - PDF)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Contents

SECTION I History and Background of Hydroponics

SECTION II Understanding Hydroponics and How Plants Grow

SECTION III Nutrients Essential to Plants and Their Sources

SECTION IV Hydroponic Systems

SECTION V Year-Round Growing in Greenhouses

SECTION VI Vegetable Crops and Their Cultural Techniques

SECTION VII Sprouts and Microgreens

List of Figures

List of Tables

Acknowledgments

This book gathers information from almost 40 years of my experience with hydroponics. During the early 1970s people were attempting to design small indoor hydroponic units, but with little knowledge of the general public of what hydroponic growing was all about, most of these business ventures into marketing of small indoor units were not successful. It took almost a decade for consumers to become more aware of hydroponics and its potential for indoor growing. Companies established at this later period in marketing such small indoor units did become very successful, and, in fact, many of them still exist today. Now they manufacture and sell all components from lights, carbon dioxide generators, nutrients, and so on, in addition to the hydroponic growing units themselves. Some of these companies now have world-wide distributors of their products.

In this book, many of these products are presented as all components of growing are key to successful indoor growing. Some of the companies that manufacture and/or sell these units and accessories mentioned in this book are listed in the Appendix. I wish to thank the following companies for the use of their photos in this book: AeroGrow International, American Hydroponics, AutoPot Global, Ltd., Bluelab Corporation Ltd., Botanicare, CO2Boost LLC., General Hydroponics, Green Air Products, Inc., Hydrofarm Horticultural Products, Hydrofogger, LumiGrow, Milwaukee Instruments, Myron L Company, Sunlight Supply, Inc.

A very special thanks to Mr. Leandro Rizzuto, President of CuisinArt Golf Resort and Spa, Anguilla, British West Indies, for permitting me to include many photos that I have taken while working at the CuisinArt Hydroponic Farm.

In no way is the use of trade names intended to imply approval of any particular source or brand name over other similar ones not mentioned in this book.

Introduction

Most of us growing vegetables in our backyard gardens face lots of challenges with the soil structure, fertility, watering, pests, and diseases. You may think that all you have to do is to sow some seeds in the soil and they will germinate and grow into productive plants. This, however, is wishful thinking, unless you know the proper techniques for successful soil growing. So, if you are faced with these challenges, is there another way to give you better control of these limiting factors to your production? The answer is hydroponic culture.

Basically, growing plants in soil or hydroponically requires similar needs from their environment for good yields. However, with hydroponics you have control over many of the limiting factors that plants encounter in soil. One step further is to grow them in a greenhouse hydroponically. In this way, you can also control some of the outside limiting factors, such as light and temperature, and exclude to a large degree pest and disease problems with your plants. In addition, you can grow year-round in a greenhouse, producing high-quality plants even during winter months. Experience production during the winter and escape from the darkness and stress of winter doldrums during these short winter days.

ABOUT THIS BOOK

In this book, focus is on the production of vegetable crops year-round within your home or in a greenhouse. By following the procedures presented, you can grow successfully with hydroponic culture. While most crops grown in soil can be grown hydroponically, the emphasis, due to economic viability, is on tomatoes, peppers, cucumbers, eggplants, lettuce, arugula, bok choy, and various herbs. I present background information on how hydroponics evolved, plant needs in terms of nutrients, water, plant growth, and show you how you can provide these basic needs to your plants. There is an explanation of nutrient solution makeup to show you how to provide the plants with their essential elements for growth. Nutrient solution formulations and their preparation are basic to successful hydroponics. However, they can be purchased from hydroponic shops and online if you wish to avoid making them up yourself.

After that, many hydroponic systems are described that you may construct yourself or purchase. These systems, with their substrates, are taking the place of the soil. They can be automated to reduce your constant caring as occurs with soil in providing fertilizers and building soil structure and fertility through composting and watering.

I take you one step further to enjoy gardening year-round with the use of a backyard greenhouse. The construction of backyard greenhouses is described along with the components needed to control the climatic conditions within the greenhouse that are favorable to plant growth. Hydroponic systems for these backyard greenhouses are the next step in assuring successful growing for the whole year.

Finally, numerous vegetable crops recommended for hydroponics are discussed in detail, including such topics as seeding, transplanting, training of the plants, and pest and disease control. Varieties I have found in the past that grow best under greenhouse hydroponics are given, along with some simple indoor systems to grow sprouts and microgreens.

TERMINOLOGY USED IN THIS BOOK

Temperatures are given in the Fahrenheit (F) and Celsius (C) scales as many countries now use Celsius. I place the Celsius temperatures in brackets after the Fahrenheit ones. *Italics* are used for plant, insect, and disease Latin names. Scientific weights and measurements will be defined as they are introduced. Other shortened forms will be placed in brackets immediately after the word(s) when first introduced. For example, electrical conductivity, basic or acid measurement, nutrient film technique (NFT), and so on.

WHY HYDROPONICS IS FOR YOU

The way I look at it, if you must spend considerable time caring for your plants in soil, why not eliminate some of the variables that are restricting good yields in your backyard by going to hydroponic culture. Hydroponics is quite logical and only requires step-by-step procedures. Doing so will greatly increase your growing success. It also is less "back breaking" work than occurs with your soil garden in weeding, hoeing, mulching, and adding soil supplements, such as steer manure, fertilizers, and so on. And you can avoid many soil-borne pests and diseases, so less spraying of pesticides is necessary. Hydroponic systems can be constructed at waist height to save on bending over to look after and harvest plants, especially low-profile ones like lettuce, bok choy, cabbages, spinach, strawberries, and herbs. You can even grow root crops like carrots, onions, and green onions in some forms of hydroponics, such as a peat-lite mixture or coco-coir substrate. Bush beans also grow well in raised beds of these media. All your efforts will be well rewarded in higher yields of your crops.

DO NOT BE FOOLED BY "ORGANIC" PLANTS

Many people believe that hydroponically-grown plants are not organic. Of course, that is not true. In fact, all plants are organic. They all require elements essential for their growth (essential elements), including carbon from carbon dioxide and oxygen and hydrogen from the air and water. There are no "organic" elements required that they only receive in soil. In fact, organic compounds (those containing carbon) must be broken down into their elemental constituents to be absorbed by plants. These organic compounds are in the form of decaying plant and animal material that through microbial decomposition release their elements in atomic (ionic) states into the soil water to form the soil solution. The plant roots are in contact with the soil solution and take up the essential elements by expending energy to transport them across their root membranes. The soil is also composed of inorganic compounds such as sand, rocks, and so on, that must be weathered to break down into their elements. Once again they are released into the soil water, resulting in the soil solution.

In hydroponics, we dissolve essential element-bearing compounds in water to form the nutrient solution. The nutrient solution serves the same function as the soil solution in providing the essential elements (13 of them) to be available to plant roots. The growth of the plants is the same whether in soil or a soilless medium. Plants through photosynthesis and respiration using carbon, hydrogen, and oxygen from the air and water manufacture their building blocks for growth.

"Organic" growing is really a misnomer as it really applies to the non-use of synthetic pesticides. These very same natural pesticides and beneficial insects are used in hydroponic growing, but they can be more efficiently applied and controlled under hydroponic culture than in soil culture. One step further is to do the growing in a greenhouse, where the pests and diseases can be excluded or restricted to some extent, and the release of beneficial insects in the closed environment of the greenhouse keeps them within the greenhouse, where they can multiply while controlling the pests.

ORGANIZATION OF THIS BOOK

This book is divided into sections. Each section covers a number of chapters related to a theme. The following is an outline of the parts.

SECTION I: HISTORY AND BACKGROUND OF HYDROPONICS

Hydroponics, while not termed that until the 1940s, was practiced by ancient cultures. As scientists later looked for the reasons behind plant growth and their needs for development, they used various forms of "nutriculture" (growing plants in substrates other than soil) to discover these factors. Knowing some of this background will help you to understand that hydroponics is not something that just developed overnight. It took many centuries of study to finally apply it to commercial growing. Where this culture is now and where it is heading in the future will provide you with insight to its many applications. This leads to its popularity and benefits that will convince you of its advantages for your growing hydroponically even on a small scale.

SECTION II: UNDERSTANDING HYDROPONICS AND HOW PLANTS GROW

This section will demonstrate that hydroponics is not just all chemistry but still regular gardening with a twist of providing plants with all of their components at more optimal levels in order to improve yields. Understanding some of the nutritional and environmental demands of plants will enable you to recognize and provide these factors for them. Next, then, is how to do this by proper watering (irrigation), nutrient application and levels, and management of the environment to make your plants happy and productive.

SECTION III: NUTRIENTS ESSENTIAL TO PLANTS AND THEIR SOURCES

While this is emphasizing hydroponics, it also applies to soil gardening. I compare hydroponics with soil growing in terms of where and how plants get their nutrients. Sources of the nutrients will assist you in finding the purist, high-quality compounds that will make these nutrients readily available to your plants. With hydroponics, you have control of providing your plants with optimal levels of nutrients (essential elements) by using specific formulations optimal to those plants you wish to grow. Emphasis is always on vegetable crops, as these are the ones that you want to maximize production. Finally, when you understand nutrition of the plants, you can observe any disorders that may occur as a result of nutrients in deficiency or excess that cause specific symptoms with the plants. When the plants are under such stress, yields will fall. Upon recognizing these shortfalls in nutrition, you are shown how to cure them.

SECTION IV: HYDROPONIC SYSTEMS

This is a real fun section as it will show you many hydroponic systems that you can build yourself or purchase. You will learn the substrates or media (other than soil) that can be used in hydroponic growing, sometimes called "soilless" culture. The characteristics of such substrates will help you to determine which form you may wish as your growing medium. Their sources and which plants thrive best with certain media help you to decide on what you should use. We start with small indoor units for your home and progress to larger ones. Do-it-yourself (DIY) designs and construction of these hydroponic units help you to decide where to start. From there I explain how to start your own plants from seed and provide you with the components you need, such as seeds, trays, substrate, and so on, and their sources. How to choose the hydroponic system for the specific crops you wish to grow is important to enhance your success as some plants prefer certain growing systems over others. Low-profile plants like lettuce and herbs are better adapted to some hydroponic systems than vine crops that need more rooting space, doing better in containerized systems. Sources of these components and the types of each you should look for will make your search easier when constructing your system or purchasing one.

SECTION V: YEAR-ROUND GROWING IN GREENHOUSES

This is a very rewarding hobby and an excellent way of getting away quickly from the winter doldrums. You can escape to a summer paradise of plants in your greenhouse during the height of winter. As pointed out earlier, to grow plants to their maximum benefit, you must provide the best possible environment for them. Those factors include temperature, light, relative humidity, irrigation, and so on that can be accomplished within a greenhouse. There are many benefits of a greenhouse to the homeowner from clean, healthy, nutritious vegetables to education for children to a psychological uplift. Presented are designs for different types of greenhouses and sizes to fit your personal taste and budget. Construction for DIY projects and commercially available prefabricated structures with all the components are presented. Sources and approximate costs of structures and environmental components, such as heaters, fans, lights, and so on, are all part of the knowledge of greenhouses. Designs, sizes, types of hydroponic systems, DIY construction, and sources of components and supplies will assist you in growing the crops you wish.

SECTION VI: VEGETABLE CROPS AND THEIR CULTURAL TECHNIQUES

Information is given to guide you on the crops most commonly grown hydroponically and how to select them from the many varieties. From there step-by-step procedures of seeding and transplanting clearly guide you through these processes. You are shown which growing supplies are best for specific cultures of individual crops. After this are detailed descriptions for training your crops, such as suckering tomatoes, peppers, cucumbers, and eggplants, supporting these plants vertically, pollination, lowering and leaning the plants, and other cultural practices specific to each crop. The next chapter tells you when to plant, how long from seed to first harvest, and when to change the crops in terms of cropping cycles to best suit your growing conditions. The management of recognizing and controlling pests and diseases in the following chapter is crucial to your success, whether in soil or soilless growing. Treating each crop for its most common pests and diseases and the specific biological or pesticide controls will keep your plants healthy and productive.

SECTION VII: SPROUTS AND MICROGREENS

The emphasis of this section is on the simplified growing of microgreens and why to grow them instead of sprouts. This is a very safe crop that can be grown on your kitchen countertop. The descriptions of straightforward procedures to grow microgreens, with sources of supplies, nutrients, trays, seeds, lights, and so on, makes this a winner in short-term growing within 5–12 days from seeding. Besides, it is a great science project in hydroponics for school classes.

FINAL ADVICE ON HOW TO GET STARTED

This section presents a simplified summary of events to follow for establishing your hydroponic gardening.

APPENDIX: SOURCES OF SUPPLIES AND INFORMATION

Guidelines are presented as tables for sources of seeds and other supplies in your area. Websites are listed on hydroponics, vegetable culture, pest and disease management, backyard greenhouses, greenhouse components, university extension agents, and so on to easily seek further information. A reference is provided of books, articles, and conferences on growing hydroponically as well as caring for your crops.

Author

Howard M. Resh is a recognized authority worldwide on hydroponics. His website (www.howardresh.com) presents information on hydroponic cultures of various vegetable crops. In addition, he has written five books on hydroponic culture for both commercial and hobby growers.

Upon graduation with his doctorate in horticulture in 1975, he became urban horticulturist for the faculty of plant science at the University of British Columbia. He held that position for three years before the call of commercial hydroponics took him to projects in Venezuela, Taiwan, Saudi Arabia, the United States, and the British West Indies, in 1999, where he is today.

While in the position of urban horticulturist, Resh taught courses in horticulture, hydroponics, plant propagation, and greenhouse design, and production. During this period and later while general manager for a large plant nursery, he continued researching and consulting for a commercial hydroponic farm growing lettuce, watercress, and other vegetables in Venezuela. Resh became project manager for the Venezuelan farm to develop hydroponic cultures of lettuce, watercress, peppers, tomatoes, and European cucumbers using a special medium of rice hulls and coco coir from local sources. He also designed and constructed a Mung bean and alfalfa sprout facility to introduce sprouts into the local market.

In the late 1980s, Resh worked with a company in Florida in the growing of lettuce in a floating raft culture system.

From 1990 to 1999, Resh worked as the technical director and project manager for hydroponic projects in the growing of watercress and herbs in California. He designed and constructed several 3-acre outdoor hydroponic watercress facilities using a unique NFT system. These overcame production losses due to drought conditions in the area.

From there in mid-1999, Resh became the hydroponic greenhouse farm manager for the first hydroponic farm associated with a high-end resort, CuisinArt Golf Resort and Spa in Anguilla, British West Indies, in the Northeastern Caribbean. The hydroponic farm is unique in being the only one in the world owned by a resort growing its own fresh salad crops and herbs exclusively for itself. This farm has become a key component of the resort in attracting guests to experience home-grown vegetables including tomatoes, cucumbers, peppers, eggplants, lettuce, bok choy, and herbs. The resort, together with its hydroponic farm, has gained world-wide recognition as one of the leading hotels of the world.

Resh continues to do consulting on many unique hydroponic greenhouse operations, such as Lufa Farms in Montreal, Canada. There he established the growing techniques and hydroponic systems for a rooftop hydroponic greenhouse in downtown Montreal. All vegetables are marketed through a community-supported agriculture program.

Section I

History and Background of Hydroponics

1 How Hydroponics Started

Its Present and Future Applications

During ancient times, people faced many challenges while gardening. Being the curious animal man is, he wanted to find out what made plants grow. Soil was a mysterious material that somehow provided the right conditions for plants to grow from seed into plants that produced edible parts. Often plagues and pestilence reduced or even destroyed the yields of plants that societies heavily depended on for their well-being. When crops failed, societies suffered famine and death. Such crop failures led to wars between neighboring communities and even the death of entire civilizations and cultures. I heard the phrase "No Agriculture, No Culture," recently on a TV historical documentary. This statement clearly points out the fact that cultures and civilizations are dependent on crops for their survival. If man knew more of the causes of these crop failures, he could try to prevent them. This became the basis of agriculture—to find out the reasons for plants to thrive so that man could cultivate plants under favorable conditions, which would lead to abundant production.

Ancient civilizations became aware that water was essential for any agricultural practices, so populations gathered in areas that had an abundant source of water that could be used for growing plants. Usually, by streams, rivers, lakes, or springs that had fresh water, civilizations developed where they could practice agriculture. Fertile soil existed in valleys of rivers and near lakes. Such soil supported productive crops and human centers. When groups of inhabitants experienced harsh environments that restricted their agricultural crops, they needed to examine what factors reduced yields and what could be done to improve them.

In the early times, man became aware of growing plants in specific environments and tried new methods of cultivation both for ascetics and food. Egyptian hieroglyphic records of several hundred years BC describe growing plants in water. Theophrastus during 372–287 BC experimented with plant nutrition. A form of hydroponics was established with the hanging gardens of Babylon, the floating gardens of the Aztecs of Mexico, and the Chinese. However, these were not called "hydroponic" culture even though they were a form of it.

Further experiments with a scientific approach to discover plant constituents were carried out by numerous scientists during the 17th century and later. They were able to discover that water, soil, and air provided elements such as carbon, hydrogen, and oxygen that were constituents of plant matter. Researchers later continued to demonstrate that the minerals that plants contained came from the soil via the soil water.

This enabled scientists to later grow plants in water alone without soil provided that these minerals were added to the water.

This became "nutriculture," where plant roots were immersed in a water solution containing salts of their essential elements.

From 1925 to 1935, laboratory-scale nutriculture was expanded to commercial-scale production of crops. However, it was not until the 1930s and 1940s that the application of nutriculture was applied on a commercial scale by Dr. W. F. Gericke of the University of California and termed "hydroponics." The word "hydroponics" was derived from two Greek words *hydro* ("water") and *ponos* ("labor")—"water working."

In the 1940s, with the war in the Pacific, Gericke applied hydroponics to commercial production in the nonarable islands where troops were stationed. After the war, hydroponic culture was adopted by the greenhouse industry to resolve problems with soil-borne diseases and pests as well as structural and nutritional challenges faced by year-round growing in greenhouses (Figure 1.1). Now, almost all crops grown in greenhouses, including vegetables and ornamentals, use some form of hydroponics. It may also be termed "soilless culture" when using an inert medium other than soil to which a nutrient solution is added.

Hydroponic greenhouse growing is now worldwide. Some of the largest vegetable greenhouse production regions include Holland, Spain, England, Canada, United States, Mexico, Turkey, China, Australia, and Middle Eastern countries. Holland has more than 25,000 acres of greenhouse production, which includes ornamentals and flowers. Canada has about 2800 acres of greenhouse hydroponic

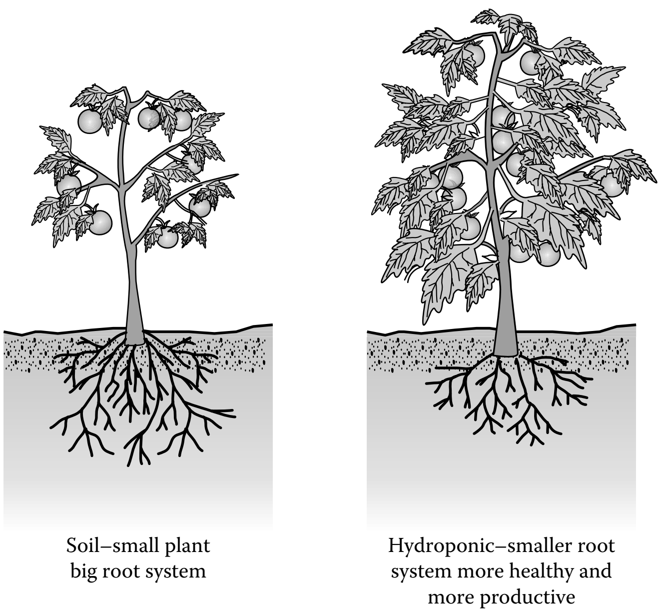


FIGURE 1.1 Comparison of plants growing in soil versus in a soilless system. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

vegetable production and the United States 1500 acres. China is rapidly expanding its greenhouse production with presently approximately 3100 acres. Other areas of expansion include Turkey, Mexico, Morocco, and Australia.

Hobby hydroponic culture started in the 1940s and 1950s with gravel and water culture systems. These were mainly "Do-It-Yourself" projects. In the 1970s, some of the first commercially available hobby hydroponic units entered the marketplace as automated systems to simplify hydroponics for households. The "City Green" hydroponicum was one of the first such units constructed of molded plastic with an upper growing tray and a nutrient reservoir below. The substrate was volcanic cinder rock or expanded clay irrigated by a small perforated plastic tube on the top of the medium. A tube from a fish aquarium pump outside was connected to the irrigation tube in the nutrient tank. The air pump tube was connected to the larger diameter irrigation tube. The space between the walls of the tubes at their connection permitted water to move up by the force of the air entering the irrigation tube as shown in Figure 1.2.

Presently, with the increased interest in home hydroponics, a vast number of designs and types of systems are marketed for all types of crops (Figures 1.3 and 1.4). They are available online and/or in hydroponic outlets in most countries. Specific types of units and their application to most suitable crops is discussed later in Chapters 12, 13, and 15. In the future, with increased awareness of food quality and safety, I am sure the general population will adapt hydroponic growing in their households, especially for herbs and salad crops.

Commercial hydroponics in the future will become associated with tourist resorts and spas as they are emphasizing wellness programs for their guests. Industries with waste heat and geothermal sites will couple with hydroponic greenhouses to produce vegetables more economically by using cheaper sources of energy for heating. Increased efficient light sources, such as light emitting diode (LED) lights, are

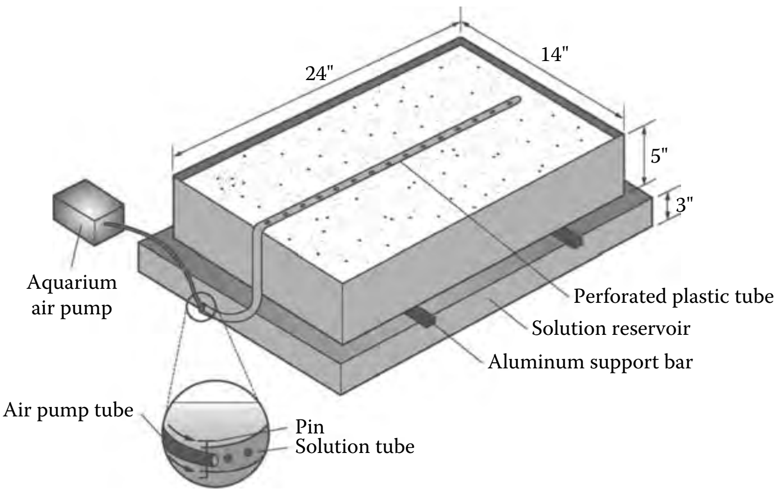


FIGURE 1.2 Components of an indoor unit. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

FIGURE 1.3 "Aerogarden" kitchen unit. (Courtesy of AeroGrow, Boulder, Colorado.)

FIGURE 1.4 Kitchen countertop garden ebb-and-flow unit. (Courtesy of American Hydroponics, Arcata, California.)

rapidly entering the greenhouse industry in northerly latitudes where light is limited during winter months. This trend will continue with new sources of lighting.

Hydroponic greenhouse operations are now being established on roof tops of buildings in the centers of cosmopolitan cities (Figure 1.5). Such operations now exist in Montreal, New York, and are presently expanding to Vancouver and New Jersey. Another approach is to locate greenhouses in parking lots adjacent to supermarkets.

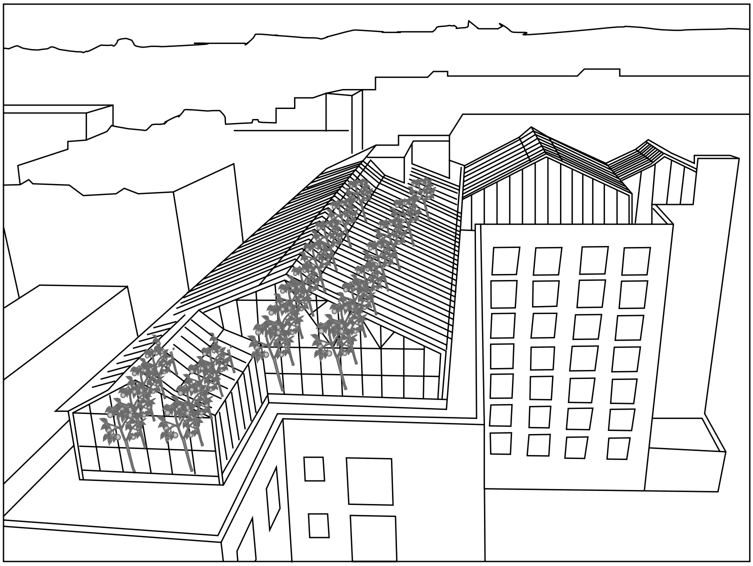


FIGURE 1.5 Greenhouse hydroponic farm on a rooftop in the city. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

These applications of hydroponics provide clients with fresh produce, free of toxic pesticides, and fully vine-ripened fruits such as tomatoes, peppers, and eggplants. The other factor is the saving of fossil fuels in long transportation for distant markets. The product is grown onsite at the retail outlet or with community-supported agriculture marketing where fresh vegetables are taken to nearby drop-off points for "subscribed" consumers to pick up. The concept is to have households sign up as a member and then pay a monthly fee for their vegetables that are in returnable baskets that are either picked up at the drop-off site or can be acquired at the greenhouse operation itself on specific days.

Going one step further into the future, I expect that high-rise vertical buildings will be constructed in city centers to grow vegetables. They could also be part of a condominium complex where some floors or a wing of the building would be modified to grow plants with highly efficient hydroponic systems, such as rotating, vertical structures. This technology of rotating, vertical hydroponic systems already exists. However, the success of these high-rise greenhouses is dependent on a very efficient source of supplementary lighting, so I believe that it could happen within a decade or so. Solar cells on the rooftop of the building or in a nearby parking space could provide the electrical needs for the lights.

Hydroponics opens up potential for growing crops under all environmental conditions including in your home and/or backyard. It is the wave of future growing for you, so be part of it!

2 The Popularity and Benefits of Hydroponic Gardening

The versatility of hydroponics makes it popular throughout the world from simple household, backyard applications through commercial greenhouses to isolated locations in the Antarctic and under zero gravity on the space station (Figure 2.1). Someday, as we probe space exploration and set foot on other planets, we will cultivate food crops under special greenhouse structures with hydroponic culture. This is already exemplified in scientific papers and even in science-fiction movies. In the future of space exploration, it will become a reality.

At the other end of the spectrum, hydroponics is a feasible culture for low-income societies. Very simplified hydroponic systems using waste materials and basic supplies of nutrients are now known as "popular hydroponics" in Latin America (Figure 2.2). In desert regions of Peru, people living under harsh conditions of existence have turned to satisfying some of their nutritional needs through hydroponic culture. Often, for example, this is a result of some assistance by local universities, such as Universidad de La Molina in Lima, Peru, and the Food and Agriculture Organization of the United Nations. These institutions provide classes and subsidized supplies for low-income rural people to initiate and carry out hydroponic culture of their basic vegetables for a more healthy diet. Often these societies come together to produce larger facilities on roof tops of schools and community centers and operate as a cooperative in exchanging produce (Figure 2.3). It also becomes an educational facility for school students. I have personally visited numerous sites of this nature in Peru and seen how people who started just to supplement their diets have expanded to become commercial operations and now make a living by growing vegetables for markets in the large cities such as Lima. This same process has happened in other countries as Colombia, Venezuela, Bolivia, Uruguay, and Brazil.

Hydroponics has become popular in all societies as people learn of the many benefits to grow crops free of weeds (Figure 2.4), in control of pests and diseases, and obtain high yields of highly nutritious and safe vegetable crops. I am not trying to mislead you by suggesting that hydroponics is the answer to future food shortages. The point is that you can grow some of the most nutritional vegetables hydroponically such as tomatoes, peppers, lettuce, herbs, and so on that provide healthy products with the least environmental footprint. That is a win–win situation for you and the environment. Do not be left out, this is the way of the future!

The benefits of hydroponics over soil culture are great. Increased demand for food production has to focus on more efficient methods of water usage,

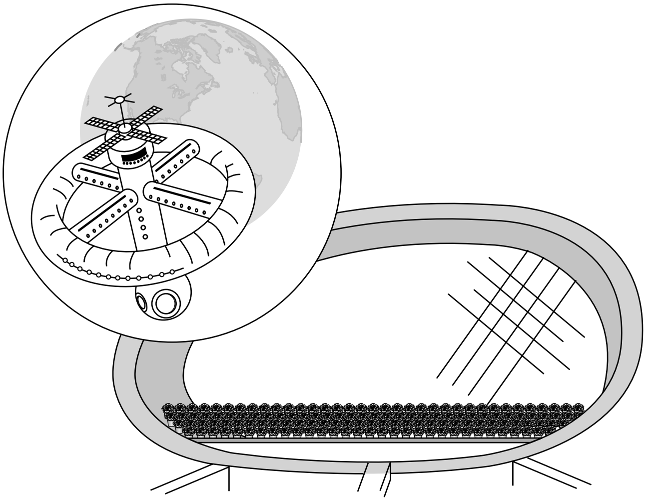


FIGURE 2.1 A hydroponic garden on a space station. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

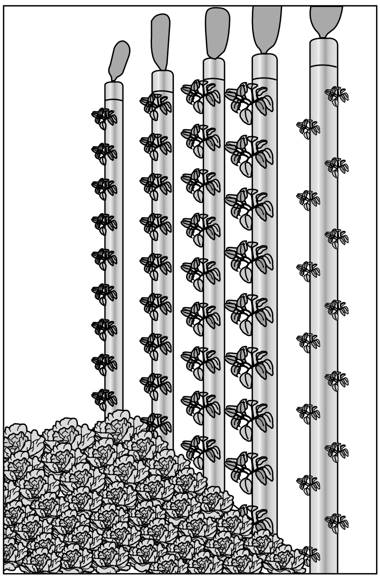


FIGURE 2.2 Simple (popular hydroponic) gardens for poor community backyards. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

less dependency on toxic pesticides, higher yields, and superior quality of products in both flavor and nutrition. These factors contribute to less demand on our environment making hydroponic culture very “green.” In hydroponic greenhouse operations, the emphasis is on “sustainable” agriculture with a minimum environmental foot print.

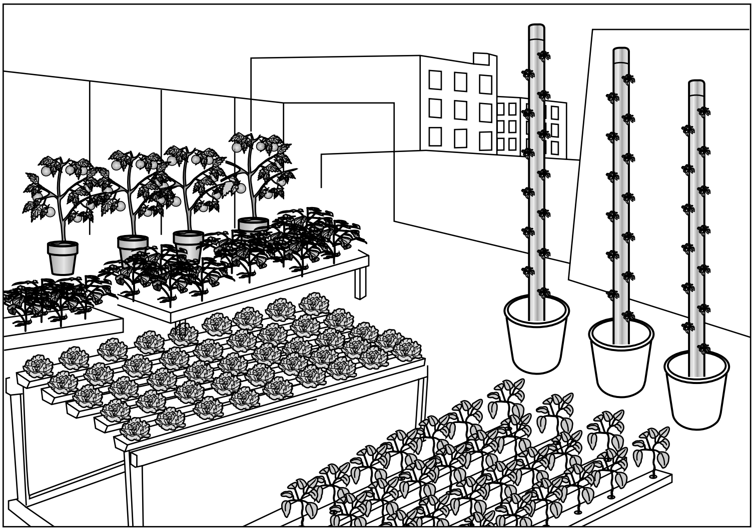


FIGURE 2.3 Simple hydroponic rooftop gardens. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

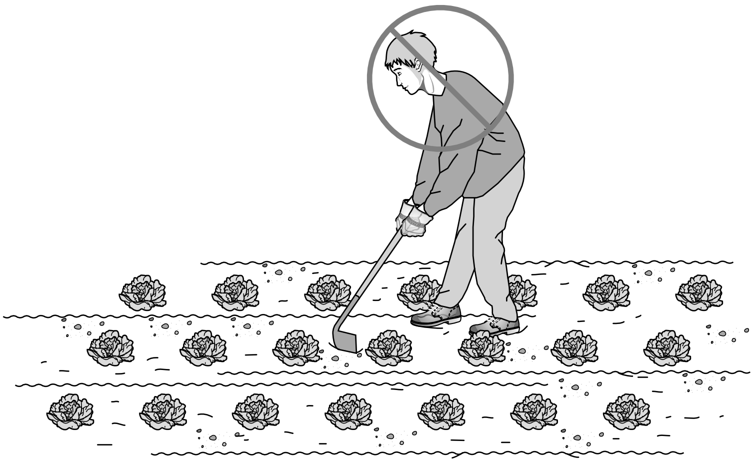


FIGURE 2.4 Avoid bending over to hoe and weed in a normal soil garden. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

Some of the obvious advantages of hydroponics over soil culture include the following:

1. Ease and efficiency of sterilization of the medium between crop turnarounds.
2. Nutrition of plants is homogenous, controlled, and stable. Specific formulations developed for specific crops will maximize yields.
3. Plants can be spaced closer together, not limited by water or nutrient availability, only by available light. This results in higher yields per unit area the plant occupies.

4. No weeds, no cultivation.
5. Efficient use of water with automation of irrigation cycles. Water is managed to suit the specific stage of plant growth and crop.
6. Quality of fruit is firmer with longer shelf-life that leads to less shrinkage on supermarket shelves.
7. The use of fertilizers is efficient in that the nutrients are directed to plant roots uniformly and are readily available. No loss of nutrients occurs beyond the root zone.
8. The products are sanitary with no biological disease organisms present.
9. Transplant "shock" is minimized by use of growing cubes to retain roots in the cubes ready to grow out immediately after transplanting to the growing system.
10. Plants mature sooner with hydroponics as they are not under nutritional or water stresses.
11. Yields are at least 20% greater over soil culture unless you are a well-experienced soil grower, then such yields may be equal to those of hydroponics. However, under the extended growing season in a greenhouse, annual yields may exceed two or three times that of outdoor soil growing.
12. Constructing growing beds at waist height or the use of vertical plant towers will relieve you of back pains.
13. It is a very clean method of gardening, no messy hands from soil and its constituents.
14. There is no need to worry over the invasion of your indoor hydroponic garden by many of the troublesome animals outside looking for a meal, such as rabbits, deer, gophers, raccoons, woodchucks, moles, mice, and small rodents. If any small rodents get into your home and indoor garden, you can easily trap them. But, their entrance into your home should seldom, if at all, occur.
15. Most essential gardening tools for your outdoor vegetable garden are eliminated. No need for hand trowels, cultivators, hoes, shovels, garden forks, rakes, wagons, garden carts, power tillers, and so on.

With all of these benefits why not garden hydroponically? These benefits far outweigh the more precise procedures to follow for hydroponic growing. Besides, many small household units are designed to minimize your making mistakes. Nutrients are prepared, so you just add them to the water in amounts clearly set out in the directions. If you wish more challenges, you can derive your own nutrients from basic fertilizer salts. It is a very satisfying hobby that will uplift your spirit by producing healthy vegetables of superior flavor and nutrition.

3 Why You Should Garden Hydroponically

Caring for your plants in hydroponic gardening is similar in terms of their training, pollination, pest and disease control, and so on; however, it takes away the less-desirable tasks of weeding, cultivation of the soil, hand watering, and fertilizer applications, which is less back strain. Weeding is eliminated as is cultivation of the medium. Watering and fertilizer application is automated with flood systems or drip irrigation. There will be much less use of pesticides as most pests and diseases can be eliminated from the medium, whereas in soil they are always present attacking the plant roots (Figure 3.1). You will feel much better in seeing your plants healthy and productive. When pests attack the roots of plants, it is often very difficult to identify the causes of your plants suffering from wilting, yellowing, and often dying. Once you determine these causes of poor plant growth, the next thing is to treat the soil with some type of pesticide. This often involves using fairly strong synthetic pesticides that are not organic based. This creates apprehension coupled with caution in applying them safely. The outcome is that your plants are no longer free of synthetic pesticides ("organic"). Even then, due to the complexities of soil composition, the treatment may not control all of the pests and will have to be applied numerous times to maintain the pest populations at tolerable levels to minimize restrictions in plant growth.

Hydroponic gardening will produce more healthy plants in both safety and nutrition. Many soil-borne pests can be avoided in hydroponics. If an infestation should be introduced, control is more effective and usually done by organically derived pesticides known as "bioagents." Apply these natural pesticides to the growing medium through the nutrient solution with the drip irrigation system of hydroponic culture. The bioagents are much safer to handle than strong synthetic pesticides. These bioagents are the same ones recommended for certified "organic" growing. There is less need for using pesticides with hydroponic culture compared with soil gardening due to the use of relatively sterile substrates free of pests. Of course, the control of pests and diseases of the foliar part of the plants will be very similar to those growing in soil. However, with optimum nutrition, the plants will have thicker cuticles and stronger cell walls to help them resist infestation.

Optimum nutrition of hydroponically grown plants enables them to yield fruit (vegetables) higher in vitamins and minerals than those of their counterparts grown in soil. Soil is heterogeneous in structure, composition, and mineral content. Some plants may grow well in one area and within a short distance others may suffer from deficiencies. In hydroponics, the plants grow in a substrate homogeneous in water and minerals with pH levels maintained optimum for mineral uptake by the plants. In soil, it is more difficult to regulate pH at ideal levels to make elements available to plant-root uptake. This equal availability of essential elements to hydroponically grown crops gives superior quality and yields. That will give you greater satisfaction in your labors of gardening plus more production that you may share with others in your neighborhood (Figure 3.2). I think one of the most disappointing aspects of gardening is when you do everything you can possibly think of that should make your plants grow well and for some mysterious reason(s) they do not give you the results you are expecting. Avoid this by growing hydroponically. Initially, you may think that hydroponics is too technical, but, that is not the case. It is really important to understand how the plants grow and what their needs are as well as what kinds of problems can stress them to reduce their productivity. This applies to all gardening, not just hydroponics. Hydroponics is a science and by following the procedures you

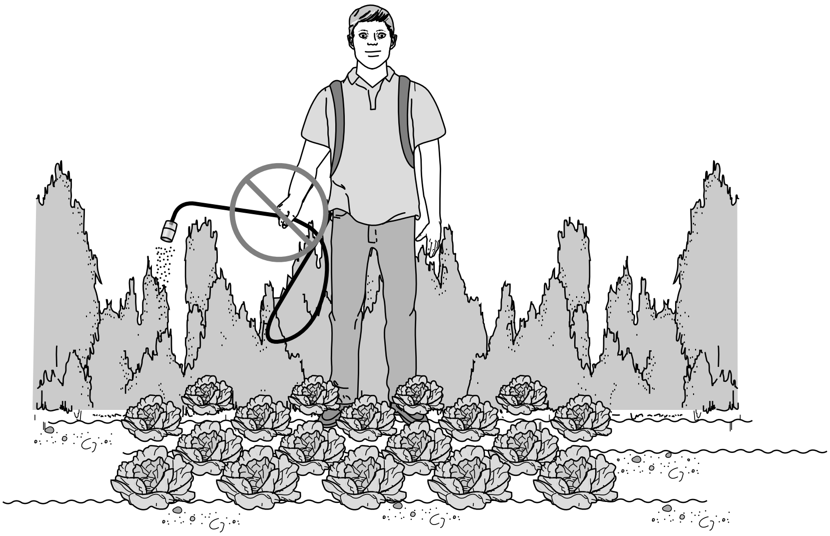


FIGURE 3.1 Avoid spraying strong pesticides in a soil garden. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

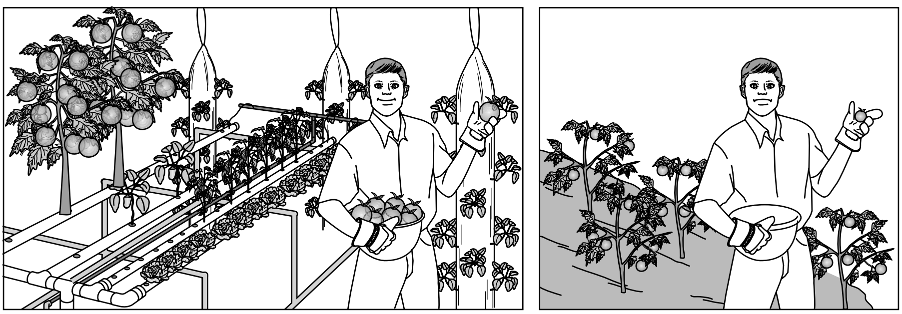


FIGURE 3.2 Productive hydroponic growing versus less-productive soil growing. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

can be successful making your labors of growing very rewarding. With the presence of many hydroponic shops and online stores you may purchase readymade hydroponic units and all supplies such as nutrients, bioagents, and others for successful growing. In addition, there is lots of help by store operators and through the Internet on seeking solutions to any challenges that occur. With all of these considerations why not garden hydroponically?

Section II

Understanding Hydroponics and How Plants Grow

4 Why Hydroponics Is Not Just Chemistry

Many people are of the opinion that hydroponics is all chemistry and that the plants grown by this technique are "inorganic" (Figure 4.1), which is not true. Some basic high-school level chemistry will help one understand how to prepare nutrient formulations, but even without such a background one can easily learn the procedures. Preparing nutrient solutions can also be done by purchasing ready-made nutrient mixtures. As far as the plants are concerned, they require the same essential elements regardless of whether they are obtained from hydroponic sources or by natural breakdown in the soil. The advantage of hydroponics is that one can provide the plants with optimum levels of each of the essential elements through the nutrient solution formulation (Figure 4.2). When growing in soil these same nutrients are added by the application of fertilizers and compost. However, because of the heterogeneity of the soil, it is more difficult to apply the nutrients at levels that are optimum for plant growth (Figure 4.3).

The nature and properties of the soil determine the availability of nutrients to plants. Different types of soils, such as, sand, sandy loam, loam and clay, are determined by their percentages of natural inorganic particle sizes and organic matter. Sandy soil composed of large mineral particles permits water and nutrients to move quickly through it and past the root zone of plants. These are not ideal for vegetable growing unless large amounts of water and fertilizers are supplied regularly. Pure igneous (volcanic) sand in fact is suitable as a hydroponic medium, where oxygenation to plant roots is readily available. At the other extreme is clayey soil that consists mainly of small particles that hold together tightly retaining water and minerals. This type of soil often has excess water with poor drainage causing lack of oxygen to plant roots. With this poor aeration, plants also suffer from lack of mineral uptake. A loamy soil has a good mixture of large and small minerals plus organic matter (humus), which provides adequate minerals, water, and oxygen to the plants. Maintaining soils in this optimum state of structure and fertility is often challenging, requiring soil tests and frequent additions of fertilizers and compost of adequate quantities for plant growth.

With hydroponics, the choice of substrate depends on the availability, cost, crop, water retention, oxygenation, structural integrity, and sterility. For most backyard gardeners, the availability and cost of the substrate are not restrictive because they use relatively small amounts. Some crops grow better in more porous substrates, whereas others grow well where there is higher water retention. However, oxygenation is important to all plants, so drainage is critical, especially for long-term crops such as tomatoes, peppers, eggplants, cucumbers, and other vine crops. Some short-term crops, such as herbs (basil, mint, and watercress) and lettuce can grow in water

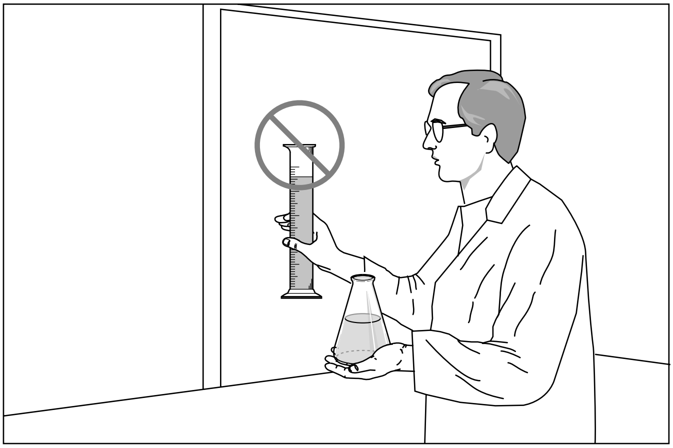


FIGURE 4.1 Hydroponics is not specialized laboratory chemistry. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

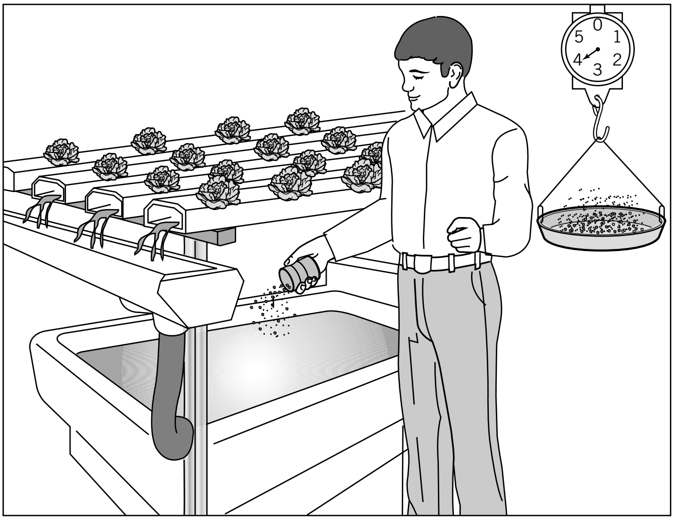


FIGURE 4.2 Use of scales for weighing and adding nutrients to a nutrient tank. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

culture systems. Structural integrity, the ability of the substrate to retain its structure and not break down during the growth of the plants, is basic to hydroponic growing. This quality and sterility are of prime importance in the selection of a medium. If the substrate is not free of pest and disease organisms, they will attack the plant roots causing decreased plant vigor and yields. You will then be in a similar situation as what often occurs with soil growing. All of the variable properties of soils that can restrict plant growth through lack of oxygen and mineral availability, and/or occurrence of structural breakdown, and the presence of pests and diseases are difficult to

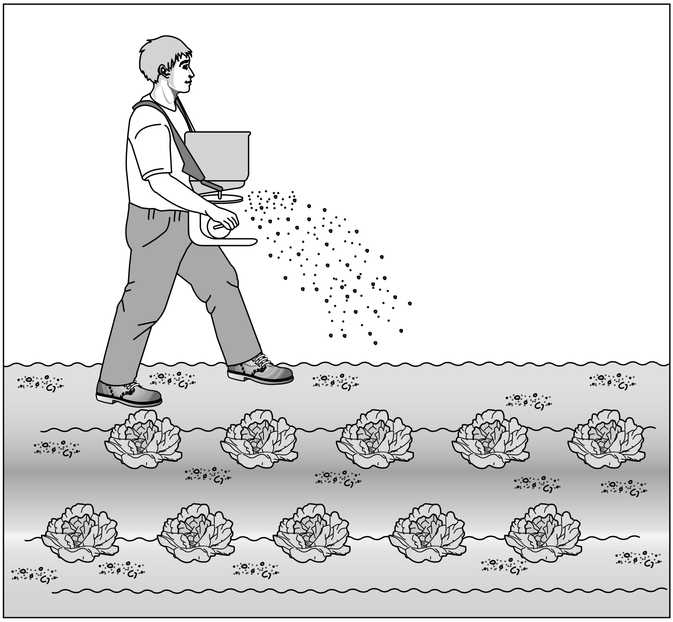


FIGURE 4.3 A gardener spreading fertilizers on the soil in his garden. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

control. With hydroponics, you choose the best substrate that provides optimum levels of oxygen, minerals, and water. In addition, most of the pest and disease factors in a soilless substrate are avoided.

Overall, hydroponics and soil growing are not different with regard to the needs of the plants. The chemistry behind hydroponics is not different from soil growing with regard to providing ideal levels of nutrients to the plants. Only the procedures and some sources of nutrients differ. With soil we like to use slow-release compounds that will not rapidly pass beyond the roots of the plants, whereas in hydroponics we want highly soluble compounds that will dissolve completely in water because the nutrient solution is applied directly to the plant roots. The chemistry is the same for the plants as they must actively take up the same nutrients and water from the soil solution of the soil, or from the nutrient solution in hydroponic culture.

The principal difference between soil and hydroponic cultivation is this precise management of the availability of the essential elements to the plant roots under hydroponics. The other techniques in the care of the above-the-ground portion of the plants are similar in both hydroponic and soil cultures. All aspects of plant training, pest and disease control, even watering by a drip irrigation system also apply to soil culture. One step further is to extend your growing season by the control of environmental factors such as temperature, light, carbon dioxide, and relative humidity through greenhouse growing. You may grow either soil or soilless in the greenhouse, but normally it is advantageous to use hydroponics under controlled environments to maximize the health and yields of your plants.

5 Plant Growth
The Environment and Its Effects on Plants

Plants are composed of 80%–95% water. Plant dry matter is 10%–20% of the fresh weight. Over 90% of the dry matter of plants is composed of carbon (C), hydrogen (H), and oxygen (O). We are all familiar with the term photosynthesis. This is the process whereby light supplies energy, water from the growing medium provides hydrogen and oxygen, and carbon dioxide (CO_2) from air produces carbon and oxygen that become the building blocks (sugars) for plant growth (Figure 5.1). All of the other elements needed in photosynthesis, making up 1.5% of the fresh weight, are from the soil or nutrient solution. These are the essential elements that we discuss in Section III of this book.

Photosynthesis may be expressed as an equation as follows:

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \xrightarrow{\text{Light}} \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

The sugar is a form of chemical energy that is used to drive all the plant's processes. Plants are the basis of almost all life on our planet and photosynthesis the source of energy for nearly all life on Earth. Photosynthesis uses light visible to our eyes (Figure 5.2). The light is absorbed by chlorophyll, the green pigment, in all plant parts, especially in the leaves where most organelles called chloroplasts are located. The chloroplasts contain chlorophyll-*a*, chlorophyll-*b*, and carotenoid pigments. Most absorption of light is in the violet–blue and red light of the visible spectrum as shown by the absorption spectrum of these pigments (Figure 5.3). When we use supplementary lights for our plants indoors, we want light that gives off most energy in this part of the visible light. There are many complex processes that take place within the plant to convert the sugar into carbohydrate products by carbon fixation whereby carbon is taken from sugars and combined to form sucrose and starch. The carbon from photosynthesis is used to form other organic compounds such as cellulose, lipids, and amino acids or others to fuel respiration.

In respiration, metabolic reactions take place in the cells of plants (and animals) to convert biochemical energy from nutrients into high-energy molecules that can later break down into smaller molecules releasing energy in the process. Respiration provides the energy to fuel cellular activity. The nutrients used by animal and plant

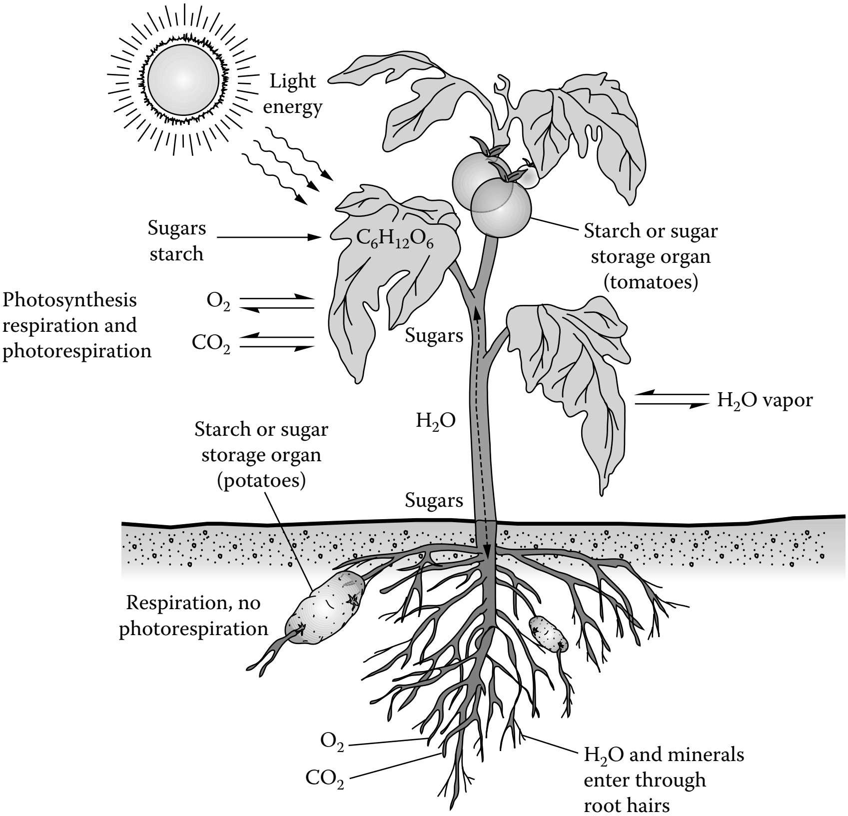


FIGURE 5.1 Photosynthesis process in plants with movement of water and manufactured sugars, and so on flowing to the roots and fruits. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

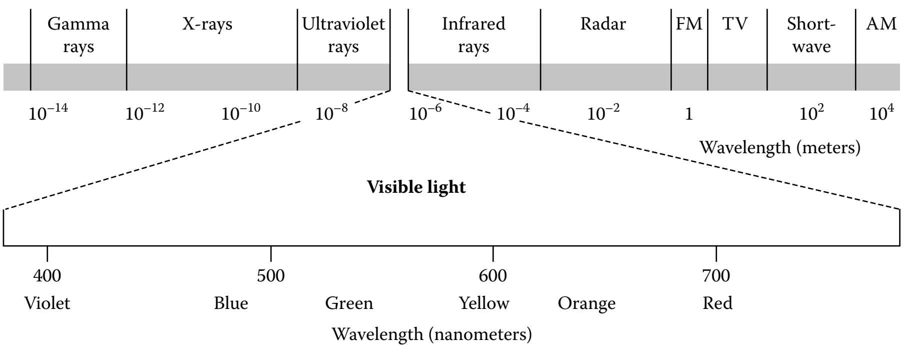


FIGURE 5.2 Visible light spectrum. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

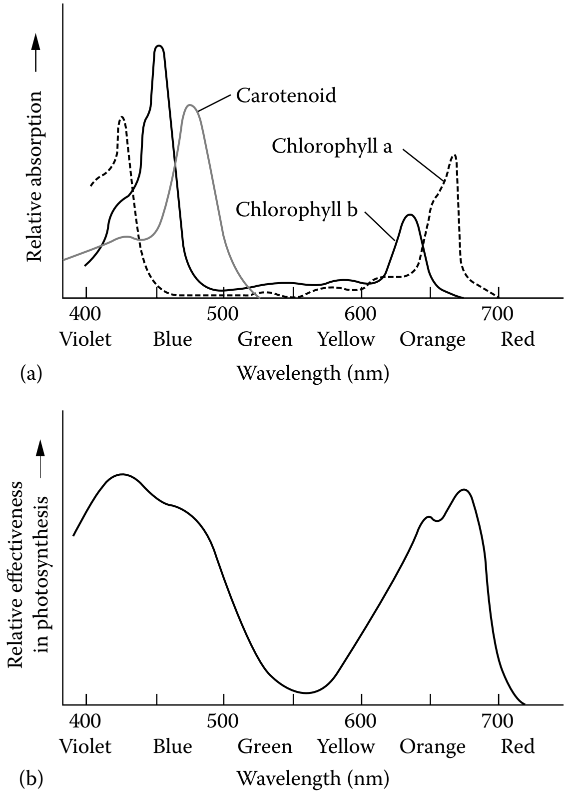


FIGURE 5.3 Visible light absorption spectra for chlorophyll and carotenoid plant pigments (a) and photosynthetically active radiation (PAR) (b). (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

cells in respiration include sugar, amino acids, and fatty acids. The energy is stored in the high-energy molecule adenosine triphosphate (ATP) and during oxidation (use of molecular oxygen), the energy stored in ATP is released to drive energy processes such as biosynthesis, locomotion (movement in animals), or transportation of molecules across cell membranes.

A simplified reaction for respiration is as follows:

$$\underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2} \rightarrow \underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} + \text{Heat}$$

Because respiration requires oxygen in plants, it is termed as aerobic respiration. It is the main process by which both fungi and plants break down organic compounds into energy needed for their growth. These organic compounds are produced during photosynthesis. In plants, respiration occurs during the dark. Consequently, at night the plants use oxygen and give off CO_2 and water.

It is important to understand these simplified basics of plant growth in order to know the key factors of the environment that plants require for healthy development. When these factors are not at optimum levels, they will limit plant growth and therefore can be termed limiting factors. During the day, plants need the correct quality and intensity of light to drive photosynthesis. The quality refers to the color of light (determined by its wavelength). Plants require light between 400 and 700 nm wavelength, which is in the visible spectrum as shown in Figure 5.2. A nanometer is 10^{-9} or 1/1,000,000,000 m (one billionth of a meter) in length. This light source that plants utilize is termed photosynthetically active radiation (PAR). This designates the solar radiation from 400 to 700 nm that plants actively utilize in photosynthesis (Figure 5.3).

Increasing light energy in the PAR range increases photosynthesis. Each crop has an optimum light intensity that maximizes plant growth. If there is insufficient light, plant growth slows down and if excess light is given, plant growth will not increase (Figure 5.4). As a result, when using lights you must be sure to give sufficient, but not excess as the cost of the additional light will not result in increased production. The quantity of light is the intensity that can be measured. In the United States, the unit for measuring light intensity is the foot-candle, whereas lux is used in Europe. An argument against the use of foot-candles is that it primarily measures visible light detected by the human eye and not necessarily the amount of light a plant receives. Most horticulturists use a unit that measures light at any instant in micromoles (μmol) per square meter (m^{-2}) per second (s^{-1}) of PAR. This unit measures the number of photons (individual particles of energy) used in photosynthesis that fall on a square meter of surface every second. Because this is an instant reading, the better unit to use is the daily light integral (DLI), which is the amount of PAR received each day (moles per day). In greenhouses, the values are normally less than 25 mol/m/day. To grow plants in your home using artificial lights you need to get sufficient light for optimum yield. Researchers have

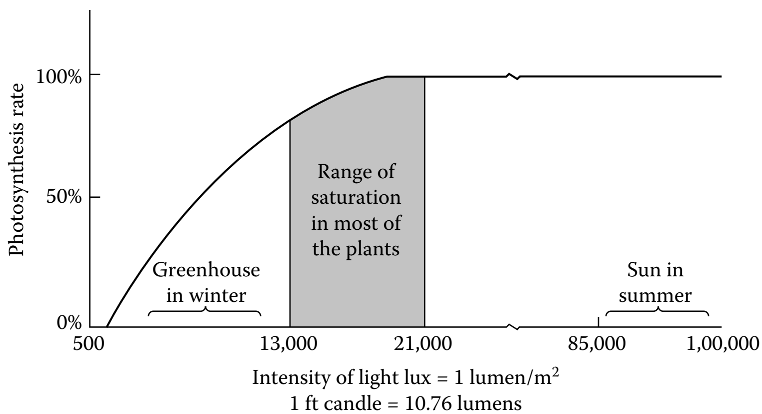


FIGURE 5.4 Graph of photosynthesis activity versus light energy (intensity). (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

developed DLI levels for groups of plants classifying them as low-light, medium-light, high-light, and very-high-light crops. Fruit-bearing crops such as tomatoes, peppers, and European cucumbers would lie in the very-high-light crops. Although this is a little more technical, it shows you what amount and type of light is best for your crops.

Another environmental factor that affects plant growth and yields is temperature (Figure 5.5). Again all crops have different optimum temperature ranges. Crops are divided into cool-season crops and warm-season crops. Cool-season crops include cabbage, cauliflower, broccoli, and lettuce, whereas warm-season crops include fruiting crops such as tomatoes, peppers, cucumbers, and eggplants. Normally, cool-season crops require night temperatures in the 50s F (10–15°C) and 60s F (16–21°C) to low 70s (22–23°C) during the day, whereas warm-season crops like 65°F (18°C) or higher at night and 75–80°F (24–27°C) during the day. When you browse through seed catalogs searching for varieties of crops to grow, information will be available on their optimum temperatures. If not, simply look up on the Internet search engines for crops and their ideal temperatures. Of course, temperature can only be regulated in greenhouse or indoor gardening, not outside in prevailing weather conditions. This, however, is significant with hydroponic growing as in most cases hydroponic culture is most applicable to greenhouse or indoor growing.

Under very-high temperatures and especially with low relative humidity (RH) (percentage of moisture in the air) plants will slowdown in growth due to their inability to keep their tissues at optimum temperatures. This causes the closing of stomata (small pores particularly numerous on the lower sides of leaves) to partially or fully close. The closing of the stomata blocks the entrance of CO_2 into the leaves and restricts water loss that in effect reduces cooling of the plants through evapotranspiration (loss of water by evaporation and transpiration). It will then reduce water and resultant nutrient uptake slowing growth further. As was pointed out earlier, plants receive CO_2 from the air as part of the photosynthesis process. Any environmental factors that are not at optimum levels for the specific crops, will restrict photosynthesis and subsequent plant growth and development (Figure 5.6). When these environmental factors are restricting or limiting growth, they are termed "limiting factors."

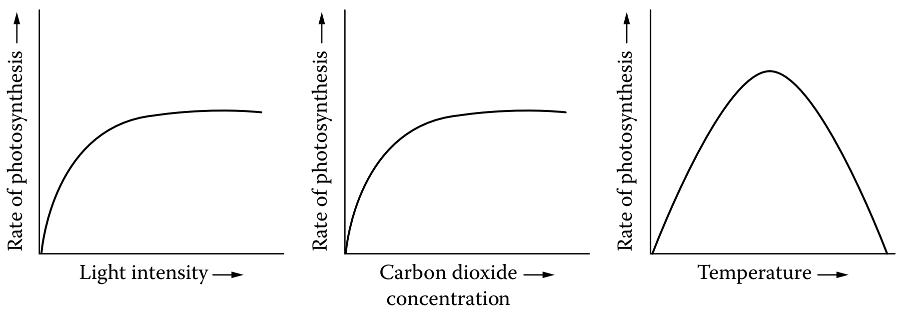


FIGURE 5.5 Graph of photosynthesis activity versus light intensity, carbon dioxide, and temperature. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

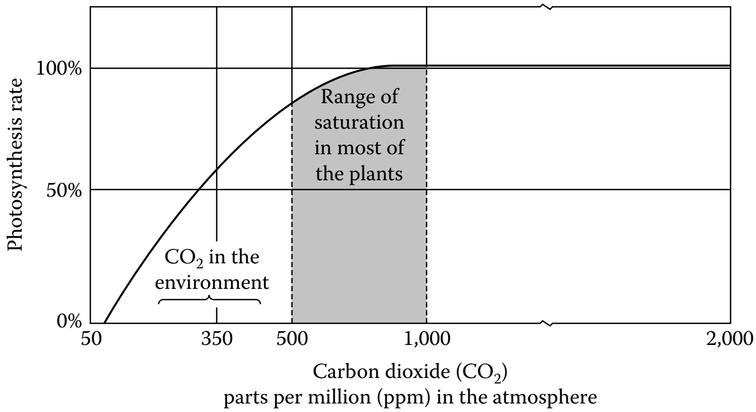


FIGURE 5.6 Graph of photosynthesis activity versus carbon dioxide. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

With hydroponic gardening in greenhouses and indoors, you must be aware of the optimum levels of light, temperature, CO_2, and RH for your crops, monitor and regulate them at levels best for crop growth to maximize yields. This is discussed in more detail in Section V under greenhouse and indoor growing.

6 Water Needs, Management, and Irrigation Practices

Water is essential for all life forms, including plants. Plants use more water than animals. Plants are 90% water, whereas animals may be 75% by weight. As mentioned in the previous chapter, water is part of the photosynthesis process and is present in cells. From the very beginning of seed germination, water is essential. Water is the medium by which plants take up minerals from the soil solution or the nutrient solution in the case of hydroponics. Plant roots actively absorb the nutrients from the water and transport all chemicals in and out of cells by water. The water is absorbed into the plant near the tips of the root by specialized root hair cells (Figure 6.1). From the root hairs the water must enter the vascular tissue (xylem) that transports the water throughout the plant (Figure 6.2). This is done through a selectively permeable membrane, a single layer of cells called the endodermis. This movement of water into the endodermis is the water going from a region where it is at a higher concentration to one where its concentration is lower (in the cell). This process is termed "osmosis."

Water moves upward in plants through the xylem cells, which are long, narrow, tubes containing no living matter (Figure 6.2). They are joined end-to-end to create long tubular pathways from the roots through the stem to the leaves. The water moves up not by just capillary force, but by the cohesion force of water molecules. Water is lost from leaves by evaporation through the leaf stomata (Figure 6.3). This is transpiration, also termed evapotranspiration, whereby the water moves out of the leaves and is the driving force to pull the water through the plant in its xylem vessels. In most plants, more than 95% of the water taken in by the roots is lost through evapotranspiration in the leaves. This has a cooling effect on the plant tissues. Higher temperatures and increased wind speeds increase the transpiration rate. As the transpiration increases, the uptake of water by the plant roots must increase to keep the plant turgid. If water uptake is less than water loss, the deficit in the plant will cause the stomata to close and the plant will lose turgidity causing wilting of leaves and then stems. This kind of stress will slow growth and production as when the stomata close, carbon dioxide cannot enter either, so the whole process of photosynthesis slows down or stops if water is not made available to the plant. This occurs in soil when it dries out to a level that the plants cannot take up sufficient water. It can also happen in hydroponic culture if there are large intervals between irrigation cycles and the substrate has insufficient water available to the plant.

In many fruiting crops, such as tomatoes and peppers, a water deficit in the plant will result in blossom-end rot of the fruit. This is caused by insufficient water uptake

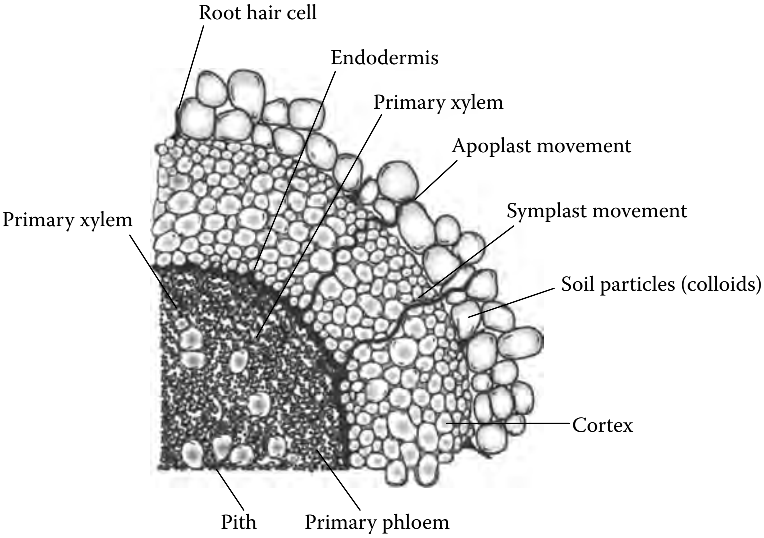


FIGURE 6.1 A cross-section of a root with movement of water and minerals. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

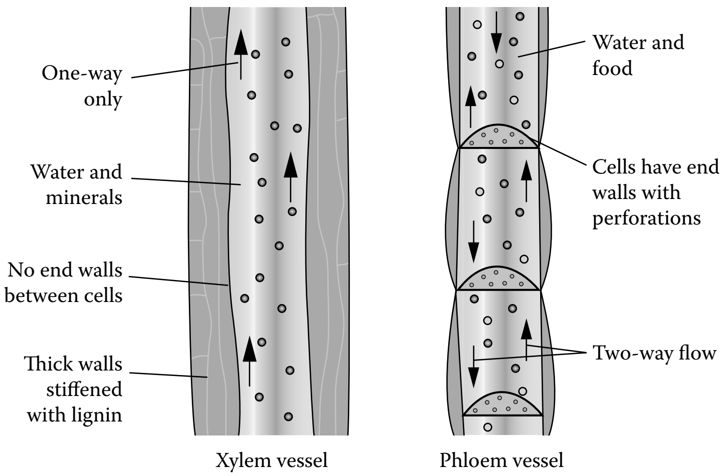


FIGURE 6.2 Xylem and phloem conducting vessels. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

and resultant loss of calcium uptake. The symptom is a dry, leathery-like, black tissue at the blossom end of the fruit. High humidity reduces transpiration rates, low humidity accelerates transpiration. An example of the effect of relative humidity on production is given by lettuce. Under high relative humidity, the plant does not release adequate water, so this slowdown of water movement from the root to the leaves causes a lack in calcium uptake resulting in "tip burn" (blackening of leaf margins) of lettuce. If you understand these functions of water within the plant and

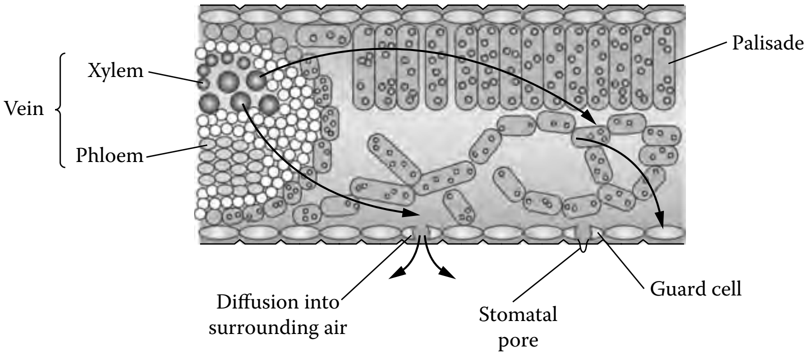


FIGURE 6.3 Plant upward movement of water and minerals in the xylem with water leaving the leaf through the stomata during the evapotranspiration process. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

how its lack can cause stress in the plant leading to symptoms and reductions in yields, you will know what signs to watch for and know when you must add water or reduce it through the irrigation cycles.

The nutrient transport system is the function of the phloem tissue (Figure 6.2). It, like the xylem, requires water as a medium to transport the photosynthetic products (photosynthates) throughout the plant from its source to the areas of utilization (sinks) (Figure 6.4). The sinks include all areas of the plant—roots, stems, and fruit—to where these food substances are transported. If you permit fruit such as tomatoes or peppers to ripen completely on the plant, you will get better flavor and higher nutrition in the fruit harvested "vine ripened" than picking the fruit before it is fully ripened. This is the outcome of allowing the fruit ("sink") to accumulate more of the food substances as it matures.

Water management is controlling the amount of water supplied to the soil or hydroponic substrate to get optimum growth by avoiding any stresses to the plant. With hydroponics you will generally use an automated system. Irrigation controllers enable the gardener to set irrigation cycle frequency according to the plant stage of growth and weather conditions. You will irrigate more frequently and with longer duration of any cycle determined by light, temperature, relative humidity, and day length. The nature of the growing substrate influences the irrigation practices. More coarse particles will require more frequent irrigation cycles than finer particles. For example, perlite substrate may need five to six cycles per day, whereas coco coir or a peatlite medium that has higher water retention, two to three daily cycles would be adequate. The principle is to keep the levels of nutrients sufficient to be readily available to the plant roots at all times. However, excessive cycles can cause lack of oxygen due to too much free water in the void spaces of the substrate. Oxygen is critical to the plant roots to allow active transport of elements into the plant.

When irrigating plants to keep the nutrient solution from concentrating in the medium by evaporation, it is also important to have a percentage of leachate to occur during irrigation cycles. This will be a function of the length of time the irrigation is activated during any cycle. The percentage of leachate varies with the substrate.

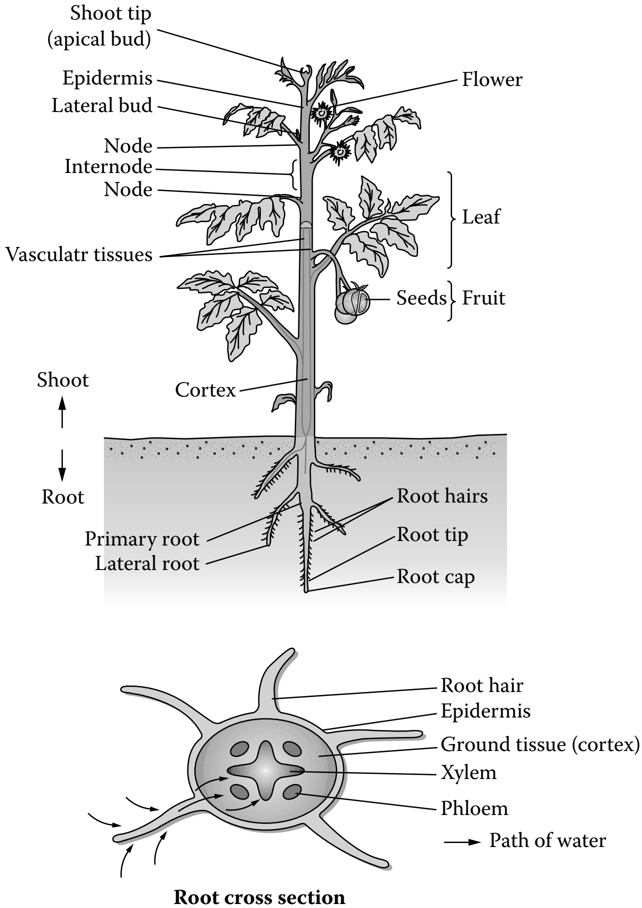


FIGURE 6.4 Movement of water and nutrients in the xylem and manufactured photosynthates in the leaves flowing through the plant stem, and so on. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

In general, with rockwool and perlite cultures we want approximately 25% leachate, whereas with coco coir and a peatlite medium it should be approximately 10%–15%. When growing in soil, gardeners can use a tensiometer that tests the moisture level in the soil. With hydroponics, moisture sensors may be placed in the medium that sense the moisture level and will activate an irrigation cycle automatically based on a preset limit. This kind of feedback system provides the crop with more uniform irrigation than a simple time-clock type of controller.

In summary, recognizing the factors that determine the water usage by plants assist you in managing the irrigation practices to keep plants most productive. Water quality, mineral content, and plant consumption under variations of weather and plant growth, plant appearance, and symptoms all assist in recognizing any imbalances with irrigation of the plants.

Section III

Nutrients Essential to Plants and Their Sources

7 Essential Nutrients to Plants and Their Functions

Minerals that are required for plant growth and development are termed "essential." These include carbon (C), hydrogen (H), and oxygen (O) as we described earlier are part of the photosynthesis process. These come from the air and water. The remaining essential elements come from the soil or nutrient solution in the case of hydroponic culture. These include nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg), which are required in relatively large amounts and therefore termed macro- or major elements. The others needed in very small amounts are termed micro-, minor, or trace elements. These include iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl). Nickel (Ni) is now believed to also be an essential element. Other elements accumulate in some plants and may be used in their growth. These are silicone (Si), aluminum (Al), cobalt (Co), vanadium (V), selenium (Se), and platinum (Pt). However, when we speak of the elements that we must provide for our plants, whether in soil or hydroponics, they are the six macro- and seven microelements (eight if we include nickel) listed above.

Each of these essential elements has specific functions within the plant. It is helpful if we understand what these functions are to assist us in recognizing nutritional disorders that may occur in the plants.

Nitrogen—Part of organic compounds, including proteins, nucleic acids, and chlorophyll.

Phosphorus—Plays a role in respiration and cellular division and is used in the synthesis of energy compounds—adenosine triphosphate and adenosine diphosphate.

Potassium—Usually found in the meristems (tips of plants) where it activates many enzymes.

Calcium—Vital part of cell walls holding them together, maintains membrane integrity and acts in the movement of substances through cell membranes.

Magnesium—Essential component of the chlorophyll molecule and activates many enzymes.

Sulfur—Part of many amino acids.

Iron—Essential for chlorophyll synthesis, enzyme activator, and acts as an electron carrier in photosynthesis and respiration.

Manganese—Enzyme activator.

Boron—Involved in calcium ion use.

Zinc—Enzyme activator.
Copper—Acts as an electron carrier and is part of certain enzymes.
Molybdenum—An electron carrier in conversion of nitrate to ammonium.
Chlorine—Acts as an enzyme activator in photosynthesis.
Nickel—Essential for urease enzyme activity.

If any of these elements is in deficiency or excess, disorders will occur in the plants. These disorders will be expressed as symptoms. Symptoms (specific colors or deformities) will give you a clue that your plants are under stress and must be corrected to avoid loss in production.

The ability of the soil or hydroponics to provide adequate nutrition through the availability of the essential elements to plant roots depends on the amounts of the various elements present, their solubility (presence in the soil water or nutrient solution in a solution and not just a suspension), and the pH of the soil or nutrient solution. Soil nutrients exist in complex, insoluble compounds, and soluble forms readily available to plants. In hydroponics, highly soluble compounds are dissolved in water to obtain the nutrient solution that has the elements readily available to the plants. The reaction of the soil or hydroponic solution (pH) determines the availability of the various elements to the plant (Figure 7.1). The pH is a measure of the acidity

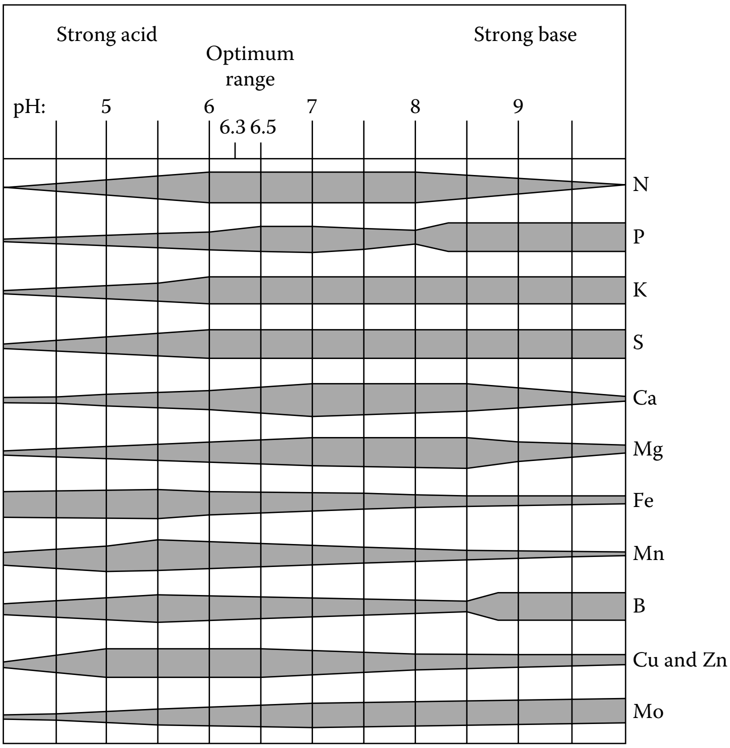


FIGURE 7.1 The effect of pH on the availability of plant nutrient uptake. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

or alkalinity. If the solution pH is less than seven it is acidic, seven is neutral, and greater than seven is alkaline. Most plants prefer a pH between 6.0 and 7.0 for optimum nutrient uptake regardless of whether it is the soil solution or a nutrient solution. Specific crops require different optimum pH ranges. For example, lettuce likes a pH between 5.5 and 5.8, whereas tomatoes, peppers, and cucumbers prefer a pH from 6.0 to 6.4.

If you encounter plant symptoms pointing to a lack of a specific element, be sure to check the pH of the solution in case the element may be present in ample amount, but, unavailable to the plant due to the incorrect pH. The pH can be tested with indicator papers, dye solutions, and pH meters. In hydroponic systems, the pH must be tested at least once a day. If it is too low, raise it with a base such as potassium hydroxide, or on a small-scale use bicarbonate of soda. With high pH values lower the pH with an acid such as sulfuric (battery) acid or phosphoric acid. You could also use vinegar (acetic acid) or citric acid for home use. The pH of cider vinegar at normal strength is 4.25–5.00. White vinegar is stronger with approximately 5%–8% acetic acid in water. It has a pH of approximately 2.4. An even easier method is to purchase a "pH Up" or "pH Down" solution from a hydroponic retail outlet or from an Internet website of hydroponic suppliers. Always remember to add acid to water to avoid splashing or fumes. It is best to use eye protection and wear gloves when using strong acids or bases to avoid burns.

8 Sources of Nutrients for Plants in Soil versus Hydroponics

Although the elements essential for plants are the same, regardless of whether they are from sources in the soil or the nutrient solution, their original form may differ. In soil, these elements come from the break down of organic matter through microbial organisms and animal decomposition. Animals would be, for example, earthworms that consume organic matter of the humus of the soil and excrete simpler forms of organic compounds. These compounds are further decomposed into more simple compounds by the microorganisms. The end process is the release of inorganic elements into the soil water to form the soil solution that brings these essential minerals in contact with plant roots where they are absorbed. The elements must be in their charged atomic state (ions) to be taken up by plants. The other component of soil that is a source of minerals is the sand, silt, clay, and rocks that break down through weathering. Wind and water will break them into very fine particles that when in contact with the soil water will be released as ions, once again available to the plant roots.

In adding nutrients to soil, we supplement with composts, manures, peatlite mixes, perlite, fertilizers, and so on to also improve the structure of the soil (Figure 8.1). Generally, with soil growing the choice of fertilizer depends on the plant and the results of a soil analysis. Normally, blends are used. Fertilizers have a guaranteed analysis that appears on their bags. All chemical and organic fertilizers have their guaranteed analysis on their label. For example, a common vegetable garden fertilizer is 5–10–5. This fertilizer contains 5 percent nitrogen, 10 percent phosphate (P_2O_5), and 5 percent potash (K_2O). The particular fertilizer should be chosen after a soil analysis. The laboratory doing the analysis will make recommendations as to the fertilizer components needed for your soil. The pH of the soil may be modified by the use of lime to raise it or sulfur to lower it. Most fertilizers used in soil gardening are available in granular and water-soluble forms. Granular fertilizers slowly release the plant nutrients to the soil water and therefore act slowly, but have the advantage of being long lasting. Water-soluble fertilizers are fast acting, but, move rapidly through the soil, so must be applied more frequently than granular forms.

In hydroponic culture, we grow in containers or some form of medium that is wrapped with plastic, such as “slabs” that are long, narrow, bags with the substrate. They generally measure 3 ft by 6–8″ wide by 4″ thick. These slabs will sit on return channels underneath that will collect the spent solution (leachate) and recycle it or drain it away from the growing area (Figure 8.2). For this reason, because the nutrient

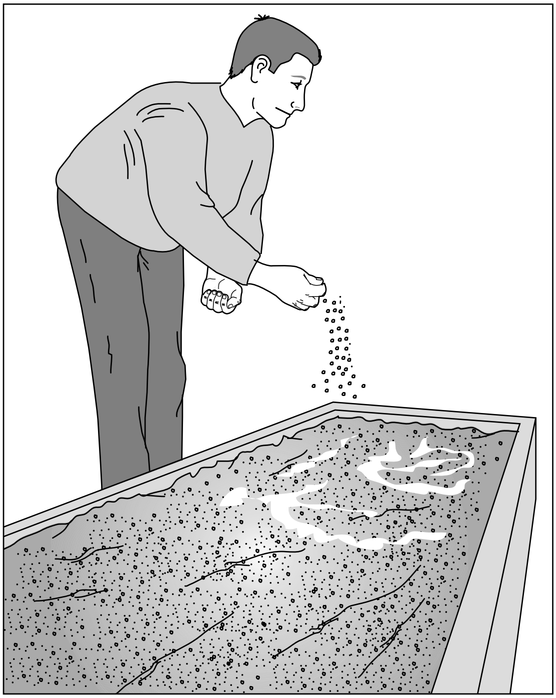


FIGURE 8.1 Gardener adding fertilizers to soil bed not knowing exactly how much is required. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

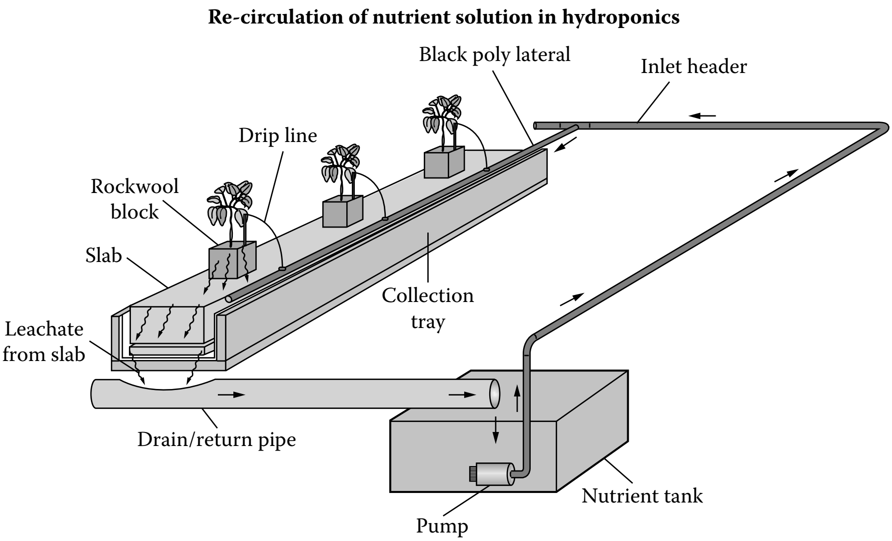


FIGURE 8.2 Nutrient solution is recycled at the root zone in a closed hydroponic system. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

soluton does not just pass the root zone but is distributed precisely near the base of the plants with a drip irrigation system highly pure and soluble fertilizers are used. These highly soluble fertilizers insure that all of their elements are released to the water to form the nutrient solution. The nutrient solution is complete in containing all 13 essential elements in the correct concentratons, measured in parts per million (ppm) or milligrams per liter (mg/L), for optimum plant growth.

The sources of the plant nutrients must be highly soluble and of high purity. Hydroponic suppliers handle many blends of nutrient solution so that you may choose the best for your crop (Figure 8.3). There are different formulations for different stages of plant growth, starting solution, initial vegetative growth, flowering stage, and fruit production. There are vegetable formulations as well as flower and ornamental ones.

Most prepared nutrients come in two components; “A” and “B.” A few are available as just one mixture. The use of a two part formulation is usually better to prevent any possible reaction from occuring among the various elemental components. Usually one will contain calcium, nitrogen, potassium, and iron. The other will have the rest of the elements, including the microelements. They are at concentrated levels when packaged or bottled, so cannot be mixed at those levels or they will react to form an insoluble hard substance, a precipitate. The precipitate cannot be re-dissolved in water. For example, if you mix concentrated calcium or iron with a sulfate, such as Epsom salts (magnesium sulfate) precipitation will result in an insoluble form of calcium sulfate or iron sulfate. Dissolve parts A and B separately in water to prevent any reaction. The ingredients of part A are normally calcium nitrate, potassium nitrate, and iron chelate. Part B may contain potassium nitrate, potassium sulfate, monopotassium phosphate, magnesium sulfate, and other sulfates of manganese, zinc, and copper. In addition, part B will have the remaining trace elements of boron, molybdenum, and chlorine.

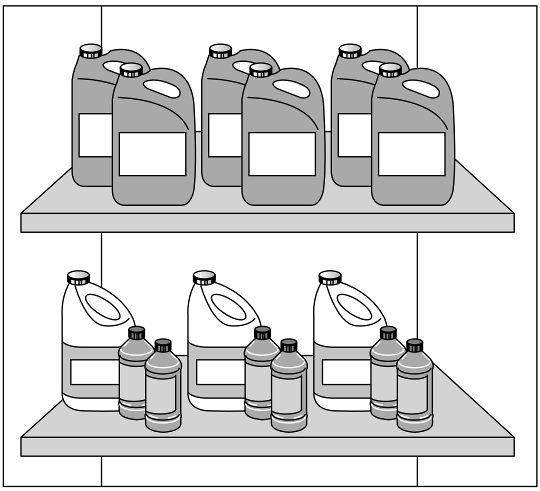


FIGURE 8.3 Many different packaged nutrient formulations available at hydroponic shops. (Courtesy of Botanicare, Tempe, Arizona.)

If you wish to take on the challenge of making up your own nutrient formulations, that is discussed in the following chapter. As I mentioned above, the compounds you select to add the essential elements for the nutrient solution must be pure and highly soluble. The following is a list of recommended compounds for the solution makeup.

Calcium Nitrate: Molecular Formula: $Ca(NO_3)_2$

It is important to purchase "Greenhouse Grade" to avoid the presence of a greasy plasticizer on lower grades. One source is called "YaraLiva" CALCINIT™ Greenhouse Grade, 15.5–0–0 with 19 percent calcium. It is a product of Norway.

Another brand of highly soluble calcium nitrate is "Haifa Cal GG." This is also a greenhouse grade made by Haifa Chemicals Ltd., Haifa, Israel, and manufactured in Slovakia.

This compound provides calcium (Ca) and nitrogen (N) for your plants.

Potassium Nitrate: Molecular Formula: KNO_3

Once again select a soluble grade of fine powder form. "Yara Krista K" is a brand of soluble potassium nitrate 13.7–0–46 coming from Chile by SQM Industrial SA.

This compound provides potassium (K) and nitrogen (N).

Magnesium Sulfate: Molecular Formula: $MgSO_4{\cdot}7H_2O$

Highly soluble brands are a white crystalline powder; that is the heptahydrate (it has seven molecules of water attached as shown in the chemical formula). It is commonly known as "Epsom salts." It contains 9.8 percent magnesium (Mg) and 12.9 percent sulfur (S). PQ Corporation in Pennsylvania produces it. This can also be purchased in small quantities, very pure form at pharmacies.

Monopotassium Phosphate: Molecular Formula: KH_2PO_4

A good highly soluble brand is Haifa Chemicals Ltd in Israel. The guaranteed analysis is 0–52–34. This compound gives potassium (K) and phosphorous (P).

Potassium Sulfate (Sulfate of Potash): Molecular Formula: K_2SO_4

"Champion" water soluble grade ("crystalline") is produced by SQM in the United States. Its analysis is 0–0–51–17 where the last figure indicates 17 percent sulfur.

It supplies potassium and sulfur for the plants.

Iron Chelate: Molecular Name: Sodium Ferric Diethylenetriamine Pentaacetate (Fe-DTPA)

This is termed "Sprint 330" and made by Becker Underwood, Inc., in the United States. It has 10 percent elemental iron (Fe).

Iron is a minor element, but is required in greater amounts than other minor elements. The plant needs may vary from 2.0 to 5.0 ppm. Other minor elements are at optimum levels less than one part per million.

Manganese Sulfate ($MnSO_4{\cdot}4H_2O$) or Manganese Chelate (MnEDTA).

Either of these compounds is a source of manganese. If your water is alkaline, the chelate is a better source because the chelating agent will keep the manganese available to the plant.

Zinc Sulfate: Molecular Formula: $ZnSO_4 \cdot 7H_2O$

This product is very soluble if the white powder form is used. It adds zinc (Zn) to the nutrient solution.

Copper Sulfate: Molecular Formula: $CuSO_4 \cdot 5H_2O$

This is also termed bluestone due to its blue crystals. It is highly soluble in providing copper (Cu).

Boric Acid: Molecular Formula: H_3BO_3

Boric acid, also called Boracic acid, is used as an antiseptic for minor burns or cuts and as an eye rinse. This provides boron (B). Boric acid is available at a pharmacy.

Ammonium Molybdate: Molecular Formula: $(NH_4)_6Mo_7O_{24}$

Sodium Molybdate: Molecular Formula: Na_2MoO_4

Either of these is highly soluble in supplying molybdenum (Mo).

Note: With the minor elements, except iron, use very small amounts so purchase them as laboratory reagents in small quantities at most laboratory suppliers. They will be very pure and soluble.

Calculations to develop a nutrient formulation and how to make a nutrient solution with the formulation is discussed in Chapter 9.

As I mentioned earlier, you do not need to get this involved in making up your own formulation and storing all of these compounds. It is far simpler to purchase a ready-made formulation from a hydroponic supplier. However, as with most hobbies, you may wish to explore more technical details of growing your crops and experimenting with formulations to find the most optimum to maximize yields. Just enjoy the success of growing hydroponically at a level that suits you best!

9 Nutrient Formulations and Solutions

Specific crops have different optimum levels of each nutrient. These levels are measured in milligrams per liter (mg/L) or parts per million (ppm). One part per million is one part of one substance in a million parts of another. Water is the solvent in hydroponics as it is in soil for the elements (solutes). An optimum formulation depends on a number of factors.

Plant: Different plants like different levels of the essential elements.

Stage of Plant Growth: When plants are young developing seedlings, they need lower levels of macroelements. As they mature and start forming fruit some elements, such as potassium, calcium, and iron will be in more demand by the plant. When plants are growing, initially we add more phosphorous to promote root growth. As fruiting crops of tomatoes, peppers, and eggplants develop flowers and fruit, we can help the plant shift into a more generative flowering–fruiting phase from its initial rapid, leafy growth of a vegetative state. This can be done by the overall concentration of the nutrient solution, frequency and duration of irrigation cycles, and temperature control. With hydroponics we can observe these characteristics and assist the plant to be more productive by altering these factors, especially when growing indoors or in greenhouses.

Weather: Light levels and day length have a great effect on plant growth. With indoor and greenhouse gardening, we can supplement with artificial lighting, although that still is not as efficient as the natural sunlight. During short days of lower light, we can slow plant growth by adjusting the irrigation cycles, temperatures, and nutrient formulation.

Total dissolved solutes instruments measure the solutes in water by electrical conductivity (EC) (Figure 9.1). When solutes are dissolved in water, the solution will conduct electricity. The quantity and nature of solutes determines its EC. This is expressed as millimhos per unit volume (mMho). By monitoring the EC of a nutrient solution, one can determine when changes occur and know when to add elements or change the nutrient solution. Nutrient solutions having adequate essential elements possess an EC range between 1.5 and 2.5 mMho or slightly higher.

Plants take up much more water than nutrients, and at a greater rate. The volume of solution should be maintained relatively constant. That can be done by the use of an automatic float valve.

The total concentration of the nutrient solution elements should be between 1000 and 1500 ppm to facilitate uptake by the plant roots. Conductivity readings of these concentrations would correspond to 1.5 and 3.5 mMhos. Cucumbers prefer lower values (1.5–2.0 mMho), whereas tomatoes do better at higher values (2.5–3.5 mMho).

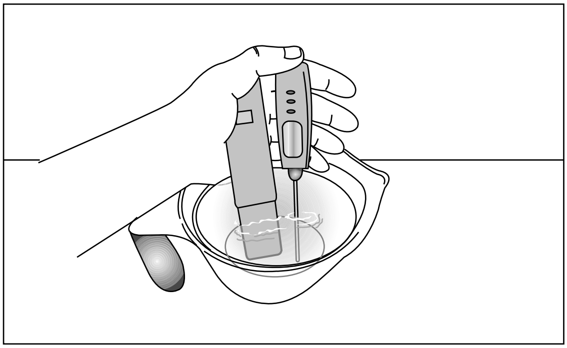


FIGURE 9.1 Person testing pH and electrical conductivity of the nutrient solution of hydroponic culture. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

Overall, plants harvested for their leaves (lettuce, herbs) prefer high nitrogen levels because it promotes vegetative growth. On the other hand, fruit-bearing crops should have lower N and higher P, K, and Ca levels.

You may find many nutrient formulations online or in books, such as my book *Hydroponic Food Production*. Formulae for different crops are available from these sources. The following is a general formulation of macronutrients plus iron for a 20-U.S.-gal tank. Because weights are small, use grams instead of ounces or pounds. You will need a gram scale that can weigh accurately within 0.1 g.

MACROELEMENT FORMULATION

• Calcium (Ca):	180 ppm	Nitrogen (N):	140 ppm
• Phosphorus (P):	50 ppm	Potassium (K):	352 ppm
• Magnesium (Mg):	50 ppm	Sulfur (S):	168 ppm
• Iron (Fe):	5 ppm		

WEIGHT/20-U.S.-GALLON TANK (GRAMS)

• Calcium Nitrate:	62 g	Potassium Nitrate:	8 g
• Potassium Sulfate:	46 g	Magnesium Sulfate:	38 g
• Monopotassium Phosphate:	17 g	Iron Chelate (10% Fe):	4 g

If you wish to use a larger or smaller volume, just use a ratio as a factor to multiply the weight. For example, if you want to make up only 10-U.S. gallons, multiply each weight of compound by the factor: $10/20 = 0.5$. So, for calcium nitrate it would be 0.5×62 g = 31 g.

With the micronutrients because their weight is very small, you can make up a concentrated “stock solution” and then use a small volume of it to add to the 20-gallon tank. Use a 5- or 10-gallon water tank to store the micronutrient stock solution. Keep it in the dark to prevent algae growth. In this case, make up a 300 times normal strength stock solution as outlined for a 10-gallon volume.

MICROELEMENT FORMULATION

- Manganese (Mn): 0.8 ppm — Copper (Cu): 0.07 ppm
- Zinc (Zn): 0.2 ppm — Boron (B): 0.3 ppm
- Molybdenum (Mo): 0.03 ppm

WEIGHT/10-U.S.-GALLON TANK (300 TIMES NORMAL STRENGTH) (GRAMS)

- Manganese Sulfate: 41 g — Copper Sulfate: 3.2 g
- Zinc Sulfate: 11 g — Boric Acid: 20.5 g
- Ammonium Molybdate: 0.6 g

Now add a portion of this stock solution to the nutrient solution. Once again for using a 20-U.S.-gal tank add 20 × (1/300) = 0.066 U.S. gallons of the micronutrient stock solution to a 20-U.S.-gal tank. The factor 1/300 is to dilute the concentrate from 300 times back to normal one-time strength. Once again it is better to measure this small volume using milliliters (1 mL = 1/1000 L). The conversion to liters from U.S. gallons is 3.785 L per gallon. The conversion is 0.066 × 3.785 = 0.250 L or 250 mL. It is best to measure this volume with a 100-mL graduated cylinder. Scales and graduated cylinders should be available at a hydroponics shop or if not go online to a science laboratory supply distributor.

Now test the pH of the nutrient solution in the stock tank and adjust it either up or down using an acid or base as described in Chapter 7. Of course, the easiest method is to purchase a "pH Up" or "pH Down" solution from a hydroponic store (Figure 9.2). Add a small volume of the pH adjuster solution slowly while stirring to get good mixing. Check the pH with an indicator paper or pH meter as mentioned also in Chapter 7. Do not be afraid of exceeding the desired pH value as you can always adjust it in the opposite direction using the opposite solution from which you were using. If that happens, you are adding too much at any time between checking it.

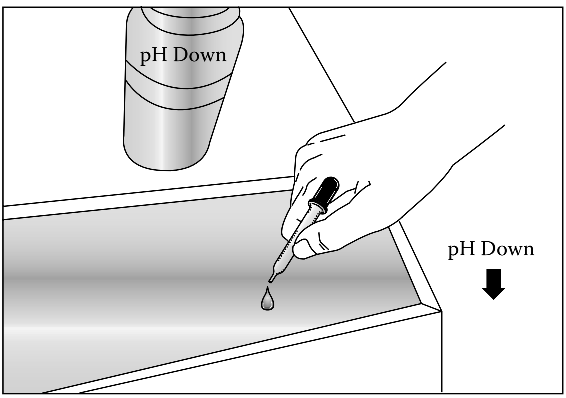


FIGURE 9.2 Person adding pH adjuster solution to nutrient tank. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

Making up your own nutrient formulation is more involved than just purchasing a ready-made concentrate solution, but it is more fun. With commercial stock solutions, simply follow directions. They often tell you to use a number of teaspoons of their concentrate to each gallon of the tank solution. To be more accurate, use a small graduated cylinder. Have fun, this goes back to your school chemistry classes!

10 Signs of Plant Nutritional and Physiological Disorders and Their Remedies

Plants are similar to us humans and animals in that when under stress from poor nutrition; our bodies suffer in growth, development, and general health. Animals show these disorders in the form of weak bones, skin discoloration, and poor weight. Plants show nutritional defects in vigor, strength of stems, color of leaves, and poor yields.

Whenever plants undergo any type of stress from environmental conditions to lack or excess of nutrients, they will express signs of disorders. Pests and diseases also cause stress and disorders within the plant. Pest and disease causes and their control are discussed later in Chapter 25. Focus now is on plant symptoms from nutrient stress. By recognizing and segregating out what is the cause of a symptom, adjustments can be made in the environment or nutrient solution to remedy the stress and bring the plant back to healthy growth. In my book, *Hydroponic Food Production*, there is detailed information on nutritional and environmental effects on plants, how to determine the specific disorder, and the function of elements within the plant. Presented here is a brief summary of symptoms that assist the gardener to discover the causal agent(s).

Symptoms of disorders within the plant may be expressed as leaf yellowing (chlorosis), browning (necrosis), burning (white coloration due to loss of chlorophyll in leaves), deformation of leaves and growing tips, and stunting of overall growth. The first thing to observe with a nutrient disorder is the location of the affected tissue. Leaves will in general show the symptoms first. If it is a root problem due to disease or lack of oxygen, examination of the roots will reveal that they are not turgid and white, but, slimy and brown (Figure 10.1). The plant will wilt during high light periods as the water loss by transpiration is greater than the roots' ability to take up sufficient water.

The location on the plant of symptoms is the first clue as to the cause of the disorder. Focusing on leaf symptoms, if the lower leaves are expressing yellowing, browning, or spots first (Figure 10.2), then the group of nutrients responsible for the disorder would be those of "mobile" elements. Mobile elements can be retranslocated within the plant from the lower older tissue to the younger tissues in the top of the plant. These elements include N, P, K, Mg, Zn, and Mo. Initial symptoms will be a yellowing (chlorosis) followed by browning or drying (necrosis) of leaf tissue. If the

FIGURE 10.1 Healthy plant compared with a diseased one. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

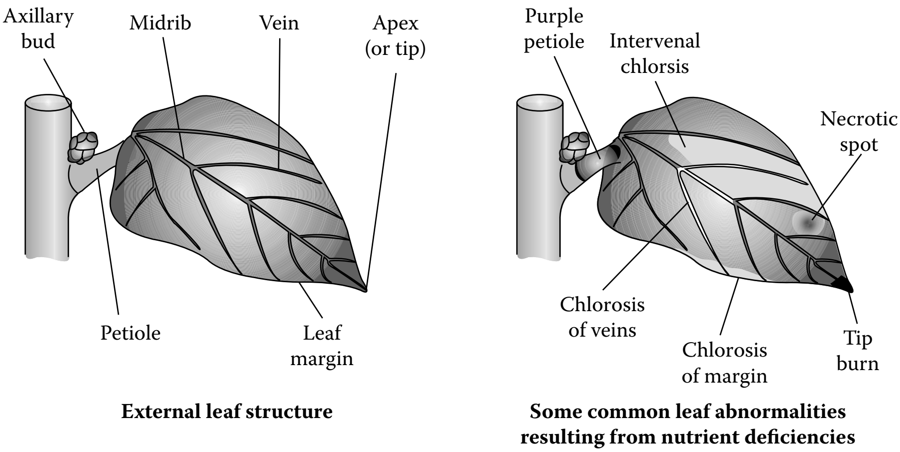


FIGURE 10.2 Common symptoms of nutrient disorders on leaves. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

symptoms appear in the young leaves at the tip of the plant this disorder is a result of a lack of "immobile" elements that cannot move from the older plant parts to the growing tip. These immobile elements are Ca, B, Cu, Mn, S, and Fe. To determine which of these is the cause of the disorder there are "keys" composed of a dichotomous table allowing you to make a number of alternative choices (Figure 10.3). Each selection narrows the possible causes until in the final step there is a single element identified.

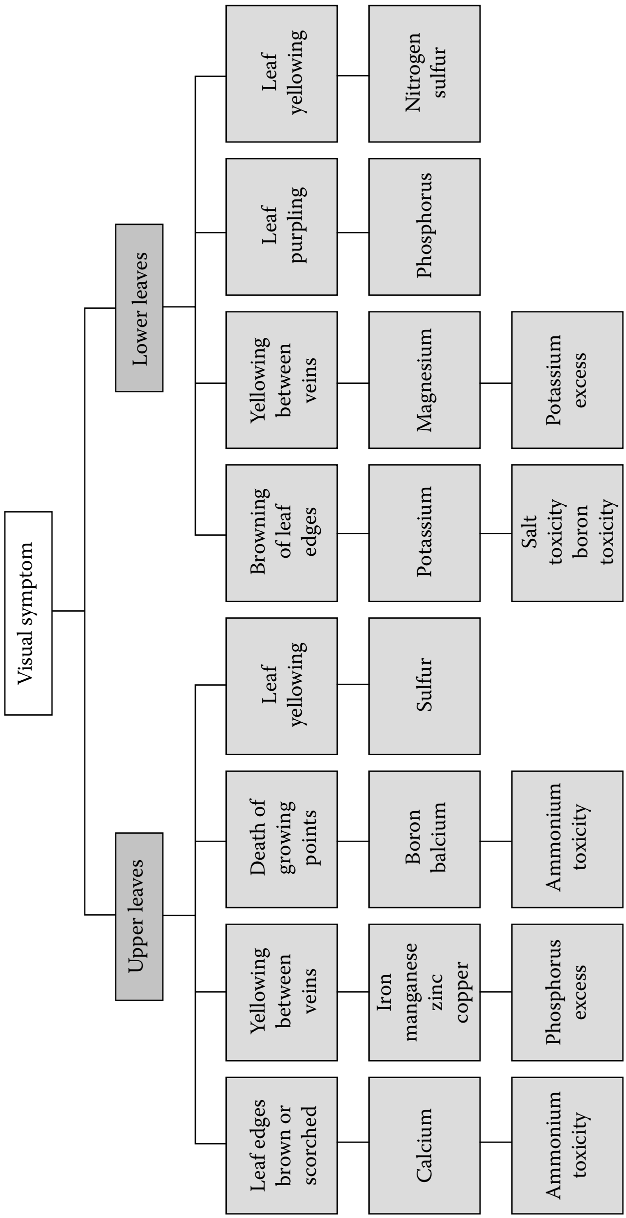


FIGURE 10.3 Key to visual symptoms on plants. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

It is critical to recognize any symptoms occurring at an early stage of the plants' expression of these stress clues because as the disorder goes on without correction, the symptoms expand progressing from simple yellowing spots to complete yellowing and necrosis. At that stage, it is very difficult to know the first form of symptoms as they spread throughout the plant giving it an overall chlorosis, necrosis, and deformations of tissues. In addition, as the stress becomes more severe, it will be difficult, taking a lot of time to correct it once identified. The loss of the plant's health may become permanent or even result in its death. Yields will be greatly reduced as the stress is not corrected. The stress may begin as a cause from a single element and then as it progresses, other element uptake is slowed or blocked and the plant suffers from multiple disorders.

A very useful procedure when a symptom first appears is to immediately change the nutrient solution. That is, make up a new batch. At the same time, to determine the exact cause send a nutrient and/or tissue sample to a laboratory for analysis. Similar to soil analysis, the laboratory will give you guidelines as to what the normal levels of each nutrient should be in the solution or in the plant and direct you to make adjustments in the nutrient solution formulation.

MOBILE ELEMENTS

Here is a summary of deficiencies of mobile elements (first symptoms on older leaves) (Figure 10.3) and possible remedies.

Nitrogen

Lower leaves become yellowish green and growth is stunted.

Remedies

Add calcium nitrate or potassium nitrate to the nutrient solution.

Phosphorous

Stunted growth of plant, a purple color of the undersides of the leaves is very distinct and leaves fall off prematurely.

Remedies

Add monopotassium phosphate to the nutrient solution.

Potassium

The leaflets on older leaves of tomatoes become scorched, curled margins, chlorosis between veins in the leaf tissue with small dry spots. Plant growth is restricted and stunted. Tomato fruits become blotchy and unevenly ripen.

Remedies

Apply a foliar spray of 2% potassium sulfate and add potassium sulfate to the nutrient solution.

Magnesium

The older leaves have interveinal (between veins) chlorosis from the leaf margins inward, necrotic spots appear.

Remedies

Apply a foliar spray of 2% magnesium sulfate. Add magnesium sulfate to the nutrient solution.

Note: When applying foliar sprays, if in a greenhouse, avoid doing so during high sunlight conditions as that can cause burning of the leaves. Apply in the early morning while the sun and temperatures are low.

Zinc

Older and terminal leaves are abnormally small. The plant may get a "bushy" appearance due to the slowing of growth at the top.

Remedies

Use a foliar spray with 0.1%–0.5% solution of zinc sulfate. Add zinc sulfate to the nutrient solution.

IMMOBILE ELEMENTS

The following is a summary of deficiencies of immobile elements (first symptoms appear on the younger leaves at the top of the plant) (Figure 10.3) with suggested remedies.

Calcium

The upper leaves show marginal yellowing progressing to leaf tips, margins wither, and petioles curl and die back. The growing point stops growing and the smaller leaves turn purple-brown color on the margins, the leaflets remain tiny and deformed. Fruit of tomatoes show blossom-end rot (BER) (leathery appearance at blossom ends of the fruit).

Remedies

Apply a foliar spray of 1.0% calcium nitrate solution. Add calcium nitrate to the nutrient solution.

Sulfur

Upper leaves become stiff and curl down, leaves turn yellow. The stems, veins, and petioles turn purple and plant growth is restricted.

Remedies

Add potassium sulfate or other sulfate compound to the nutrient solution. A sulfur deficiency is usually rare because it is added to the nutrient solution by use of potassium, magnesium, and other sulfate salts.

Iron

The terminal leaves start turning yellow at the margins and progress through the entire leaf leading eventually to necrosis. Initially the smallest veins remain green giving a reticulate pattern. Flowers abort and fall off, growth is stunted and spindly in appearance.

Remedies

Apply a foliar spray with 0.02%–0.05% solution of iron chelate every 3–4 days. Add iron chelate to the nutrient solution.

Boron

The growing point withers and dies. Upper leaves curl inward and are deformed having interveinal mottling (blotchy pattern of yellowing). The upper smaller leaves become very brittle and break easily.

Remedies

Apply a foliar spray of 0.1%–0.25% borax solution. Add borax or boric acid to the nutrient solution.

Copper

Young leaves remain small, margins turn into a tube toward the midribs in tomatoes, petioles bend downward, and growth is stunted to get a "bushy" appearance of the plant at the top.

Remedies

Use a foliar spray of 0.1%–0.2% solution of copper sulfate. Add copper sulfate to the nutrient solution.

Note: Whenever applying a foliar nutrient spray, apply it first to a few plants and wait to apply it to all plants for about a day to be sure that no burn occurs from the spray.

Manganese

Middle and younger leaves turn pale and develop a characteristic checkered pattern of green veins with yellowish interveinal areas. Later small necrotic spots form in the pale areas. Shoots will become stunted.

Remedies

Apply foliar spray of 0.1% manganese sulfate solution. Add manganese sulfate to the nutrient solution.

Molybdenum

All leaves show a pale green to yellowish interveinal mottling, usually progresses from the older to the younger leaves.

Remedies

Apply a foliar spray of 0.07%–0.1% solution of ammonium or sodium molybdate. Add ammonium or sodium molybdate to the nutrient solution.

You will note that distinguishing among the symptom differences, especially with copper and molybdenum is difficult. The differences among iron, boron, and manganese are very prominent with the effects on the growing points and the distinct checkering coloration of manganese.

A deficiency in calcium is very similar to that of boron in the growing point; however, calcium will cause the BER on the fruit of especially tomatoes and peppers. Nonetheless, always remember to check the moisture level in the substrate and adjust irrigation cycles to give adequate watering so that wilting of the plant does not occur, as such water stress would be the first cause of the BER symptom.

PHYSIOLOGICAL DISORDERS

These disorders occur from environmental stresses such as high relative humidity, excessive temperatures (either high or low), very high light intensity, and incorrect irrigation. Often unfavorable environmental conditions cause upsets in nutrient uptake and therefore will also appear as a nutrient disorder. These disorders, including the entire nutrient disorders described in this chapter, are not encountered only in hydroponics, but are very common in soil growing also.

Blossom End Rot (Tomatoes, Peppers, Eggplants)

A brown, leathery tissue forms at the blossom end of the fruit (Figure 10.4).

Causes and Remedies

Calcium deficiency, water stress due to insufficient irrigation frequency or too much on compact clay soils that causes poor root aeration. In hydroponics, it is a lack of irrigation cycles, especially under high temperatures and light intensity. It is often a calcium deficiency induced by poor irrigation practices. Adding calcium will not rectify the problem if the irrigation frequency is not corrected.

Fruit Cracking (Tomatoes, Peppers, Eggplants)

Cracks radiate from the stem end, especially on maturing fruit (Figure 10.5).

Causes and Remedies

Poor irrigation is the cause of water deficit, especially under high temperatures, when an irrigation cycle is initiated the water is taken up very rapidly by the plant that directs it to the fruit where the sudden expansion is too fast for the skin to expand and it cracks. This can be prevented by avoiding high temperatures with shading and maintaining uniform soil moisture levels. Start irrigation cycles 1–2 hours after sunrise and the last one no later than 1 hour before sunset.

FIGURE 10.4 Blossom-end rot of tomato fruit.

Blotchy Ripening (Tomatoes)

Fruit color is uneven with brown vascular tissue inside the fruit.

Causes and Remedies

There are a number of environmental and possible induced nutritional disorders. Low light intensity, cool temperatures, high medium moisture levels, high nitrogen and low potassium are all potential causes. Avoid this condition by adding

FIGURE 10.5 Cracking of tomato fruit.

supplementary lighting, or using less irrigation cycles under low light conditions and lower nitrogen levels in the nutrient solution.

Green Shoulder, Sunscald (Tomatoes, Peppers, Eggplants)

The top shoulder area of the fruit remains a blotchy green while the rest of the fruit is colored. This is particularly common in some tomato varieties. A lot of varieties have resistance to this disorder. With peppers and eggplants, a blackened leathery spot appears on the fruit as a result of sunscald.

Causes and Remedies

The cause is high temperatures combined with direct sunlight striking the fruit. This can be prevented by keeping good leaf growth above the ripening fruit and in a greenhouse provide shading in the hot, summer months. Also, if peppers have a lot of fruit developing at a given time, this high production slows the plant growth and fruit forms near the tops of the plants where few, or small developing leaves cannot shade the fruit sufficiently. You can add nitrogen to the nutrient solution to promote more vegetative growth in the plant. In addition, with peppers, do not permit more than five to six fruits to form on each stem of the plant. Thin, if necessary, to reduce the fruit load and this will also give you larger fruit.

Catfacing, Misshapen Fruit (Tomatoes, Peppers, Eggplants)

This is fruit distortion with protuberances and indentations (Figure 10.6).

FIGURE 10.6 Catfacing of tomato fruit.

Causes and Remedies

High relative humidity and low light levels cause poor pollination. Avoid these environmental conditions with ventilation and addition of supplementary lights, especially with indoor growing to increase light intensity.

Crooking (Cucumbers)

This is the bending of the fruit as it expands (Figure 10.7).

Causes and Remedies

The causes include any poor temperatures that cause slowing of growth, fruit hanging up on leaves, tendrils (long stringy appendages of the cucumber) attaching to the fruit, mechanical damage, or pest injury during the rapid fruit expansion. The cure is to keep good temperatures and avoid the other causes by proper training of the plant as described in Chapter 24.

Abortion of Fruit (Cucumbers, Peppers, Eggplants)

The fruit gets soft, yellows, and shrivels when very small.

Causes and Remedies

This condition can be caused by poor nutrition, too heavy of fruit load, low light, and improper training of the plant. Keep the plant pruned and thin the fruit set if necessary.

Note: Proper training of the plants is presented in detail in Section VI, Chapter 24.

FIGURE 10.7 Crooking of cucumber fruit.

SUMMARY

In summary, it is essential for good production to recognize any nutritional and/or environmental-induced disorders in plants early from symptoms they express when under stress. Their early correction will prevent losses in yields and their decline in vigor. There are many books available with photos describing these symptoms and keys to assist in identifying nutritional disorders such as in my book, *Hydroponic Food Production*.

Section IV

Hydroponic Systems

11 Substrates to Use and Their Sources for Hydroponics

Plants will grow in most media as long as they get water, oxygen, and nutrients. Of course, not all are well suited to provide optimum growth. Heavy clay soils are cold and have so much water that oxygen to plant roots is restricted limiting growth. There are a number of qualities that must be considered when choosing a substrate for hydroponic growing. Here are some important characteristics.

Structure: The structure must be durable for at least one or more crops and not break down into small particles that will impair oxygenation to plant roots.

Composition: The particles of the substrate must not react with the nutrient solution or release elements into the water as that will upset the balance of the nutrient solution. For example, calcareous rock releases calcium and magnesium causing the pH to rise above optimal levels. Some substrates such as coco coir must be well washed to remove any residual sodium chloride as often the coconut husks are found near salt water where the palm trees are growing. Bark and sawdust must be sourced from Douglas Fir, Hemlock, or Redwood timber as they are known not to release any turpines or other resins found naturally in pine and cedar wood. Rice hulls have to be aged for some time in piles that are watered, to permit those with embryos to germinate. Composting will generate heat and kill the seedlings of the rice. Alternatively, the rice hulls can be burned under a smoldering fire to carbonize them. This process gives the rice hulls less smooth surface so that it will retain more water than raw husks. The burning process will also sterilize the rice hulls and kill any embryos present.

Sterility: Substrates for hydroponic culture must be free of pest and disease organisms. If you are uncertain as to the sterility of the medium, heat it to 160°F (71°C) for half an hour to kill the organisms. This can be done in a kitchen stove oven or if there is intense sunlight and high temperatures, place the substrate on a black polyethylene and also cover it with a black polyethylene. This process should be okay after about 1 week. Gravel and some coarse sands could be sterilized using a 10% bleach solution. Other finer substrates like perlite can be pre-treated with "Zerotol," a hydrogen dioxide compound that is highly oxidizing. It must be soaked 2–3 days prior to sowing or transplanting.

Water Retention: The hydroponic substrate must not have properties of very high or very low water retention. However, the acceptable water retention will also be a function of the type of hydroponic system. Coarse gravel can be used with a sub-irrigation or ebb-and-flow watering system. The water (nutrient solution) will enter the void spaces among the rock particles when the bed is being flooded and wets the particle surfaces. As the solution drains back out it will pull air into the substrate. This method of hydroponics functions well with coarse substrates.

With fine substrates like rockwool, sawdust, coco coir, and peatlite mixes, use a drip irrigation system that applies the solution on the top and spreads through the substrate by capillary action and drains out the bottom of the container.

Water retention must not be excessive causing lack of oxygenation or be insufficient to cause the substrate to dry quickly and starve the plant of both water and nutrients.

Root Support: The substrate must allow roots to easily penetrate between the particles and anchor the plant as the roots enter the void spaces seeking water. If the substrate is too fine, the roots cannot spread readily into the medium, whereas, if it is too coarse, the plant roots will not be able to hold onto the particles and the plant can easily fall over. Most long-term crops need a substrate to anchor their roots and take up oxygen, water, and nutrients.

Availability and Cost: For small hydroponic gardens, the cost is not an important factor as relatively small amounts of substrate are needed. Many types of substrates are available for hydroponics and may be purchased online or at hydroponic shops.

MEDIA (SUBSTRATES)

The following is a description of many of these suitable substrates for hydroponic growing. When we discuss the various hydroponic systems for different plants, specific substrates are recommended.

1. **Gravel**: This was one of the original substrates used in hydroponic culture from the 1940s through the 1960s. It was the substrate introduced by Dr. W.F. Gericke to establish outdoor hydroponic operations during World War II on non-arable islands of the Pacific. In many of those islands, volcanic rock was suitable for hydroponics and it was plentiful.
   Choosing the most desirable rock takes into account a number of characteristics or properties. It should be irregular in shape (crushed is best), free of fine particles (fine sand to silt), and should be aggregate of ½–¾″ in diameter (Figure 11.1). The particles must be of igneous (volcanic) origin and be structurally stable. They must retain adequate moisture in void spaces yet drain well to provide oxygen to the plant roots. Avoid the use of calcareous gravel (sedimentary origin-like limestone) as their release of calcium carbonate will continually alter the pH.
2. **Pebbles (Bird's Eye and Pea Gravel)**: These gravels have round, smooth surfaces with size ranging from a ⅛″ to ¼″ diameter (bird's eye vs. pea gravel) (Figure 11.1). Since their surface is less irregular, the smaller size is critical to their suitability. If you select gravel larger than pea gravel size, it must be with a sub-irrigation system as described earlier for gravel. Again, this material must be of igneous origin. With this substrate, I have used drip irrigation or soaker hoses to distribute the nutrient solution to the base of the plants. However, due to the rapid percolation, it is best to use a recycle system of hydroponic culture and more frequent irrigation cycles than for

other finer materials. These media, like gravel, can be sterilized with a 10% bleach solution between crops. Always remember to flush the substrate with raw water after using a bleach solution to remove any residual chlorine.

3. **Leca (Expanded Clay)**: This fired clay (Figure 11.1) is sometimes called "Haydite" or "Herculite" as it is light weight and is used in construction. It has good water retention from its irregular surface and is especially suitable for small hobby units and indoor gardening. It does fracture with time resulting in the release of fine sand and silt, but with a hobby unit it can be replaced when this build-up of fines occurs.
4. **Scoria**: Crushed rock from volcanic origin is highly vesicular (full of holes from escaping gases during cooling from molten magma) (Figure 11.1). It is usually dark brown, black, or purplish red and light in weight. It can also be called cinder. It is fairly good in retaining water and at the same time gives good oxygenation. Various particle sizes can be used for hydroponics, ranging from ½″ to less than ⅛″ in diameter.
5. **Sand**: The best sand is river sand of igneous origin. It must be well washed by the quarry operator. This washed river sand is available from most aggregate suppliers. Do not use mortar sand as its fine particles cause puddling, water coming to the surface when vibrated. The settling of the very fine particles will reduce any void spaces and eliminate the available oxygen. If properly screened to eliminate any particles of diameter over 2 mm (0.0625″) and under 0.6 mm or 0.025″, the sand will drain freely and provide adequate oxygen to plant roots.
6. **Sawdust**: Where large forest industries are present, sawdust is a good medium provided the source is from Douglas fir or western hemlock trees.

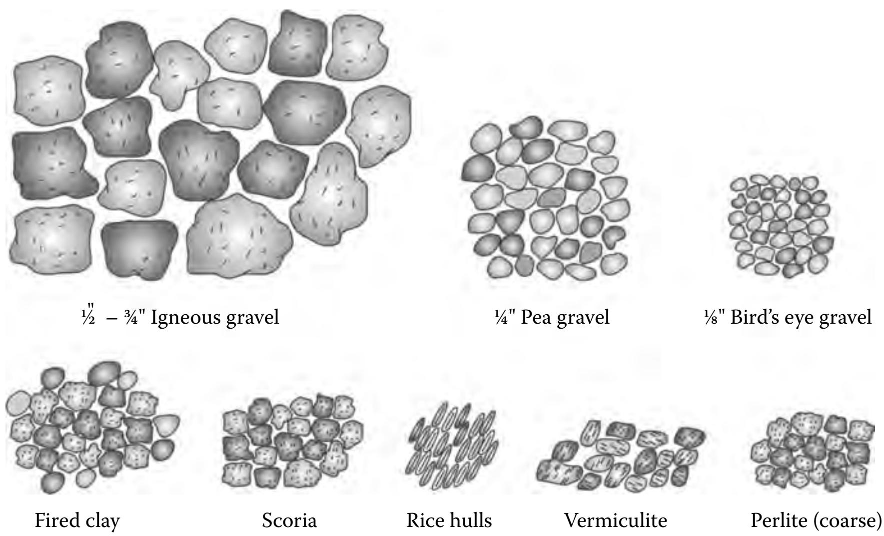


FIGURE 11.1 Various substrates. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

Western red cedar and pines should not be used as their resins are toxic to plants. In many locations, logs are floated in barges on the ocean and they collect sodium chloride from the water. Test the sawdust for sodium chloride content and leach it thoroughly with pure raw water before planting.

7. **Peat**: Peat is partially decomposed freshwater marsh or swamp vegetation. Use peat from sphagnum moss, as some of the other types are very fine and hold too much water. Other peats from sedges, reeds, and hypnum moss decompose rapidly upsetting the structural integrity of the medium. Peat is readily available in 3.8 cubic foot bales in compressed form. There are many blends available mixed with various percentages of perlite, vermiculite, or Styrofoam particles to add aeration to the medium. It also comes with the beneficial microorganism, Mycorrhizae. For example, Premier Tech Horticulture offers a line of peat-based substrates. Their "Pro-Mix BX Mycorrhizae" is a general purpose peat-based medium designed for greenhouse/indoor growing and contains a mycorrhizal inoculum. The symbiotic fungi colonize the root systems of plants and increase water and nutrient acquisition. The ingredients of this mix include perlite, vermiculite, dolomite lime to adjust the pH, and a wetting agent to assist in absorption of water during its initial dry state.
8. **Peatlite Mixes**: There are various mixtures of peat-based media that have been developed with extensive research by various universities. The two most popular ones are the UC mix (University of California) and the Cornell "Peat-Lite" mixes (Cornell University, New York). These mixtures are combinations of peat, sand, perlite, pumice, and vermiculite with added nutrients and dolomite lime to adjust the pH. The pH of peat is very low so a base, such as dolomite lime, is needed to increase the pH. You may refer to these and other mixes on the Internet or in my book *Hydroponic Food Production*. It is easiest to simply purchase a complete mix such as the "Pro-Mix."
9. **Redwood Bark**: As the name suggests this is bark from redwood trees. It is much coarser than sawdust with particle diameters from ⅛″ to ⅓″ or larger. This is usually the preferred medium for the growing of orchids, but not commonly used in other hydroponic cultures.
10. **Rice Hulls**: This is the outer husk or shell of rice (Figure 11.1). This is a by-product of rice milling and is a waste product. They will last from 3 to 5 years without decomposing. They have a smooth surface so do not retain water readily and have poor capillary (lateral) movement of water. If they are burned by a smoldering fire, the surface is improved to give more water retention. Rice hulls are best mixed with peat or coco coir, usually at 20% rice hulls.
11. **Vermiculite**: Vermiculite is expanded mica through a heating process to form spongy particles (Figure 11.1). Heating also insures that the medium is sterile. With the layers (cleavage) formed in each particle water retention is high. The irregular shape of the particles also creates ample void spaces to retain moisture and make oxygen available to the plants. The horticultural vermiculite comes in four grades from the coarse material

of particle size from 0.2″ to 0.3″ in diameter to the fine material with particle size of 0.04″ (1 mm). Use the coarse grade for hydroponic growing and the fine to medium grade for seed germination. Be careful not to press the vermiculite together when adding water as that will destroy its structure.

12. **Perlite**: This comes from volcanic pumice. It is crushed and heated to expand the particles (Figure 11.1). It is very light-weight and is sterile due to the process of heating. A coarse particle size between 2 mm and 3 mm (0.065–0.13″) is best for hydroponics. Particles are irregular, but more structurally stable than that of vermiculite. It contains no nutrients and has a pH of 6.0–8.0. A fine grade is used for seed germination while the coarse grade is best to use in plant growth. It may be used by itself or in mixtures with peat as explained earlier with peatlite mixtures.
13. **Coco Coir**: Coco coir is ground-up dried coconut palm husk. The processed material includes coir fibers and pulp. Most comes from Indonesia, India, Sri Lanka, Thailand, and Brazil. This substrate is now becoming the principal one used in large greenhouse operations basing their production on "sustainable" agricultural technology. The reason for that is that coconut husks are a renewable product.

    A number of different forms of coco coir are available in the market. There is a compressed bale or block that expands upon the addition of water. The blocks will expand to double their size within 15 min of soaking in water. A product created especially for greenhouse hydroponics is the slab form where the coco coir is encased in a long plastic bag (Figure 11.2). It measures about 1 m (39.4″) long by 6–8″ wide by 3–4″ thick. These slabs are aimed at growing vine crops such as tomatoes, cucumbers, peppers, and eggplants. They are available in different grades of coco coir with varying percentages of the coir pulp and fibers. This imparts a series of air-holding capacities from 20% to 40% air capacity at saturation. The choice depends upon the crop to be grown. Slabs of half husk chips and half coco pith are recommended for tomatoes and peppers while those of 100% husk chips are for cucumbers. Coco coir plugs and blocks are also available to start and transplant seedlings.

    Coco coir can be mixed with perlite, rice hulls, or vermiculite similar to the peatlite mixtures described earlier. One fact to consider is the source of the coco coir as that from coastal areas may contain sodium chloride. In that case, it is necessary to flush the coco coir with pure raw water to remove the sodium chloride. Most manufacturers do that during processing so their products will not require initial flushing.
14. **Rockwool**: Rockwool is made from basaltic rock (solidified lava) that is liquefied at 1500°C (2732°F). It is spun and then pressed into sheets that are cut into slabs, blocks, and cubes (Figure 11.3). The slabs have similar measurements to coco coir slabs. Rockwool is slightly alkaline but inert and does not decompose. With 95% pore spaces, it has good water-holding capacity. The pH between 7 and 8.5 must be adjusted before seeding or planting by saturation with an acid nutrient solution to reach an optimum

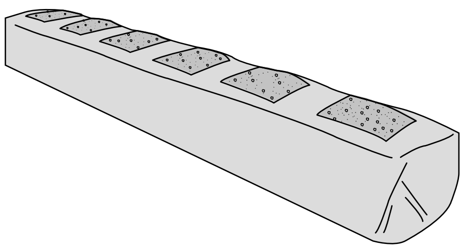


FIGURE 11.2 Slab of coco coir. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

FIGURE 11.3 Rockwool cubes, blocks, and slabs. (Courtesy of Botanicare, Tempe, AZ.)

pH of 6.0–6.5 for most vine crops. A drip irrigation system is used as is the case with coco coir, peatlite, perlite, and other fine mixtures. Managing the irrigation cycles is crucial to success as rockwool needs a 20%–30% leachate (drainage) to prevent any mineral build-up in the substrate. Emphasis now is on recycling the leachate back to a tank where its pH and electrical conductivity are adjusted with an injection system before its reuse in the crop. Special trays are now on the market to collect the leachate from the slabs and return it to a central batch adjustment tank. The same principle of recirculation of spent nutrient solution with rockwool applies to home gardening. These details are described in Section V.

Rockwool cubes and blocks are the standard method of starting your plants for hydroponic culture. Even if you do not use rockwool as a final growing medium, it is still best to start your seedlings in rockwool cubes that are transplanted to larger rockwool blocks before their final transplanting to the growing area. Rockwool cubes are available in 1½″ × 1½″ × 1½″ size for tomatoes, cucumbers, peppers, and eggplants, and 1″ × 1″ × 1½″ deep smaller ones for lettuce and herbs. The blocks come in several sizes as well, with larger ones for plants that you wish to keep in the seedling area longer. They are available as 3″ × 3″ × 2.5″, 3″ × 3″ × 4″, 4″ × 4″ × 2.5″, and 4″ × 4″ × 3″. The blocks have round holes of 1½″ diameter by 1½″ deep to fit the cubes during transplanting.

Loose rockwool granules can be used in containers and/or mixed with other media of larger aggregates such as scoria to improve moisture retention.

Do not confuse rockwool with insulating material, such as the pink or sandy color bats for your home, since it is not suitable for growing plants. It absorbs a lot of water and remains saturated excluding oxygen from plant roots. It also collapses in on itself structurally when squeezed.

15. **Water**: The use of water alone is the choice of medium for growing lettuce, basil, arugula, and some herbs. The systems discussed later are those of the raft culture and nutrient film technique (NFT). In these systems, the plant roots are suspended directly into the nutrient solution. A supporting cover of Styrofoam boards (raft culture) and channels or gutters in the case of NFT keep the plants above the nutrient solution (Figure 11.4).

    Water, of course, is the medium for the essential elements to form the nutrient solution. Water must be very pure with few or no extraneous elements. It must not have sodium chloride present in excess of 50 ppm. If your source of water is from a city reservoir, it will be safe to use in hydroponics. If it comes from well water, you will need to have it tested to determine what elements are present and at what levels. Once you know the levels of the elements, you can determine if it is necessary to adjust the nutrient formulation to take these into account. You simply subtract the concentration of each of the elements present from the total you wish to add and calculate the balance of each you must add to get your optimum formulation. Often raw water is “hard.” That means that there is calcium and magnesium carbonates present, so the pH will have to be lowered with an acid. Remember that both calcium and magnesium are essential macro-elements; therefore, you will adjust the levels to add by those levels present in the raw water. In effect, this will save on the amount of calcium and magnesium used in the nutrient solution. Be particularly aware of any micronutrients that are present in raw water, especially boron as sometimes there is sufficient in the raw water that it will not have to be added to the formulation.

FIGURE 11.4 Plant roots suspended in a nutrient solution of raft culture. (Courtesy of CuisinArt Golf Resort and Spa, Anguilla.)

If the water is just hard, you can purchase a prepared nutrient formulation specifically for hard waters assuming that you may not wish to make up your own formulation.

Water analyses are offered by a number of laboratories that also do soil and tissue analyses. Please refer to the reference section for specific websites. Whether growing in soil or hydroponics, it is important to know the elements and their concentrations in the raw water in order to adjust your fertilization program to avoid excess levels of any element. With hydroponics, it is much easier to make these adjustments to your nutritional program compared to soil growing.

12 Small Indoor Hydroponic Units
Types and Construction

INTRODUCTION

There is a great variety of hobby indoor hydroponic systems in the market. All hydroponic systems, whether hobby or commercial size, can be placed within two groups according to their circulation of the nutrient solution. One is the recirculated or closed system; the other is that which is a nonrecycled or open system. Clearly, indoors in your home you must use a recirculation or a waste water collection system to prevent flooding your basement or other location having the hydroponic facility. In terms of nutrient management, recycled systems are more challenging than open systems. This is due to shifts in pH and nutrient levels of each element within the nutrient solution. Plants do not take up all elements at the same rate or quantity, especially under varying environmental conditions. As a result, each essential element in the nutrient solution changes with time at differing rates. This causes shifts in pH and the total salts in the solution measured by electrical conductivity (EC). However, in small household units when you find large changes in EC occurring you can simply dump the old solution (use it on your houseplants) and make up a new batch. The pH can easily be adjusted at any time with an acid or base as described earlier in Chapters 7 and 9.

Open systems are easier to manage since each irrigation cycle adds new solution. You must add sufficient solution to get some leachate as was discussed in Chapter 6. To overcome problems of disposal of the leachate (drainage) during each irrigation, simply place the growing units above a collection pipe that can conduct the spent solution to a waste reservoir. The waste solution can be used to water your house plants or even outside soil garden. Open systems have the advantage that if a disease got into the system, it would not spread back into the plants as it may in a recycled system.

SMALL INDOOR SYSTEMS

The following discussion of small indoor units is organized from the most simplified ones to more complex ones. These are all recycled systems. In Chapter 13, larger systems of both recycled and nonrecycled systems are presented.

NURSERY TRAY

This is a very simple system using a standard plastic flat (10½″ × 21″) without holes and a compact cell tray insert (Figure 12.1). These compact cell trays come in many different sized cells or cube partitions. They are readily available in garden centers. You may even have some left over from the last time you bought bedding plants for your outside garden. The best size for growing herbs and small lettuces is either a "24" or "36" cell tray. Cut out one corner of sufficient size to fit a plastic 1-gallon container. The plastic container must have a large lid of about 4″–5″ in diameter. Drill a ¼″ diameter hole in the middle of the lid and glue a ¼″ wide cork ring of 3″ in diameter. If you cannot find such cork rings, you may purchase a sheet of ¼″ thick cork and cut one from it. Remove a small gap from the ring, about ½″, so that it is not complete (Figure 12.2). This gap is going to allow the solution to flow from the bottle to the bottom of the tray. Place your finger on the hole in the lid after filling the bottle with nutrient solution and invert it into the corner of the flat where the corner of the cell tray was removed. Solution will flow from it until the level in the tray reaches the level of the hole in the lid. From then on, it will automatically siphon whenever the solution level in the tray falls below the lid face allowing air to enter the bottle. Refill the solution bottle as it empties from the plants' water demand.

Use either perlite or vermiculite or a mixture of 20% peat with 80% of either perlite or vermiculite as the substrate. Place the substrate in the cell tray; water it with a watering wand or watering can to thoroughly moisten the medium prior to sowing the seeds. You must use raw water only until germination of the seeds takes place and

FIGURE 12.1 Simple hydroponic nursery tray system. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

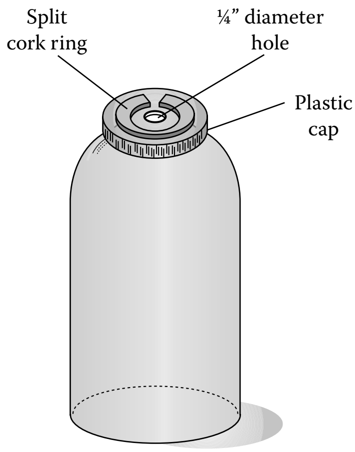


FIGURE 12.2 Nutrient reservoir bottle with cut ring and hole. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

the seedlings form their first true leaves, then use a half-strength nutrient solution for the next few weeks before using full strength solution. Do not use the inverted bottle reservoir in the tray until the seedlings are ready for the nutrient solution. You must harvest the herbs, basil, arugula, and lettuce fairly small otherwise they will extend due to the tight spacing restricting light to each individual plant. These types of crops would normally be for 4–6 weeks depending upon their nature of growth. The tray may be used to grow mesclun mixes of baby lettuce, herbs, arugula, beets, mustards, mizuna, chard, and spinach.

WICK SYSTEM

The wick system is an old system, but it works, especially for individual pots. This is a very simple form of hydroponics. It can be set up as a single pot or a series of pots or a tray of medium sitting on top of a nutrient reservoir (Figure 12.3). One or more wicks are positioned in the substrate and hang down into a reservoir of nutrient solution below. Capillary action moves the solution from the reservoir to the base of the plants as the medium dries. Use cotton or nylon fibrous rope. Bury one end of the wicks in the substrate close to where the plants are growing and let the other end dangle down into the nutrient reservoir below. It is best to flare the ends of the wicks to get better uptake and distribution of the solution. The choice of medium to use in this system is a 50/50 mixture of perlite and vermiculite.

MANUAL SYSTEMS

These are any simple systems whereby no electricity is needed for pumps or other components. It is simply the addition of nutrient solution to the growing unit by raising and lowering of a tank during an irrigation cycle (Figure 12.4). This can be done by hand. When the reservoir is raised, the solution will flow from the tank

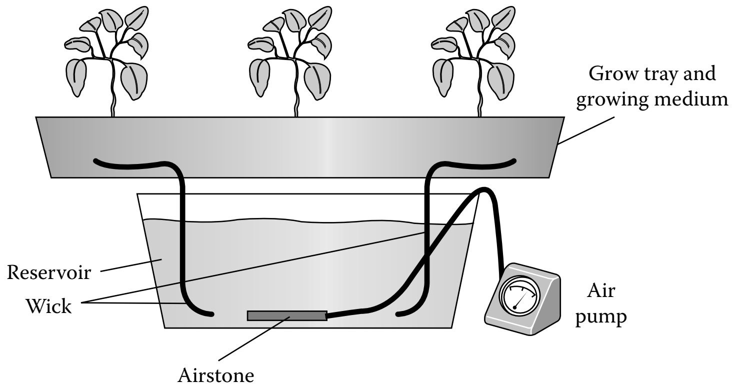


FIGURE 12.3 Wick system with wicks suspended to solution tank below. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

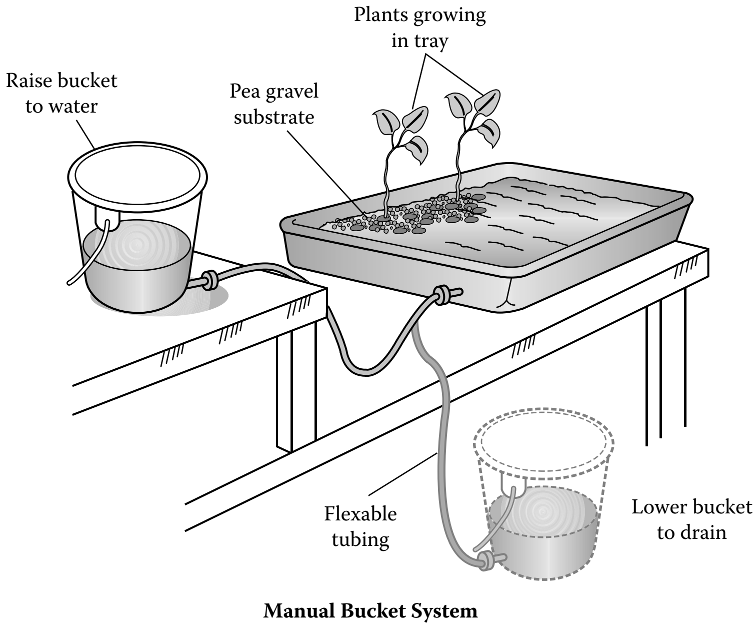


FIGURE 12.4 Manual system of raising reservoir to irrigate plant tray and lowering it for drainage. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

to the plant tray and when the reservoir is lowered below the level of the growing bed the water will drain back into the tank. This technique is a flood and drain system. The frequency of irrigation cycles depends upon the nature of the growing substrate. You may use perlite alone, a mixture of perlite and peat (50/50), perlite and vermiculite (50/50), peatlite mixture, coco coir mixture, gravel, pebbles, coarse sand, scoria, or expanded clay. The finer the material, the less irrigation

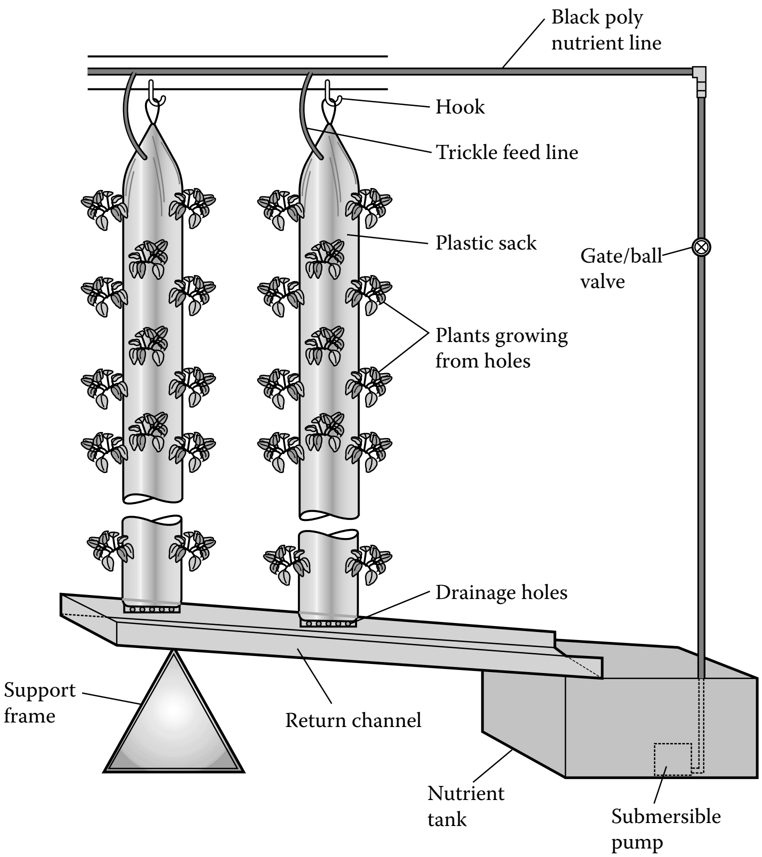


FIGURE 12.5 Small sack culture system design. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

cycles needed per day. With peatlite or coco coir alone, one irrigation per day would be sufficient.

This same principle may be applied to growing herbs, lettuce, arugula, basil, and even flowers in vertical sacks (Figure 12.5). Sacks are constructed of 6-mil layflat polyethylene that will give a diameter of 6–8″ when filled with a substrate. Cut the sacks about 6 ft long. Tie the bottom with string and fill the sack with moistened peatlite or coco coir. To make it lighter make a mixture of 70% coco coir and 30% rice hulls.

This medium must be moistened prior to placing it in the sack as water will not wet the dry substrate thoroughly when placed in the sack. Break up the peat or coco coir and mix it with some water in a wheelbarrow. Add a little water at a time and mix it uniformly. Test the moisture level in the medium by taking a handful of it and squeeze it until you see a small amount of water coming out. When you release pressure on it, the ball of medium should slightly break apart, but not collapse. At that point you have adequate water incorporated into the substrate. Be careful not to add too much water. That would be indicated by the ball not breaking slightly and excess moisture draining through your fingers upon squeezing it.

Once you fill the sack, tie the top of the sack leaving about 10″–12″ empty. Fold this end over and tie it again back to the sack. This will allow a loop by which you can support the sack to a frame above with a hook or rope. Use a 2 L (1/2 gallon) plastic water bottle as the solution reservoir. Cut a hole in the top of the sack immediately below the tie of the string. Insert the neck of the bottle in the sack through the hole. For a collection tank use a pail or plastic container with a top. Make some holes in the top of the lid and place it directly under the sack drain end. To irrigate take the water from the collection tank and fill the top irrigation bottle letting it percolate through the sack. Replace the collection pail under the sack to reuse the solution. Of course, as the plants use the solution you will need to add more new solution to the fill bottle.

Cut 1″ holes in the sack going down the sack spacing them at 6–8″ depending upon the crop you wish to grow. Use closer spacing for smaller plants. Stagger the position of the holes to improve light penetration to the crop. Start seedlings in rockwool or Oasis cubes and transplant to the sacks once they are about 2″ tall (usually 3–4 weeks old).

You can do this same vertical culture using 6″ diameter polyvinyl chloride (PVC) pipe instead of the plastic sacks (Figure 12.6). Cut 1″ holes in the pipe for the transplants similar to that for the sacks. However, it is best to use 1″ 90° elbows for the plant sites as shown in Figure 12.6. This will support the plants during transplanting. The PVC pipe can sit on a collection pipe of similar diameter that would conduct the solution to a tank. Cut the collection pipe in half lengthwise and fill it with gravel substrate to permit unobstructed drainage to the collection tank. The vertical pipe can also be supported by the collection pipe with additional support to secure its position at the top. Place a one-gallon plastic bottle on top of the pipe.

Remove the bottle cap from the container and invert it into the top of the growing pipe. You can use this fill bottle as a funnel or simply keep it as a storage bottle with nutrient solution that you collect from the drainage of the vertical grow pipe.

In the preceding systems of sack and column culture, a substrate is used to grow the plants.

These sack and column culture systems can be fully automated by having a nutrient reservoir underneath with a submersible pump operated by a time clock. Such automated systems with their plumbing are shown in Figures 12.5 and 12.6. The column culture system may also be set up as an aeroponic method without any substrate. In that case, the nutrient line will have mist jets every 6″ along the pipe opposite the plant sites. The pipe may be installed inside the column or outside entering the column from above as shown in Figure 12.6 as alternative piping. If the column is used with a substrate, the outside plumbing method would be used with drip lines at the top of the column similar to the sack culture system. The plant sites should be arranged spirally down the column at 6–8″ centers.

Both sack culture and column culture are suitable only for low-profile plants like lettuce, arugula, basil, and herbs.

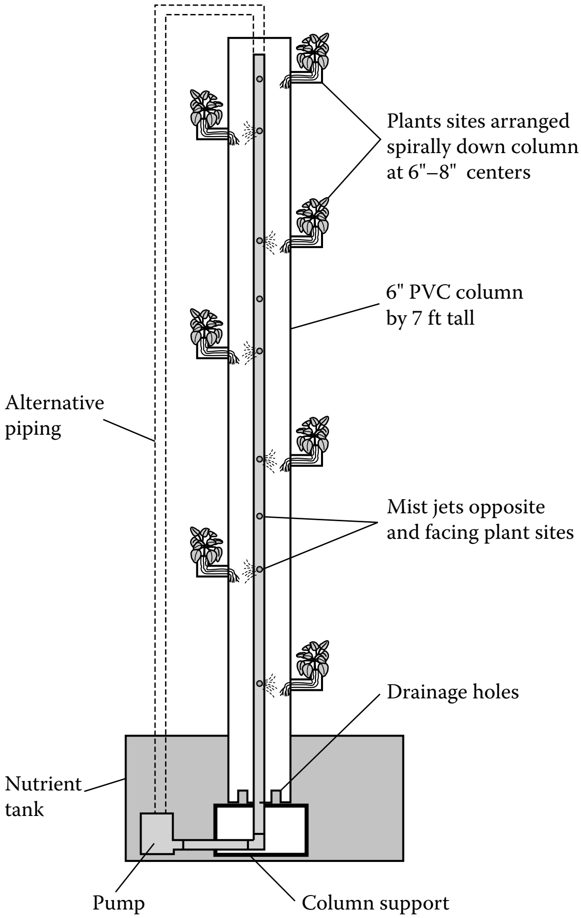


FIGURE 12.6 Self-contained column culture using PVC pipe. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

WATER CULTURE (FLOATING OR RAFT)

If you wish to grow lettuce, arugula, basil, and some herbs, a simple raft culture system may be constructed. With this system construct a bed from concrete blocks or treated wood. The blocks can be 4″ thick by 8″ by 16″. Place them on edge to get an 8″ depth of the bed. Make the inside dimensions several inches wider on each side of a 4 ft × 4 ft frame. Line it with 12-mil polyethylene (black) or a 20-mil thick vinyl swimming pool liner. Fold the inner corners up like an envelope and glue these laps, if vinyl, using vinyl cement. If using polyethylene bring the liner onto the top of the cement blocks and hold it down with a perimeter piece of lumber. If you use 2″ × 8″ treated lumber, you can staple the liner to the top of the lumber and then nail a lathe around the perimeter to secure the liner edge uniformly.

Purchase a 4 ft × 8 ft × 1″ thick Styrofoam. Use the pink or blue "Roofmate" denser material as it will not break as easily as the less dense white material. Cut the board into 4 ft × 4 ft. Using a saw hole drill cut holes of ¾–⅞″ diameter so that the grow cubes (rockwool or Oasis) will fit snugly into the holes during transplanting. The holes are spaced 6″ × 6″ center to center. Make up nutrient solution to fill the raft bed to within 1″ from the top. The volume of water in this size of bed is as follows:

Volume = length × width × height
V = 4 ft × 4 ft × 7″/12″ = 9.33 cubic feet
Conversion to U.S. gallons: 1 cubic ft = 7.48 gallons
Therefore: 9.33 × 7.48 = 70 gallons

Start your seedlings as explained in Chapter 14.

Upon transplanting the seedlings to the raft system aerate the solution several times a day by beating the solution with a whisk. Alternatively, of course, you could add an air pump with a tube attached to an airstone in the bottom of the bed.

There are two main water culture systems, raft or floating and nutrient film technique. In this section the raft system is presented. This system is ideal for lettuce, arugula, basil, mint, watercress, and a few other herbs. It is not suitable for vine crops or long-term plants due to eventual lack of oxygenation to plant roots. A small indoor unit can be constructed of the following components.

Supplies

1. A plastic storage bin with lid for keeping clothes or other items is great for a nutrient reservoir (Figure 12.7). Use a large one at least 14″ wide by 18″ long by 8″ deep, between 12 and 15 gallons. It must have a relatively flat lid and the bin should be of an opaque color such as black or dark blue to prevent light from entering. If light comes in contact with the nutrient solution, algae will grow in it causing plugging of lines and unwanted build-up of slime in the system. Also, you can wrap the bin with aluminum foil to

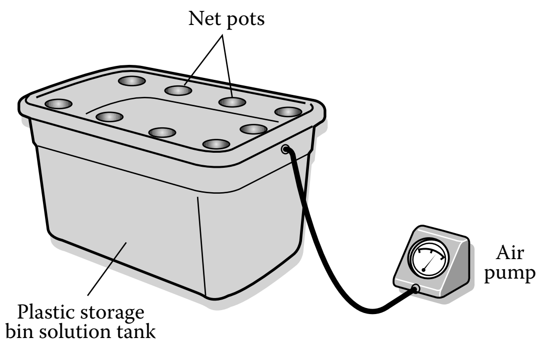


FIGURE 12.7 Simple deep flow system using a plastic storage bin with lid. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

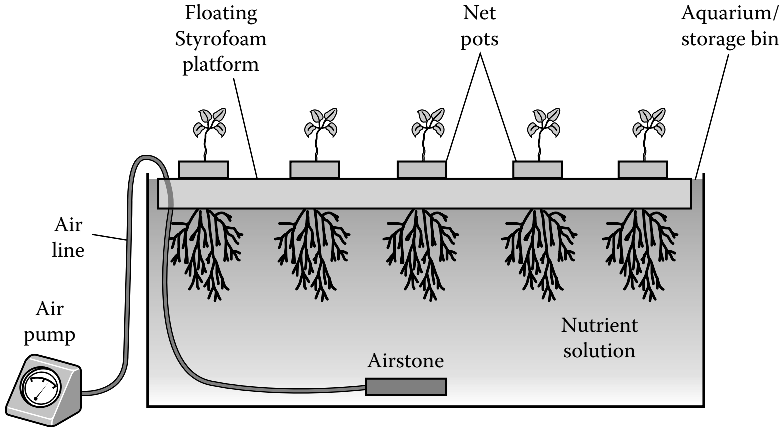


FIGURE 12.8 Simple raft system using a plastic storage bin, Styrofoam board cover, air pump, tubing, and so on. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

prevent light and heat accumulation. The plants are seeded in rockwool or Oasis cubes and within 3 weeks transplanted to 2″ diameter net pots that support the plants in the lid of the storage bin (nutrient tank).

Alternatively, use storage or tote bins without a lid and cut a 1″ thick Styrofoam board to float on top of the solution (Figure 12.8). Prepare it as described earlier in “Manual Systems.” Be sure to use the dense “Roofmate” type of Styrofoam. Cut ¾″ holes spaced 6″ × 6″ for lettuce, arugula, and basil. For smaller herbs make the spacing 4″ × 4″. The use of the Styrofoam cover over a plastic lid is that it insulates the solution below, but that should not be an issue if this is for growing plants inside your home under artificial lights.

2. An air pump, such as a fish aquarium pump with plastic tubing.
3. A fish aquarium airstone attached to the other end of the tubing. This is located in the nutrient reservoir to add oxygen to the solution. You may purchase this equipment at a pet store where fish and aquariums are sold. Use an airstone 4–6″ long to give lots of oxygen to the nutrient solution. Assembly is shown in Figures 12.7 and 12.8.

WATER CULTURE-NUTRIENT FILM TECHNIQUE (NFT) SYSTEM

The principle of the NFT system is to keep a constant flow of thin layer of solution through the plant roots in a channel or grow tray. This is a recirculation method returning the solution from the grow tray back to the nutrient reservoir below. The components are as follows.

Supplies

1. One or two grow trays or gutters constructed from a 2″ PVC pipe. There are commercial NFT channels available at hydroponic stores. If you want

to use a 2″ PVC pipe, you will need the following fittings for each channel: one end cap, one 2″ 90° elbow with a 2″ × 1″ reduced bushing, 4″ of 1″ PVC pipe as the drain spout back to the reservoir underneath. If an elbow is used one end cap will be sufficient. However, it would be better to use one 2″ × 1″ reduced tee just before the end of the pipe and another end cap. That would be more effective than using the elbow and reduced bushing at the drain end of the pipe. Then, the end of the tee with the added 1″ spout would enter the lid of the reservoir.

2. Purchase a small submersible pump, such as a "Little Giant" fountain pump or a smaller submersible pump, at a hydroponic or irrigation store. Poly tubing to connect the pump with the inlet end to the growing channel. Drill a small hole on the top of the pipe at the front end where the solution will enter.
3. A nutrient reservoir of a storage bin as described earlier in "Floating System."
4. An aquarium air pump and airstone as was also described in "Floating System."
5. Small 2″ × 2″ round plastic mesh pots available at a hydroponic shop. These are needed to support the growing cube with the transplant. During transplanting place the seedling in the mesh pot, which sits in the hole in the growing channel.

Assembly

1. Drill one small hole in the storage bin lid near one end and the other at the opposite end. These must be just large enough to fit the poly hoses from the pump in the nutrient tank going to the NFT channels and the other from the air pump to the reservoir connecting the airstone.
2. The NFT channels will need 2″ diameter holes drilled at the plant spacing of 6″ or 4″ according to the crop spacing needed. Be sure that these holes will not cut the sides of the pipe. These plant holes are to fit the 2″ net pots with the transplants as shown in Figure 12.9.

   Keep all the holes in line at the top edge of the pipe. Do this by snapping a chalk line along the top. Once the holes have been drilled, use sandpaper to eliminate all sharp edges of the holes. Then, glue an end cap at the inlet end and a reduced tee (2″ × 1″) before the end cap at the drain end of each channel.
3. Drill a 1¼″ hole in the reservoir lid at the return end of the NFT channels to allow the 1″ diameter tee and spout to enter the tank for drainage back to it.
4. Make a support pipe to be placed at the top edge of the grow pipes. This is done by using a short piece of 3″ PVC pipe and cutting 2″ holes in it to hold the grow pipes. Be sure that in this case the 2″ or slightly larger holes will cut the side of the support pipe to permit the nesting of the grow pipes. This can be done with a hole saw and then widen the edges with a hacksaw until the grow pipes nest securely. You could also use a short piece of 4″ diameter pipe to do this as the support pipe. The principle here is to support one end

FIGURE 12.9 Net pot in 2″ PVC pipe NFT channel.

of the growing pipe at least 2″ above the lid of the reservoir underneath. This will give adequate slope so that the solution will quickly run back to the nutrient reservoir giving the solution some oxygenation as it falls back into the reservoir. Simply lay the support pipe on top of the reservoir lid at the inlet end of the growing pipe as shown in the plan view of Figure 12.10.

The flow of the nutrient solution should be between 1 and 2 L (¼–½ gallon) per minute. That rate of flow will provide good oxygenation. If you use ¼″ tubing from the pump to the channel insert a small piece of drip line into the end where it is entering the channel to reduce the flow, if necessary.

The final assembly will appear as in the diagram (Figure 12.10).

EBB AND FLOW (FLOOD AND DRAIN) SYSTEMS

This system consists of a growing tray sitting above a nutrient solution reservoir. The principle here is to flood the growing tray with the nutrient solution and then allow it to drain back to the reservoir below. Substrate should be porous such as gravel, pea gravel, expanded clay, or coarse sand. Do not use any fine medium like peatlite, coco coir, or sawdust as these will hold too much moisture and there will be a lack of oxygen to the plants.

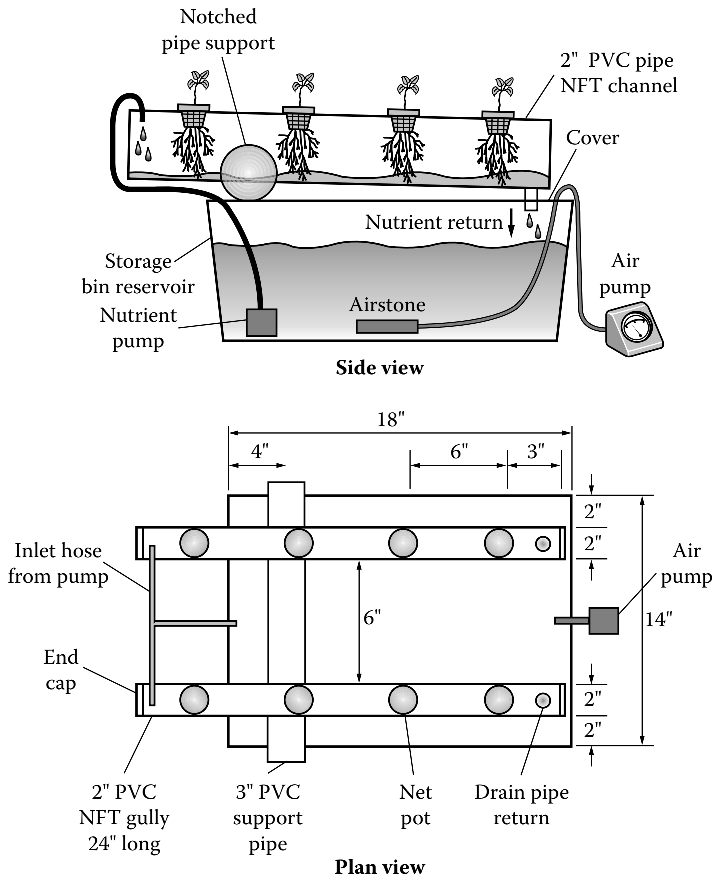


FIGURE 12.10 Side and plan views of simple NFT system. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

A submersible pump in the solution reservoir pumps the solution into the tray. The pump is operated by a timer to automatically irrigate several times a day depending on the stage of plant growth and moisture retention of the medium. A sealed fill/drain fitting must be attached to the bottom of the grow tray. When the timer shuts off the pump, the solution will run back to the reservoir below through the pump.

This type of hydroponic system can grow most plants including vine crops of tomatoes, peppers, eggplants, and cucumbers.

Supplies

1. Two storage bins, one for the nutrient tank and the other for the growing tray. The growing tray may be larger than the solution reservoir, but should be shallower. A large grow tray would sit on top of the solution reservoir.

Use at least a 15–20 gallon bin for the reservoir with a depth of 1 ft or more. The grow tray should be wider and longer in order to sit above the solution tank supported by ¾″ square metal tubing spanning the reservoir (Figure 12.11). The depth of the growing tray should be 8–10″. A second option is to have the length and width of the growing tray slightly smaller than that of the reservoir enabling it to nest within the reservoir as shown in Figures 12.12 and 12.13.

2. A frame to support the growing tray may be constructed of 1″ schedule 40 PVC or ¾″ square steel or aluminum tubing that could be cut and bolted together with brackets or if the reservoir bin is strong enough, simply place a few square steel tubing bars across it as shown in Figure 12.11.
3. A submersible pump with ½″ polyethylene tubing.
4. One bulk-head fitting to seal the entrance of the tube from the pump into the bottom of the grow tray. Bulk-head fittings have rubber washers on each side and screw tightly against the tray to seal it from leaking. Alternatively,

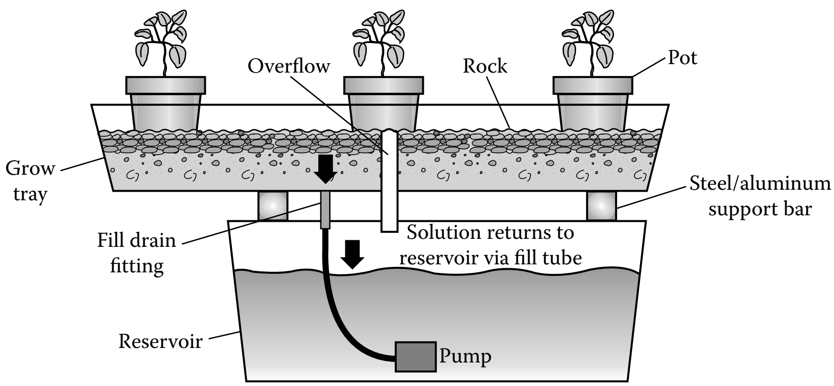


FIGURE 12.11 An ebb and flow indoor unit showing drain cycle with pump off. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

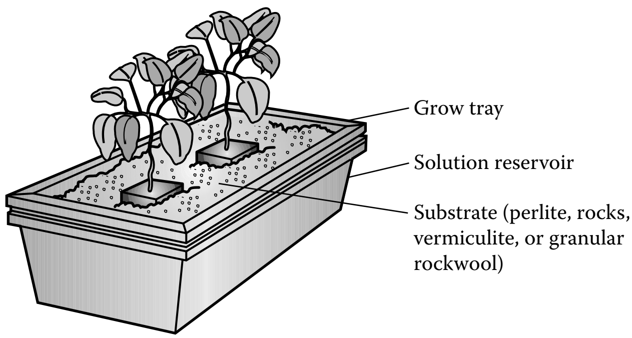


FIGURE 12.12 Alternative ebb and flow system made from two plastic storage bins. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

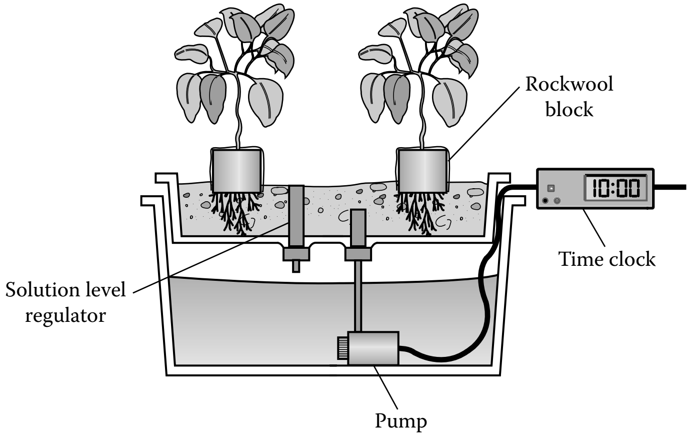


FIGURE 12.13 Piping details of ebb and flow system. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

you could use some air-hose fittings available in an aquarium shop. Seal those with silicone rubber.

5. An overflow pipe that regulates the maximum height of the solution entering the grow tray. This pipe should be long enough to regulate the solution level within 1″ from the surface of the substrate in the grow tray and extend below into the solution reservoir to avoid any spillage. It must also be sealed with some type of fitting similar to the pump inlet tube.

Assembly and Solution Makeup

Assemble the ebb and flow system as shown in the diagrams (Figures 12.11 through 12.13). Probably the most difficult parts to install are the inlet pipe and overflow pipe in the bottom of the grow tray so that a water-proof seal is attained. The construction of the support frame for the grow tray must maintain the grow tray level in all directions above the nutrient reservoir. Be sure to wrap the reservoir with aluminum foil to prevent light from entering. Also, purchase a lid for the storage-bin reservoir. Make an access panel of 2″ × 2″ at one corner of the lid to enable the addition of water to the tank.

When mixing the nutrient solution remove the lid of the tank, pump, and fittings and slide the tank from underneath the growing tray. It is important to construct the frame of the growing tray high and wide enough so as not to restrict movement of the reservoir below for making up the solution. When the plants use up about half of the nutrient solution in the reservoir add water only the first time, and the second time it goes down change the solution. Clean the reservoir well with a 10% bleach solution to disinfect it and then rinse it with clean water before making up the solution.

Alternative System

This ebb and flow system can be modified to use pots with substrate instead of a full tray of aggregate. To construct this system use a grow tray of 4–6″ deep instead of 8–10″. Place 1″ of aggregate in the bottom of the grow tray to prevent algae growth in the tray. Set three-gallon nursery pots on top of the gravel in the tray as shown in Figure 12.11. Fill the nursery pots with coarse sand or perlite. The rest of the growing tray is made similar to that described earlier with the exception that the overflow pipe is set 2″ high above the base of the tray. The remaining components are the same.

DRIP IRRIGATION SYSTEMS

Drip irrigation is the most widely used and versatile method of hydroponics. Operation is simple with a timer activating a pump to initiate an irrigation cycle. During a cycle of irrigation, the solution is pumped from the nutrient reservoir to the base of the plants through a drip line (Figure 12.14). Drip irrigation systems may recycle the nutrient solution to the nutrient tank or it may leach to waste. In a recirculation (closed) system the pH and strength (EC) of the solution must be checked periodically and adjusted. As a result, the recycled system is more complicated to manage compared to an open system in which the excess solution drainage (leachate) is run to waste. In the nonrecovery design, the nutrient solution is made up and applied to the plants during irrigation cycles with the same pH and concentration without needing adjustments. The nutrient solution may be stored in a large cistern or tank. It can also be mixed as concentrated "stock" solutions that are diluted by

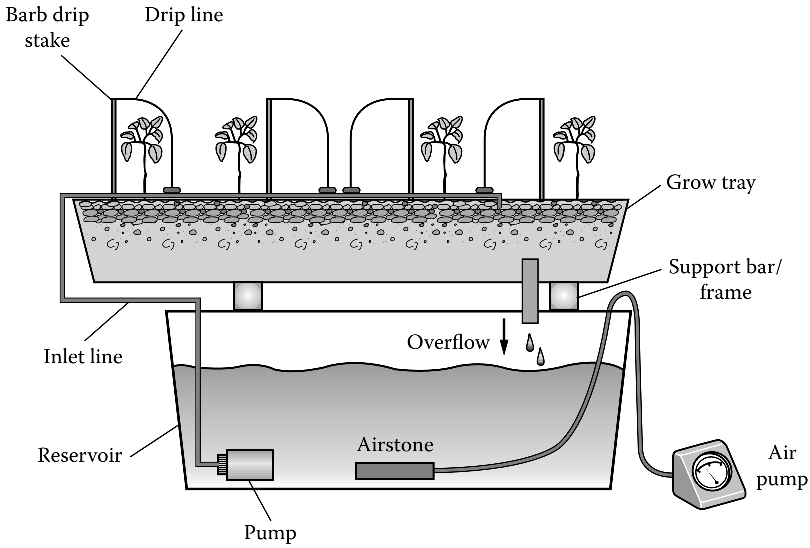


FIGURE 12.14 A drip irrigation system with grow tray of substrate above a nutrient tank. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

an injector system upon demand for an irrigation cycle. This is the most common method for large hydroponic operations. For indoor hobby units simply make up a batch of nutrient solution in a storage tank. The larger the tank the less frequent will be its makeup.

Suitable substrates include peatlite, coco coir, perlite, vermiculite, sawdust, rockwool, rice hulls, and expanded clay. Any of these will grow most plants including the vine crops. The basic setup is very similar to that of ebb and flow systems with the exception that the nutrient solution is pumped to the base of the plants at the top of the tray and distributed with a drip manifold to individual drip lines (Figure 12.14). The solution is returned to the tank underneath by a drain pipe sealed to the bottom of the grow tray. The growing tray must be level in all directions to prevent any water accumulation. An option to fill the grow tray with medium is to use pots in the tray. Set them on top of a black weed mat or on about 1″ of gravel or expanded clay to facilitate drainage and to prevent algae growth. The size and number of pots is dependent upon the crop grown. For lettuce and herbs use eight 4″ pots. For vine crops a maximum of two 10″ pots is feasible providing the plants are V-cordon trained in both directions. In this manner, separate the top of the crop sufficiently to get 3.5 sq ft of surface per plant. Place two drip lines in each pot. It is advantageous to include an air pump connected to an airstone placed inside the solution tank to improve oxygenation.

Supplies

1. Two plastic storage bins as described earlier for the ebb and flow system. The grow tray should be 8–10″ deep so that there is adequate space for growing vine crops.
2. PVC or steel pipe framework to support the grow tray above the solution reservoir.
3. Submersible pump with tubing, drip manifold, drip lines, and stakes to hold the drip lines in place.
4. An aquarium air pump placed outside, connected with poly tubing to an airstone (4–6″) in the solution tank.
5. A ¾–1″ diameter drain pipe attached flush with the bottom of the grow tray on one end using a bulk-head fitting or other that gives a complete seal against leaking.
6. A time clock to control irrigation cycles by the pump.

Assembly

The assembly as shown in Figure 12.14 is very similar to that of the ebb and flow system with the exception of the different placement of the drain pipe and the use of the drip lines to the top of the grow tray. Drip irrigation supplies may be purchased from an irrigation or hydroponic store or online.

Seedlings are started in rockwool cubes, transplanted to blocks (vine crops), and later transplanted again to the grow tray once they are 6″ or so tall. The procedures for growing seedlings are discussed in Chapter 14.

Alternative System

One of the very earliest indoor units using drip irrigation was that of the "tube-in-tube" design as was shown in Figure 1.2 of Chapter 1. A fish aquarium air pump is mounted on one edge of the growing tray with a ¼″ diameter poly hose connecting it to a slightly larger diameter hose in the nutrient solution of the reservoir underneath. The key to success here is to use a slightly larger hose to join about 1″ insertion of the smaller diameter hose allowing the air to suck in the nutrient solution as it enters the larger hose. Connect the larger tube to the smaller one with a pin. The larger hose must be loose enough for the solution to enter at the union as the air is bubbled up through the larger hose. The movement of air drags the nutrient solution into the larger tube and raises it up into the grow tray above. The larger hose enters the grow tray and lies on the top of the substrate. This area of the hose above the substrate has small holes drilled into it every 2″. The holes must be no larger than 1⁄16″ in diameter so that all of the nutrient will be carried along its length on the top of the medium.

To support the grow tray without a tray support frame do as follows: Purchase the grow tray a few inches smaller in length and width than the reservoir. Drill ¼″ diameter drainage holes in the bottom of the grow tray 3″ × 3″ spacing to within 2″ of the outside perimeter. Do not use a lid on the reservoir below. Place two or three ½″ square aluminum- or chrome-plated supports across the top of the nutrient tank and set the grow tray on top of those bars in a position between the drainage holes. To use a lid on the lower tray, it is possible if it has a lip that seals the bin around the edges. However, to get good drainage position the upper grow tray on top of the lid of the lower reservoir and drill holes through both the bottom of the grow tray and the lid of the reservoir at the same time in the identical same positions. Glue or silicone a few guides, using small plastic tubing, positioned at the corners of the grow tray and adhered to the lid of the reservoir. In that way, when you place the grow tray on the top of the reservoir, the drainage holes will line up. Refer to Figure 1.2 to follow the assembly of the drip systems.

The air pump can be activated with a time clock for the use of fine substrates in the grow tray or for coarser material such as rocks or pebbles allow the pump to run constantly. The air pump not only moves the solution from the reservoir below, but also adds oxygen to the solution as it moves up to the grow tray.

For this form of drip system, you may use expanded clay, pea gravel, coarse sand, perlite, vermiculite, or rockwool granules. Do not use peatlite mix or coco coir due to excessive moisture retention. You could use rice hulls as they have lower water retention. Coarse vermiculite and perlite are the best substrates for this system. If you wish to use pea gravel or expanded clay add a ½″-thick layer of peatlite or coco coir layer on top to achieve capillary sideways movement of the solution.

ROCKWOOL SYSTEM

Rockwool is a common substrate used in hydroponic culture and it is available at hydroponic stores. As discussed in Chapter 14, the seedlings are started in

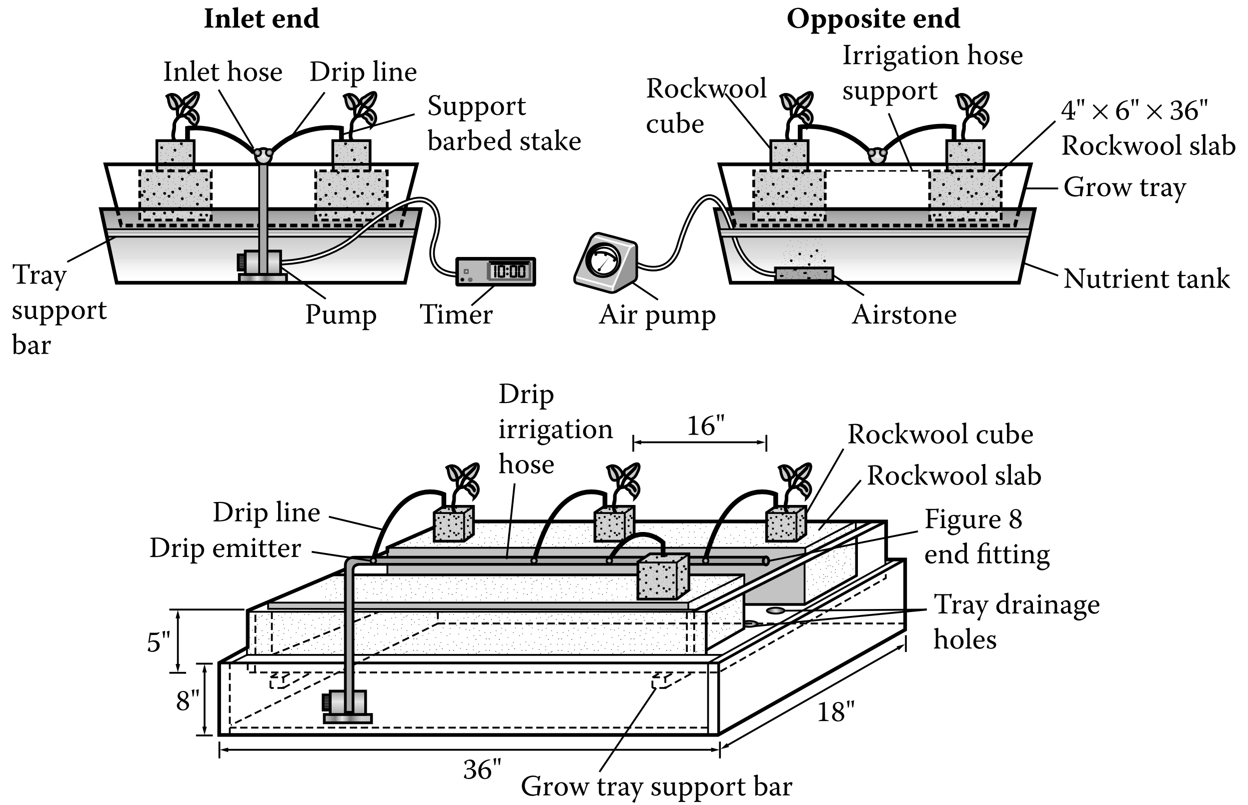


FIGURE 12.15 Rockwool slab system with drip irrigation and a nutrient tank below. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

rockwool cubes that are transplanted to rockwool blocks. From there, they are transplanted to the rockwool growing system using rockwool slabs 4″ thick by 6″ wide by 36–39″ long. The simplest method of construction for an individual unit is to purchase a plastic bin of minimum length of 36″ by 18″ wide by at least 8–10″ deep (Figure 12.15). A greater depth is fine as that will increase the overall volume of the tank and reduce the frequency of adding water and/or changing the solution. If you can find this size of container, a second grow tray above will not be necessary providing the tray has a locking lid that positions the lid top below the sides of the bin. If such dimensions are not available use two bins as described for the drip irrigation system.

Use the lid as the support tray for the rockwool slabs. With the preceding dimensions of the bin, the system will fit two slabs. Feeding of the plants to their bases is by a drip irrigation system operated by a timer. As described for drip irrigation systems, position the end of the drip line with a special barbed stake guide. There are several differences with this drip system compared to the ones described earlier. The pump is connected to PVC pipe that is converted to ½″ black poly hose using a barbed adapter at the entrance to the slabs above the lid. The black poly line runs along the length of the lid between the two slabs. Drip lines are attached to the black poly line using 0.5-gallon per hour pressure compensating emitters punched into the line. Each emitter is attached to a 16″ length of drip line of 0.160–0.220″ diameter.

With vine crops such as tomatoes, peppers, cucumbers, or eggplants, each slab will contain three plants so a total of six drip lines are required, one to each plant base. The end of the black poly hose is bent over and secured with a figure "8" adapter or a short 3″ piece of 1″ diameter PVC pipe. The key to success with this number of plants is the V-cordon training in both directions to provide 3.5 sq ft per plant at ceiling height. Plant only one cucumber plant per slab.

Supplies

1. One plastic storage bin with a lid measuring 36″ × 18″ × 8–10″ or more in depth.
2. Submersible pump of minimum capacity of 80 gallons per hour (gph).
3. Compensating emitters of 0.5 gph.
4. Drip line—0.160–0.220″ diameter, 10 ft.
5. Barbed stakes: six.
6. Figure "8" end stop or 3″ of 1″ diameter PVC pipe.
7. Schedule 40, ¾″ diameter PVC pipe: 2 ft.
8. Male adapter to fit pump outlet diameter, a reduced bushing from ¾″ diameter to the diameter of the pump outlet.
9. Fittings: ¾″ PVC 90° elbow, ¾″ × ½″ slip by thread bushing, ½″ barbed adapter (thread-barb), 1″ hose clamp.
10. PVC glue and cleaner
11. An aquarium pump, poly tubing, and 6″ airstone to aerate the solution.
12. A 24-h time clock with 5–15 min intervals, no greater.
13. A poly punch tool to make the holes in the black poly hose for the emitters.

Assembly

First assemble the drip hose and emitter system. Glue the various fittings, punch the holes for the emitters (six for vine crops) evenly along the length of the black poly hose starting at 3″ from the PVC adapter and no closer than 6″ to the end. Push in the emitters and attach the drip lines with the barbed stakes at their ends. Then, make up the PVC piping from the pump to the black poly lateral hose. Use Teflon tape on all threaded fittings. Refer to the diagram for details.

With the air pump attach a section of poly tubing long enough to reach the inside of the reservoir and there connect to the airstone.

Make ¼″ drainage holes on the top of the lid for recycling the solution leachate from the slabs to the reservoir below. Make two rows of these holes about 4″ apart going down the center of the lid and within 1½″ of the edge. Drill the two rows of holes 4″ apart and stagger their positions (Figure 12.16). At one end make holes 4″ apart to intercept any runoff that does not go down the center of the lid.

Drill a hole large enough to fit the PVC pipe from the pump in the middle of the opposite end to the drain holes, 3″ from the edge of the reservoir. Construct a little stand about 1″ high at one of the corners of the lid to support the air pump. Drill a ½″-diameter hole for the air hose to enter the reservoir to connect to the airstone. Cut a 3″ × 3″ square access panel in the lid at the middle or corner of one end to permit the addition of water to the reservoir. Refer to the diagrams for details (Figures 12.15 and 12.16).

If you cannot find a storage bin 36″ long, design the system as explained earlier, but cut the rockwool slabs shorter to fit the lid dimensions. It may be possible to grow only four vine crops in such a smaller unit. If you cut the end of a slab staple it closed.

When growing vine crops that are trained vertically in a small hydroponic unit support them above with a wire and space this wire to give adequate light to the entire plants as explained in Chapter 24. V-cordon train them away from the grow tray. The support cable must be at least 30″ apart at the top of the mature plants. In your basement or a spare room use ceiling hooks to support the plant strings.

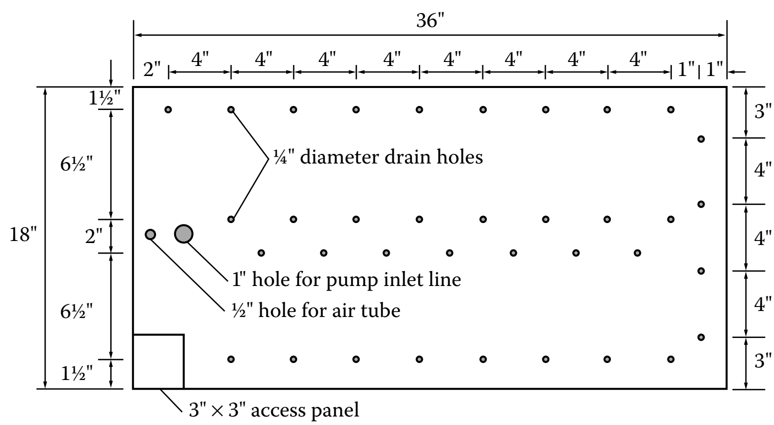


FIGURE 12.16 Drainage hole positions in lid of nutrient tank. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

COCO COIR SYSTEM

This system is the very same as the rockwool one, but instead of using rockwool slabs, use coco coir slabs. The dimensions of the coco coir slabs are similar to those of rockwool. The biggest difference in cultural techniques is that coco coir needs less frequent irrigation cycles compared to rockwool. Generally, two to three cycles per day are sufficient. You need a 15% leachate during each irrigation, whereas with rockwool the leachate should be 20%–25%.

AEROPONIC SYSTEM

An aeroponic system is one of the most highly technical methods of hydroponics and most risky should a loss of power occur to delay irrigation cycles. In this system, the plants are supported in the top (lid) of the reservoir with their roots suspended below in the air space between the solution and top cover. The roots are misted every few minutes with nutrient solution. The submersible nutrient pump is controlled by a timer that runs the pump for a 1 min and 4 min off on a 24-h basis.

The nutrient reservoir should be of 15–20 gallons with a depth of at least 12″. It must come with a lid that secures the sides of the bin. This system is best for small plants such as lettuce, basil, arugula, and herbs, but with care and experience it could grow vine crops. All of the crops are started in rockwool cubes and transplanted to 2″ mesh pots that are placed in 1¾″ diameter holes on the top of the bin lid. For lettuce, basil, and arugula use 6″ × 6″ spacing of holes, and for other herbs you may use 4″ × 4″ spacing. Stagger the position of the holes if possible. The exact layout of the plant holes depends upon the dimensions of the storage bin. For example, a bin 16″ wide by 20″ long by 12″ deep, as shown in Figure 12.17, has a volume of 17 U.S. gallons. It would hold eight plants (four per row) in two rows spaced 8″ apart. The spacing within each row is 2½″—5″—5″—5″—2½″.

Supplies

1. A 15–20-gallon storage bin (2–2½ cu ft) with lid.
2. A high pressure submersible pump.
3. PVC pipe of ¾″ diameter for the mist nozzle distribution pipe and the support pipe frame.
4. Various PVC fittings for the mist distribution pipe.
5. An accurate 24-h timer with minute intervals. Alternatively, use two timers, one of 24-h intervals and the other of 1 h with 1-min intervals. Place these in series.

Assembly

The pump and all piping are set within the nutrient reservoir. The mist jets mounted in the PVC header pipe is located above the level of the nutrient solution. Assemble the piping and mist jets first then place them in the nutrient reservoir. A supporting

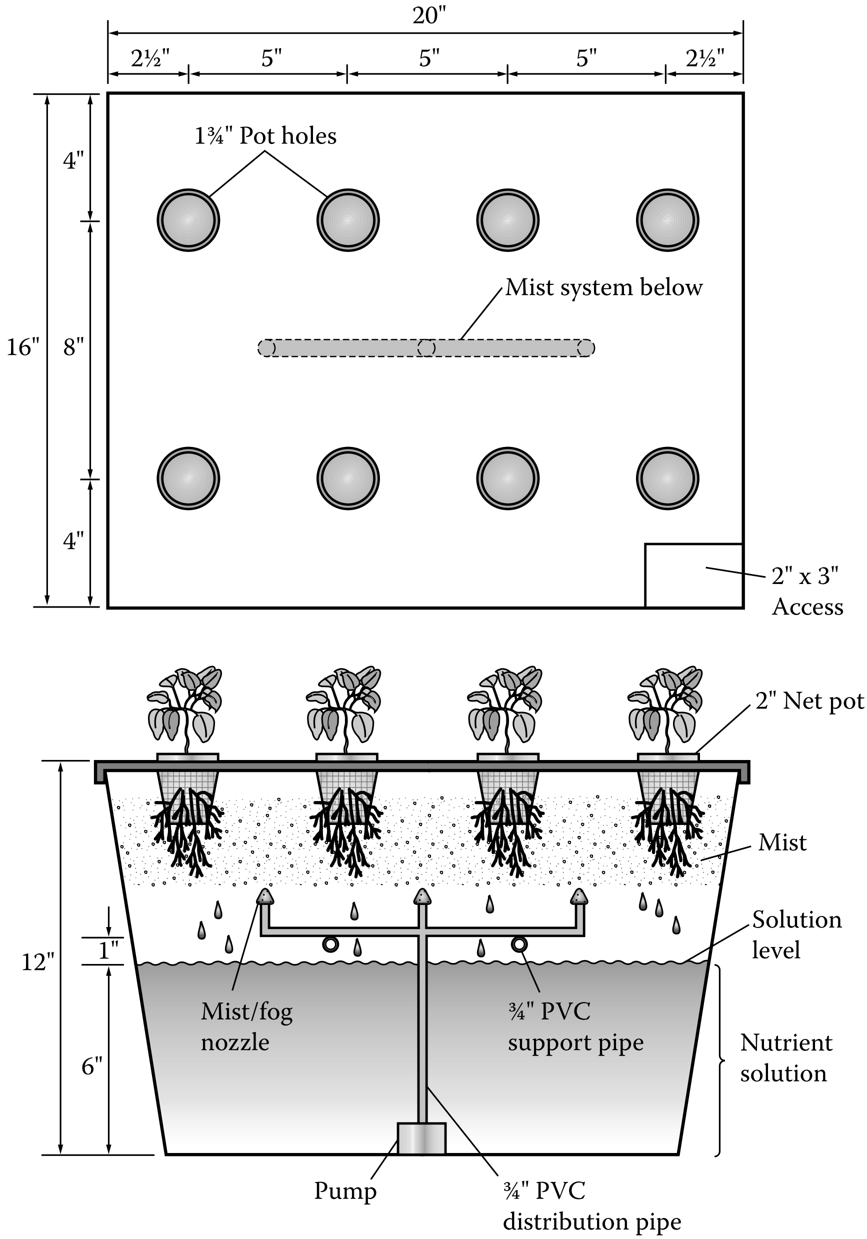


FIGURE 12.17 Aeroponic simple system showing mist jets. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

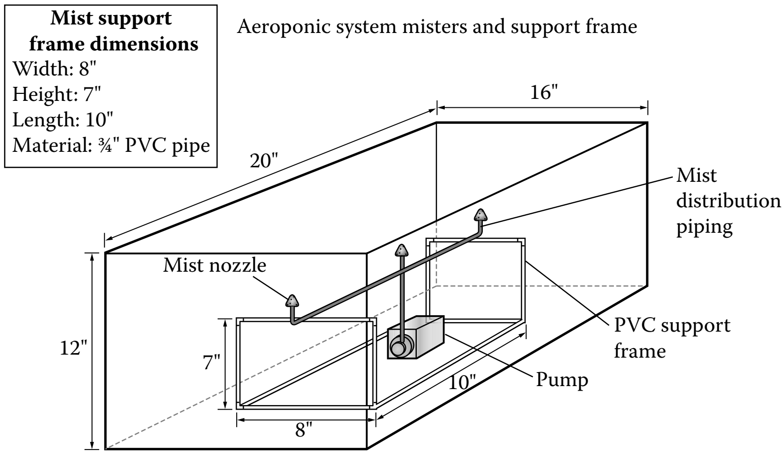


FIGURE 12.18 PVC frame supporting mist jets in nutrient tank. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

frame of PVC pipe is constructed to support the mist-jet manifold above the level of the nutrient solution.

Cut 1¾″ diameter holes in the reservoir lid at spacing according to the nature of the crop as described earlier. Make a 2″ × 3″ access panel at one corner of the lid to add water or nutrients. The mist nozzles should be located about 4″ below the top of the lid. The maximum level of the solution is to be 6″ to permit adequate air space above for the mist distribution and the aeration of the plant roots. These details are outlined in Figures 12.17 and 12.18.

Alternative Design

Use two bins, a lower nutrient reservoir and an upper growing tray. The growing tray should be several inches smaller in length and width from the reservoir so that it will sit flat on the cover of the reservoir. The growing tray should be about 6″ deep with a cover. It sits on top of the lid of the nutrient tank. Install a ½″ diameter drain pipe at the center of one end of the grow tray to return the solution to the tank below. Seal the drain pipe to the bottom of the grow tray as explained earlier for other units.

Use ½″ high-pressure tubing from the submersible pump to the base of the grow tray. As it enters the grow tray use a rubber washer to seal it. Connect the tubing to a ½″ barbed tee as it enters the growing tray. With a short piece of tubing connect both sides of the tee to ½″ PVC using barbed-PVC adapters as shown in Figure 12.19. This will allow the growing tray to be detached during cleaning between crops. In the grow tray, the PVC pipe is branched with the tee to form two mist nozzle manifolds. Insert the mist nozzles at about 6″ spacing along the manifold depending upon the grow tray dimensions. The misting assembly sits on the base of the grow tray as shown in the diagrams of Figure 12.19. Cut holes in the grow-tray cover for the plant

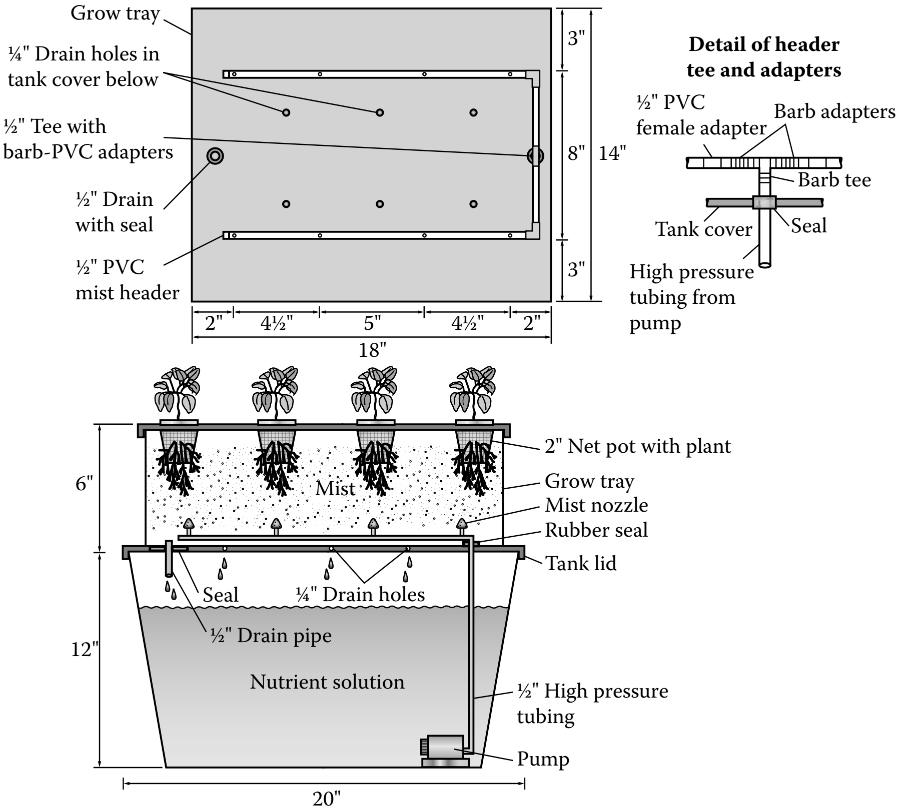


FIGURE 12.19 Alternative design using two bins with details of the aeroponic system. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

pots as described earlier. Use Schedule 40 or 80 PVC pipe that has thick walls so that the mist nozzles can be attached to the pipe.

Drill ¼″ holes in the lid of the nutrient tank about 5–6″ apart for drainage back to the solution tank of any solution that may leak from the grow tray.

These types of aeroponic units are available at hydroponic shops and online (refer to Appendix).

13 Large Indoor Hydroponic Units
Designs and Construction

Chapter 12 exemplified individual unit systems. This chapter shows how to construct a series of pots, gutters, slabs, and so on that drain to a central reservoir. These growing systems are more complex in their construction due to the need for supporting structures for the growing trays and more plumbing to connect them to the feeding and draining systems. Some of the systems are more suitable to low-profile plants such as lettuce, arugula, basil, and herbs, while others are more versatile and can also grow vine crops such as tomatoes, peppers, cucumbers, and eggplants.

MULTI-POT OR GROW TRAY WICK SYSTEM

This system is the same principle as the single-pot wick design, but instead of just one pot a series of pots are supported in the lid of the nutrient solution reservoir (Figure 13.1). This system is for low-profile crops. Use 4″ diameter plastic pots to contain perlite and/or vermiculite as the substrate. These pots are supported by the lid of the nutrient tank. Drill approximately 3¾″ diameter holes in the lid at 6″ × 6″ spacing. Be sure to measure the diameter of the pot directly below the lip so that the top lip section of the pot remains above the lid.

A second method is to place a grow tray on top of the nutrient solution tank and extend wicks from the solution tank through the base of the grow tray into the substrate of the grow tray where the plants are positioned, as was presented in Figure 12.3.

MATERIALS

1. Storage bin with a snap-on lid
2. Cotton or fibrous nylon rope
3. Four-inch diameter plastic pots
4. Perlite and vermiculite mixture at half and half of each
5. Air pump and 4″ airstone

ASSEMBLY

Drill the holes for the pots in the lid staggering their positions. If a large storage bin greater than 12″ × 18″ is used, reinforce the lid by placing a ¼″-thick plastic sheet on top and drill the holes at the same time through it and the lid to line them up

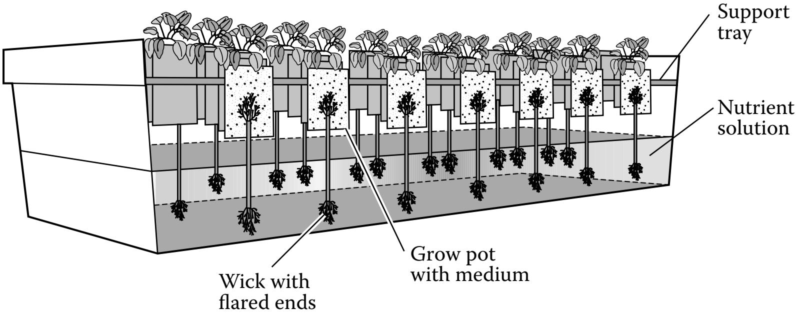


FIGURE 13.1 Multi-pot wick system using a large plastic storage bin. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

correctly. Without this additional support, the thin lid of the reservoir storage bin will sag and possibly break with the weight of the medium and plants.

Make a 2″ square access panel at one corner of the lid to add water and/or nutrients. This can also be the entrance of the poly tube from the air pump to the airstone within the reservoir.

Flare the ends of the rope to form the wick and bury it into the medium of the pot about one-third. If using a grow tray of medium, locate the wicks below the plant sites and drill through the grow tray at those positions. Make the wicks long enough to reach within ½″ of the bottom of the solution reservoir. Add raw water to the nutrient reservoir, place the lid on top, and add the pots. Seed the pots in place in the system and water the pots from above to initially moisten the substrate. Use a half-strength nutrient formulation after the plants have their first true leaves unfolding. About 10–14 days later, make up the full-strength formulation solution.

WATER CULTURE (FLOATING) SYSTEM

This culture is most suited to low-profile leafy crops such as lettuce, spinach, basil, arugula, and various herbs. The design is similar to the small-scale unit, with the exception that beds (sometimes called raceways) are larger. Cut the boards from 4 ft × 8 ft × 1″ thick "Roofmate" Styrofoam. The raceway can be constructed of 2″ × 10″ treated and painted cedar planks and lined with a 20-mil vinyl swimming pool liner (Figure 13.2). The raceway may be constructed on the floor or as a raised bed. The raised bed form is better as it can drain by gravity to an underlying cistern (Figure 13.3).

Materials

1. Lumber of 2″ × 10″ dimension. Length to suit your specific needs, but the raceway must be a multiple of 2 ft in length to fit the boards.
2. Swimming pool vinyl liner of 20-mil thickness.
3. Vinyl cement.
4. Various PVC pipes (¾″ schedule 40) and fittings.

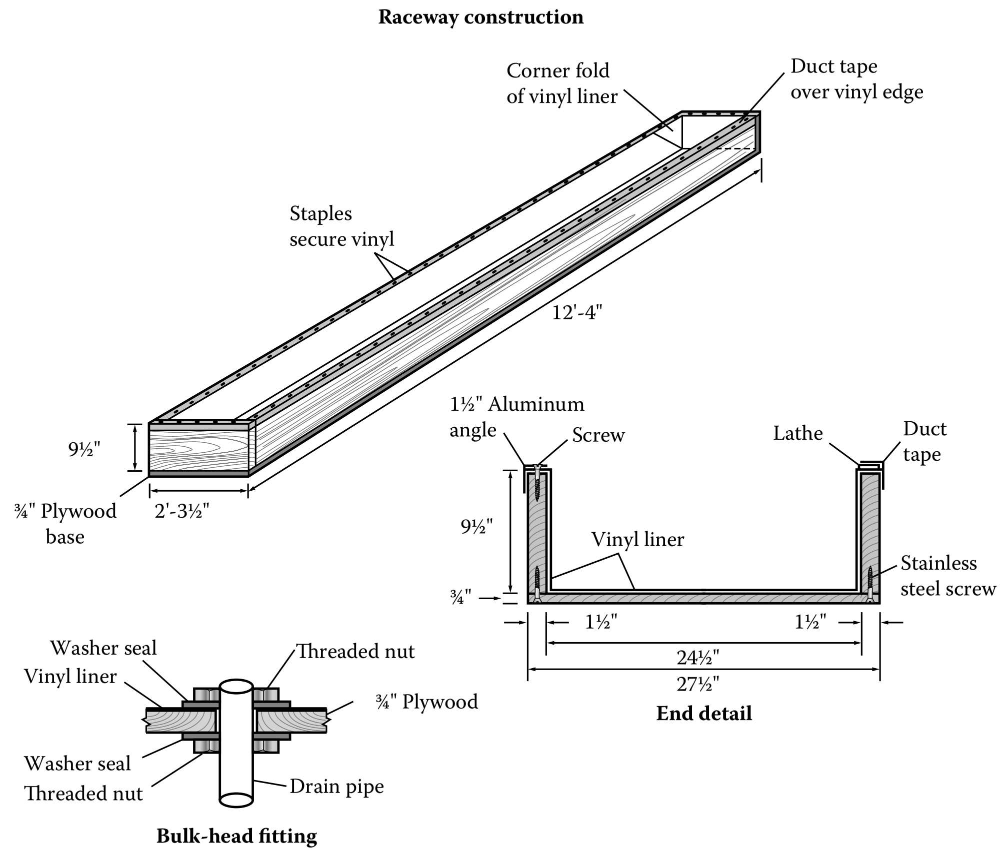


FIGURE 13.2 Construction of wooden raceway for raft culture. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

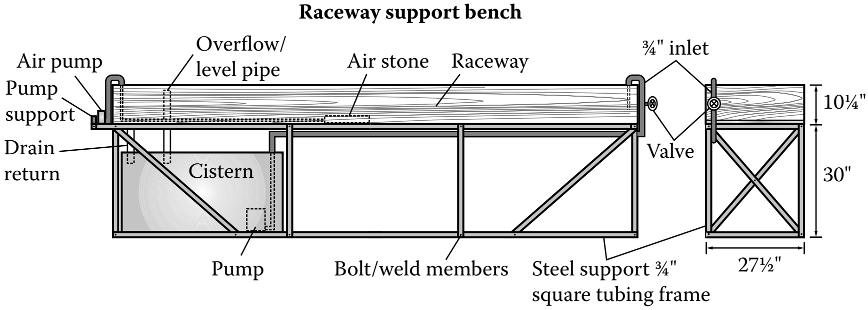


FIGURE 13.3 Support frame with cistern underneath and piping details. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

5. Lathes 1″ × ¼″ thick or 1½″ × 1½″ aluminum angle.
6. An air pump and air stones are available from fish aquarium stores or aquaculture suppliers.
7. Submersible pump with a timer.
8. Nursery landscape weed mat if this is outside or in a greenhouse.
9. 6–8″ nursery staples to secure the weed mat.
10. 50–100-gal cistern tank. The size depends upon the length of the raceway. For a short raceway up to 20 ft, a 50-gal cistern is adequate.
11. Galvanized or chrome plated ¾″ square steel tubing for a support frame.
12. White oil-based paint.

Assembly

If the system is located inside the house, a weed mat is unnecessary. The raceway sits above a solution tank so it must be raised up on a supporting frame (Figure 13.3). Construct the raceway before the support frame.

Make the inside dimensions of the raceway frame ½″ wider and 1″ longer than the total dimensions of the boards. For example, to construct a raceway 12 ft long by 2 ft wide, make the inside dimensions 12 ft 1″ (145″) long by 2 ft ½″ (24½″) wide to allow for some free play and the thickness of the vinyl liner. If the raceway is to be located on a frame, make a bottom of ¾″ plywood. Attach the frame and bottom with stainless steel screws to avoid any corrosion and glue all joints for added strength as water is very heavy. Cut a 1½″ diameter hole at the bottom of one end of the raceway, about 4″ from the end in the center. Paint the inside and outside of the raceway framework with an oil-based paint.

Line the raceway with 20-mil vinyl liner. Place it tightly against the bottom and all corners to get a smooth flat surface. At the corners fold it similar to wrapping a parcel and glue the wrapped corners. Bring the vinyl over the edge of the wooden frame and secure it under a lathe on top around the perimeter with aluminum nails or stainless steel screws. Alternatively, staple the vinyl to the top edge of the frame and cover the staples with ducting tape bringing the tape over the edge to make a very nice finish as shown in Figure 13.2. To make a very nice finish, screw an aluminum angle on top of the vinyl around the top edge of the raceway. You will have to make a small slit at the top of each corner to permit the vinyl to lay flat at that point. Cut the excess vinyl flush to the wooden frame. Where the drain hole was cut, hold the vinyl tightly and make a cross cut in the vinyl to within ¼″ of the width of the hole. Install a bulk-head fitting through the vinyl and hole gluing the vinyl between the bulk-head fitting seals. Caulk with silicone rubber. The bulk-head fitting must give a complete seal to avoid any leakage of water between the liner and plywood bottom of the frame.

Construct a steel tubing frame to support the raceway (Figure 13.3). The frame must keep the raceway about 30″ above the floor to permit the cistern to fit underneath. Locate the cistern under the drain pipe of the raceway. The support frame must be level in all directions to get good drainage from the raceway. Locate an air pump at one corner of the raceway frame and run a poly hose down the center connecting to a 6″ air stone.

Place a 1½″ diameter by 9″ long PVC pipe in the drain to maintain 8″ of solution in the raceway. Do not glue this pipe. This is the overflow pipe to re-circulate the nutrient solution to the cistern.

Cut a notch in the top of this pipe so that flow from the raceway will not be impeded by the boards floating on top of the solution.

Install a submersible pump with a ¾″ outlet and plumb it with fittings and ¾″ PVC schedule 40 pipe from the pump underneath and attached to the metal support frame going to the opposite end from the drain. Then, with elbows, extend the pipe over the end of the raceway to enter the top of the raceway as an inlet for the solution (Figure 13.3). Put a ball valve at the vertical side to regulate the flow. This keeps a constant flow of solution aerating and replenishing the solution in the raceway for the plants.

The next step is to make the boards. Cut the boards 6″ × 2 ft, 1 × 2 ft, 2 × 4 ft, or 4 × 4 ft long exactly depending upon the raceway width. Use a very sharp kitchen knife or gyproc knife guiding it with a straight edge. Alternatively, a saw with fine teeth will do the job. Smooth the edges with fine sand paper. Drill ¾″ diameter holes at 6″ centers for lettuce, arugula, and basil with 4″ centers for small herbs. For 6″ centers start the holes 3″ from the edge. For 1 × 4 ft boards make two rows of four holes forming eight plant sites per board. The hole pattern across the raceway is 3″–6″–6″–6″–3″ (four holes) and the other way 3″–6″–3″ (two rows). For 4″ centers, start 2″ from the edge and space 4″ apart to get a total of six holes within the row and in the other direction start again 2″ in from the edge to form three rows. They are not staggered in their position. After making the holes, smooth the edges with sand paper. Refer to the diagrams of Figure 13.4 for the board dimensions and hole patterns.

Alternative Simplified System

In this design we can eliminate the nutrient reservoir below the raceway. You can even eliminate the supporting frame if you wish to construct the raceway on the floor. Simply set the raceway on top of 1–2″-thick Styrofoam for insulation from a cold basement floor.

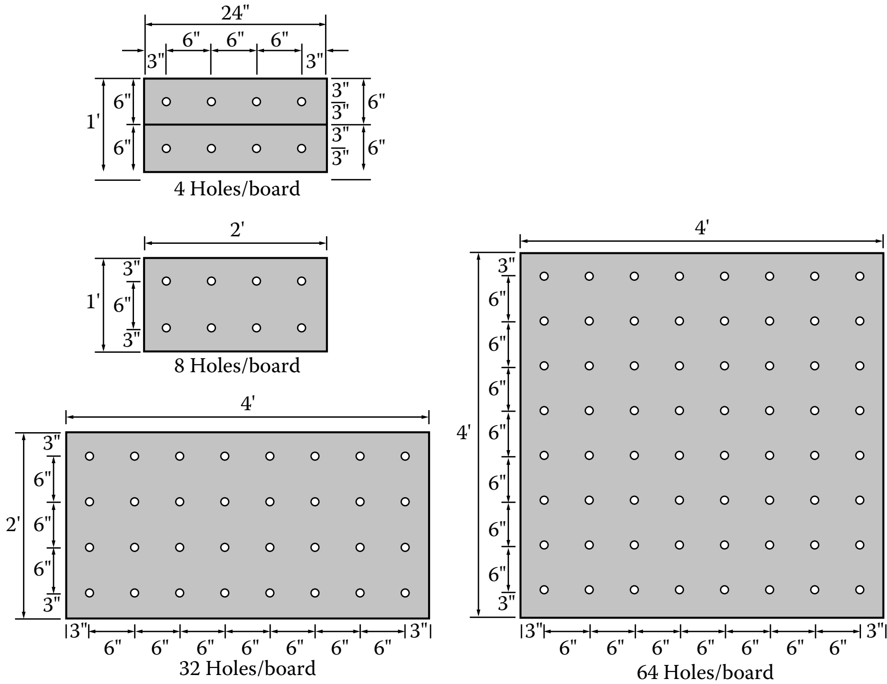


FIGURE 13.4 Details of hole spacing in raft culture boards. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

Construct the raceway itself of dimensions either 2 or 4 ft wide by whatever length is convenient for your space. Since plywood sheets come as 4 ft wide, make the overall outside bed dimension a maximum of 4 ft. With the framing of 2″ lumber, which is dressed dimension to 1⅝″ thick, the sides will use 2 × 1⅝″ = 3¼″. The Styrofoam sheets will have to be cut to a width of 48″–(3¼″ + ½″ of play) = 44¼″ or about 44″ to allow sufficient free play between the sides and liner. The boards may be 2 ft or 4 ft × 44″.

Place the raceway at the floor level on Styrofoam insulation or make a frame as described earlier. However, no drain hole for returning the solution to a reservoir tank is needed. Make up the nutrient solution directly in the raceway and keep it mixed and aerated using an air pump and tubing to air stones as explained earlier. This design eliminates the complexity of returning the solution to a nutrient tank, thus avoiding the drainage and irrigation systems requiring a pump, and so on.

Check the pH and electrical conductivity of the solution at least once a day and add a small portion of solution (up to about 10% of the original makeup) every few weeks, if necessary. Change the nutrient solution once every few months by pumping it out with a sump pump and cleaning the raceway with a 10% bleach solution.

The plants that were growing in the raceway can be taken out in situ with the boards and kept moist by stacking the boards together root-to-root. You may also mist the roots with water to keep them from drying while cleaning the raceway. As soon as you finish cleaning the raceway and start filling it with water, place the boards with their plants still in place back into the raceway and then make up the nutrient solution.

NFT SYSTEM

This is the most common method of hydroponics for low-profile crops such as, lettuce, basil, arugula, bok choy, and spinach. The growing channels may be constructed from 2″ PVC pipes as shown in Figures 12.9 and 12.10 or it is best to purchase special NFT channels from a hydroponic store. The commercial NFT channels have either ridges on the inside bottom of the channels or a sloped bottom with or without ridges to direct water from flowing around plant roots when the seedlings are transplanted (Figure 13.5). There are two types of channels: a one-piece fixed top and a two-piece with a removable top to facilitate cleaning between crops (Figures 13.5 and 13.6). The covers have plant site holes of correct diameter and spacing for the crop you wish to grow.

The NFT system, regardless of whether it is PVC pipe or other channels, must be located on a frame above a solution reservoir. The bench must have a 3% slope back toward the reservoir. The channels must not exceed 12 ft in length to prevent a temperature rise and oxygen loss in the nutrient solution as it travels along the channel. The benching should be at waist height, about 30″.

Many small NFT systems of various sizes and number of channels are available from hydroponic stores and online (refer to the Appendix). The following materials list is for a system of four channels.

Materials

1. NFT channels 12 ft in length or 2″ PVC pipe 12 ft (8 ft length shown in Figures 13.7 through 13.9).
2. PVC fittings—elbows, tees, reduced bushings, ball valves, and so on.
3. PVC cleaner and glue.
4. PVC piping—1″ and ¾″ diameter schedule 40.
5. A submersible pump with 1″ or ¾″ outlet. Flow rate must be 2 L per minute per channel.

   For four channels, a pump of at least 3–4 gal per min (gpm) is needed with a head (lift) of 6 ft.
6. Drip irrigation tubing—about 10 ft.
7. Square steel tubing ¾″ by ¾″ or lumber 2″ × 2″ treated and/or painted white.

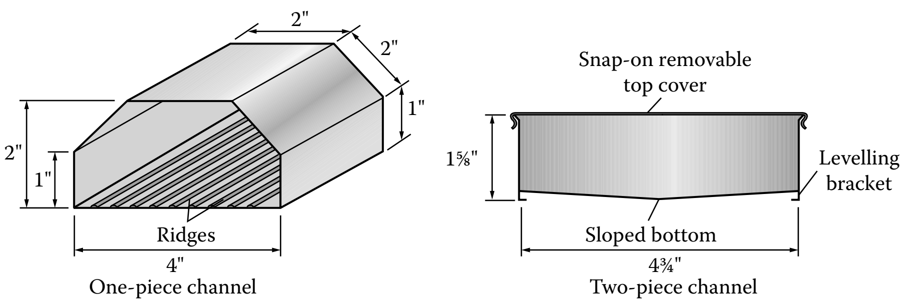


FIGURE 13.5 Commercial NFT gutters. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

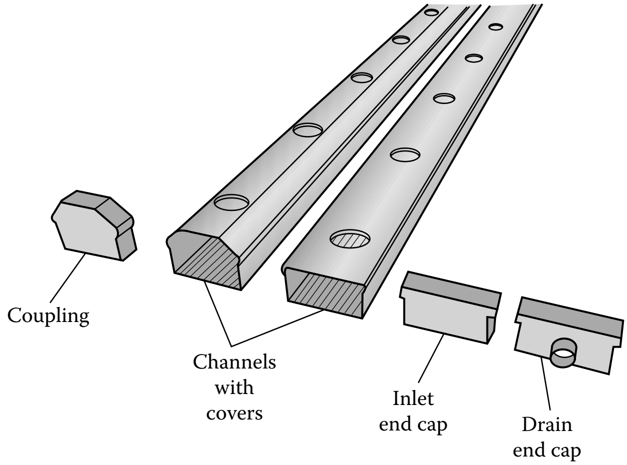


FIGURE 13.6 Various NFT components and channel configurations. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

8. A plastic 50-gal nutrient reservoir, preferably opaque in color with a cover. The nutrient tank may be smaller for shorter and less channels per system. For example, two 10- to 12-ft channels can be served with a 20-gal reservoir.

Assembly

A small system is discussed first followed by further details of larger, more complex systems. Starting with two 8-ft channels and a 20-gal reservoir, the channels can drain at the lower end directly into the nutrient reservoir at the lower end. The first step is to construct the supports for the growing channels. With two channels that are spaced 6–8″ apart, set the drain ends on the edge of the nutrient reservoir (Figure 13.7).

The support frame can be constructed the same for either 2″ PVC channels or purchased NFT channels. Construct one A-frame "sawhorse" structure 3″ higher than the height of the nutrient tank, for the upper inlet end of the channels. It should be about 2 ft long. If you prefer not to rest the lower end on the nutrient tank, make a second A-frame that is several inches higher than the nutrient tank and make the inlet support frame 3″ higher than the lower one. These support frames can be constructed of wooden 2″ × 4″ lumber and painted white. They can also be made of ¾″ square steel tubing or PVC pipe. But, when using PVC make the frame somewhat different from wood or steel tubing. Use 1″ PVC schedule 40 pipe. First, make a rectangular base 18″ × 24″. In the middle of the 18″ sides attach a tee. From there glue a riser of 14–18½″ depending on the height of the nutrient tank as the taller support must be 5″ above the tank height if the lower support at the tank end is 2″ above the tank. This gives a slope of 3″ for the growing channels. Use 1″ tees at the top of the riser and connect a horizontal pipe between the two tees. This completes the supports as shown in Figures 13.7 and 13.8. Another one exactly the same for the middle

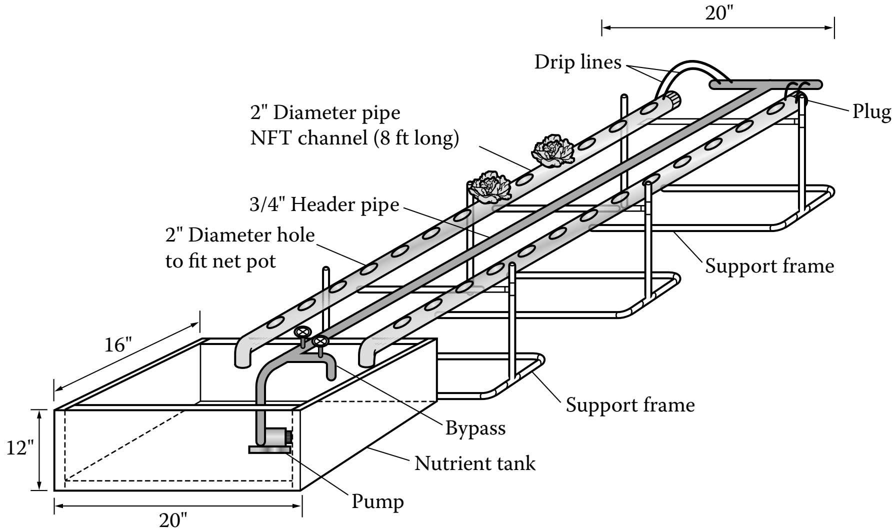


FIGURE 13.7 NFT pipe system. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

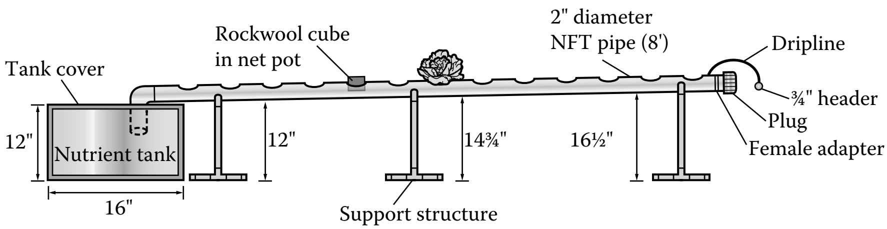


FIGURE 13.8 NFT pipe system side view showing support structures. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

is needed to prevent the channels from sagging with the weight of the solution and plants. Make this one 1½″ shorter than the highest one at the inlet end.

The piping from a submersible pump in the nutrient tank to the upper inlet end of the channels is as follows. Attach a ¾″ pipe to the pump with a threaded male adapter. Make this riser long enough to reach up through the tank lid and to the top of the support frame. Just above the tank cover, install a return bypass line with a ball valve to regulate the flow of solution to the inlets of the channels. In this way, if the pump has more capacity than needed, the flow is shunted back to the tank. From there use a 90° elbow to attach the pipe going on top of the support frames to the inlet end of the channels. At the inlet end attach a tee and make a header going each way.

Glue a cap on one end of the header and a threaded female adapter to which a plug can be placed to permit cleaning of the pipe. This header should be about 18–20″ long to span between both growing channels. From it use a special grommet seal and insert several drip lines for each channel. Two drip lines enter the top of each

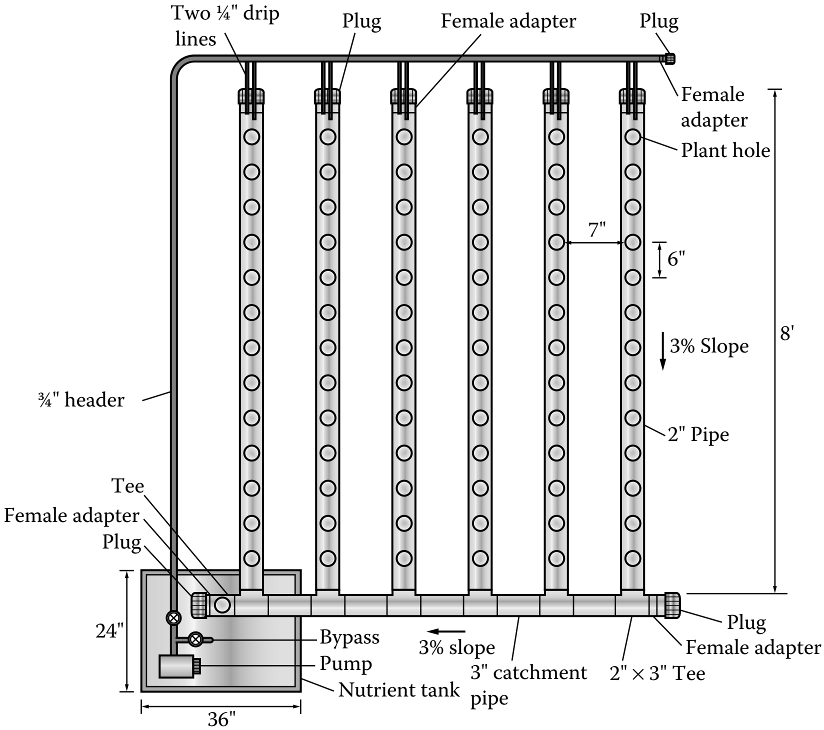


FIGURE 13.9 Details of NFT pipe system with multiple growing pipes. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

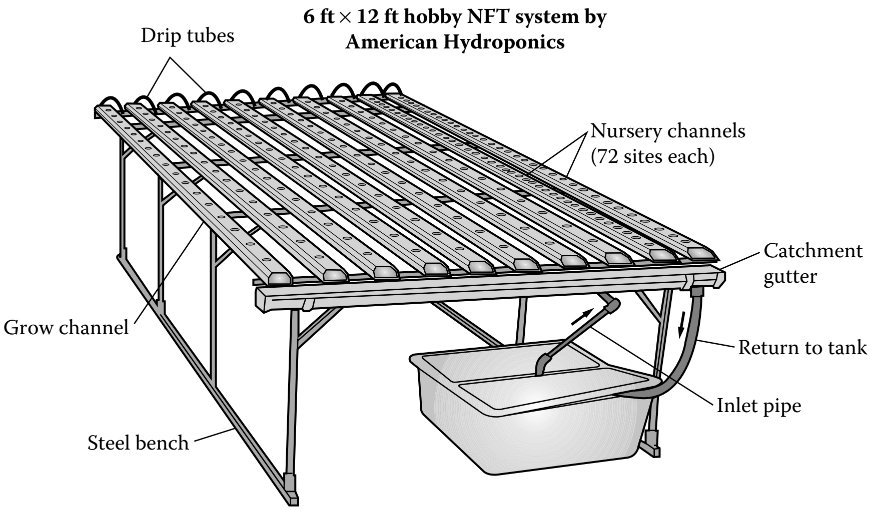


FIGURE 13.10 Details of a 6 ft × 12 ft hobby NFT system. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

growing channel by drilling snug holes. Alternatively convert to ½″ black poly tubing with barbed adapters at the tee and punch holes for drip lines at the grow pipe positions. The solution flows constantly so a timer is not needed for the submersible pump. Refer to Figures 13.7 and 13.8 for details of the design.

If you wish to make the grow channels from 2″ PVC pipes, you must drill the plant site holes similar to that mentioned in Chapter 12 for simple units. Make the holes 2″ in diameter as the mesh pots have a 1⁄16″ lip around their tops as shown in Figure 12.9. This will prevent the mesh pot from falling into the pipe. Locate the holes in a straight line at 6″ centers for lettuce, arugula, bok choy, and basil. To hold the growing pipe in position on the support frame, use plastic electrical straps around the 2″ PVC growing channels securing them to the 1″ PVC support frame. Glue a 2″ female adapter on the ends of the growing channels and fit them with a threaded plug to enable access for cleaning. A multi-pipe NFT system is set similar to the two-pipe system with the exception of plumbing the drain ends of the grow pipes into a 3″ diameter catchment pipe that returns the solution to the nutrient tank (Figure 13.9). The irrigation system is the same as described earlier as appears in Figures 13.7 and 13.8.

LARGER NFT SYSTEM

The next are steps to build a somewhat larger and more complex system. The materials list is basically the same, but with more channels and a larger benching frame. The following is a design similar to that available from American Hydroponics (see Appendix). The system has eight production channels and two seedling channels to grow 144 lettuce, basil, arugula, or bok choy. It occupies an area of 6 ft × 12 ft. Construct the bench framework first using ¾″ square steel as shown in Figure 13.10. The bench is 34–38″ high. This gives a slope of 4″ in 138″ or about 3%. Since the channels are exactly 12 ft long, make the bench slightly shorter at 11½ ft (138″) to allow the channels to extend out from the bench. There are a total of four cross members placed at 46″ centers. Set these on a base extending the 11½ ft on each side. Put braces between each corner at the top of each cross member as shown in the diagram. It would be best to weld the entire structure, but if that is not possible, drill holes and secure each member with bolts.

Each of the eight growing channels has 1¾″ diameter holes spaced at 8″ centers to permit 18 plant sites per channel as shown in Figure 13.11. The two nursery channels have the same size of holes spaced at 2″ centers to fit 72 seedlings per channel. The production gullies house 144 plants (8 × 18 = 144). The gullies come with a cover and are ready to set up with the irrigation system. They drain into a closed collection pipe that conducts the solution back to the nutrient tank.

There are many sizes and types of NFT systems available from hydroponic stores and online. If you do not want the work of constructing one, I recommend purchasing a complete unit (see Appendix). You may also buy NFT gutters of various lengths (4 ft, 6 ft, or 8 ft).

To grow vine crops use wider channels or larger PVC pipes of 4–6″ diameter. Wider NFT channels of 4″, 6″, and 9″ with plant site holes at 8″ for the 4″ and 6″ wide channels and at 12″ for the 9″ channel are available. Plant hole diameters are

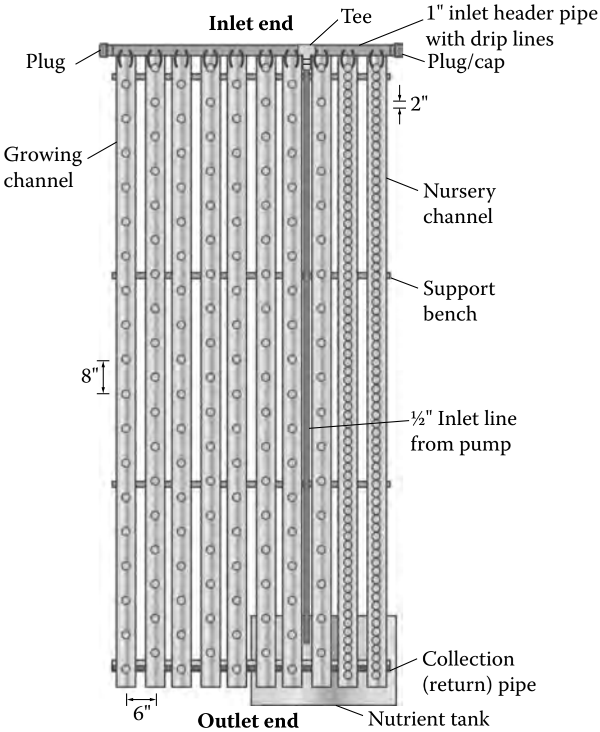


FIGURE 13.11 Plan of gullies on a bench with hole locations for nursery and growing channels. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

offered for 2″, 4″, and 6″ net pots. The larger net pots can be filled with substrates as expanded clay particles or granular rockwool.

For vine crops use 9″ wide channels with 12″ spacing for 6″ net pots with a substrate. Whatever substrate or sizes of pots are utilized, begin the seedlings in the conventional method of rockwool cubes and transplant to the net pots. When using a substrate in large net pots, this is really a combination of NFT and another culture.

The following is a smaller NFT system using four channels of 8 ft in length. Purchase the channels with end caps and covers from a hydroponic supplier or make your own from 2″ PVC pipes as described earlier. A support frame and inlet and return piping will have to be constructed. The system described is for lettuce, arugula, basil, bok choy, and herbs in 2″ pipes and vine crops in 4″ diameter pipes.

Materials

1. Two 8 ft 2″ PVC pipes and two 8 ft 4″ PVC pipes.
2. Fittings: two 2″ caps, two 4″ caps.
3. Construct the support frame of 1½″ PVC pipe or of ¾″ square steel tubing.
4. Return pipe of 3″ PVC pipe schedule 40.

5. Five 3″ tees, two 3″ female adapters, two 3″ thread plugs, two 3″ × 2″ reduced bushings, two 4″ × 3″ reduced bushings.
6. Twenty feet of ¾″ diameter PVC for inlet main and header with fittings for attachment to the pump including bypass and ball valve.
7. Submersible pump of ¾″ outlet of at least 4 gpm capacity.
8. Timer 24-h cycle with 1 min intervals.
9. A 20-gal plastic storage bin with a lid for the solution reservoir.
10. Twenty feet of drip line, with grommets to attach to the inlet header.

Assembly

Start with the support frame. Construct it of 1½″ PVC pipe or ¾″ steel tubing. Make the frame dimensions 90″ by 54″ wide by 24″ high on the inlet end side and 21″ at the drain end as shown in the diagram (Figure 13.12). The channels sit on the 48″ wide side. Using a male adapter and several 90° elbows connect the ¾″ inlet line from the pump to a header. Secure the header with strapping underneath the support frame. Install a bypass pipe with a valve above the lid of the reservoir to permit regulation of flow to the inlet pipe. Install the drip lines in the header and into the channels (two per channel). Alternatively, convert to ½″ poly hose for the header into which the drip lines are inserted. They can be inserted without emitters to achieve a minimum flow rate of 1–2 L per minute (¼–½ gal/min).

At the drain ends of the channels assemble a 3″ PVC collection pipe that returns the solution to the reservoir. This is held up by the bench frame with brackets. Two methods for the collection pipe and drainage of the channels are feasible. One is to leave the ends of the growing pipes open and allow them to empty into the collection pipe at open slits 2″ wide. If you use NFT commercial channels attach a 1″ diameter drain pipe to the bottom of the gullies at their drain end and drill 1½″ holes in the collection pipe at the positions of the drain pipes from the gullies. The difficulty doing it this way is to seal the joints with glue or silicone rubber to the NFT gully. However, the advantage is that light can be excluded from entering the collection pipe, which will prevent algae growth. If using PVC pipe channels, glue them into the 3″ PVC header using tees. With this method end the collection pipe with threaded plugs to enable cleaning. Then, place one tee in this collection manifold above the tank to conduct the solution to the tank as shown in Figure 13.12. If the former method of an open gully end into the collection pipe is used, cover the outlet ends with black polyethylene to exclude light from entering. Tie a nylon mesh screen over the end of the return line to collect any debris returning from the growing channels. Drill holes in the reservoir lid for the entrance of the return pipe and for the inlet line and bypass line. You may also install a 100 mesh filter in the inlet line above the pump before the bypass to collect any extraneous particulate matter.

Remember to make or purchase gullies with the correct size and spacing of plant site holes for the specific crops you wish to grow, either low-profile or vine crops. If you want to grow vine crops, you would need only two NFT channels, spaced about 2 ft apart. Then V-cordon training the plants to an overhead support wire or

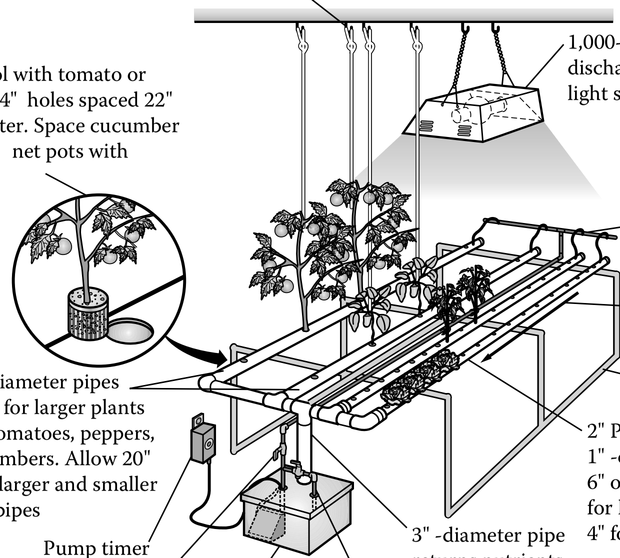


FIGURE 13.12 Frame support and growing channels of small NFT system. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

hook using plastic string and vine clamps as is explained later in Chapter 24 on the training of vegetable crops.

For growing both vine crops and low-profile plants such as lettuce, herbs, and arugula, space the 2″ diameter pipes for the low-profile plants at 7″ centers and then the next two 4″ pipes at 20″ centers. It would be better to use large net pots with some expanded clay substrate for the vine crops to increase root aeration than simply setting the plants in their growing cubes into the bottom of the channels.

WALL NFT GARDENS

In this system arrange the NFT channels mounted with brackets to fences, walls, garages, or any vertical surface having good light (Figure 13.13). Use the standard 4″ wide gullies. The most appropriate crops include lettuce, arugula, basil, strawberries, and herbs. The system consists of two or three gullies of length up to 12 ft, the choice depending upon the available space. A 30-gallon solution reservoir with a lid collects and recycles the solution through an inlet header and return plumbing.

FIGURE 13.13 Wall garden NFT system. (Courtesy of American Hydroponics, Arcata, California.)

Materials

1. NFT channels 8–12 ft long.
2. Wall bracket support system. These are available in hardware and building supply stores. These should be heavy duty forms that screw into the wall. Most have adjustable shelf positions.
3. A 30-gal plastic solution tank with cover.
4. PVC piping to fit the channel drain outlets.
5. Submersible pump, fittings, ball valve, and ¾″ PVC or ½″ black poly inlet hose.

Assembly

Attach the wall support bracket with 2″ screws to the structure holding the NFT garden. At least two of the vertical bracket plates are required for 6–8 ft NFT gullies and three to four for anything longer. Position the support brackets into the backing plates so that at least a 3% slope is obtained. In this system, the solution will run from one gully into the next one and finally into the nutrient reservoir at the bottom. As shown in the diagram (Figure 13.14), slope one gully in one direction and then the next one in the opposite direction working down so that the solution flows from the lower end of the channel above to the higher (inlet) of the next one below. It is easiest to use flexible hose, like black poly hose, from the drain outlet pipe of the channel above to enter the top of the inlet end of the next channel. The lowest gully has a drain hose into the nutrient tank. Refer to the diagram of Figure 13.14 for details.

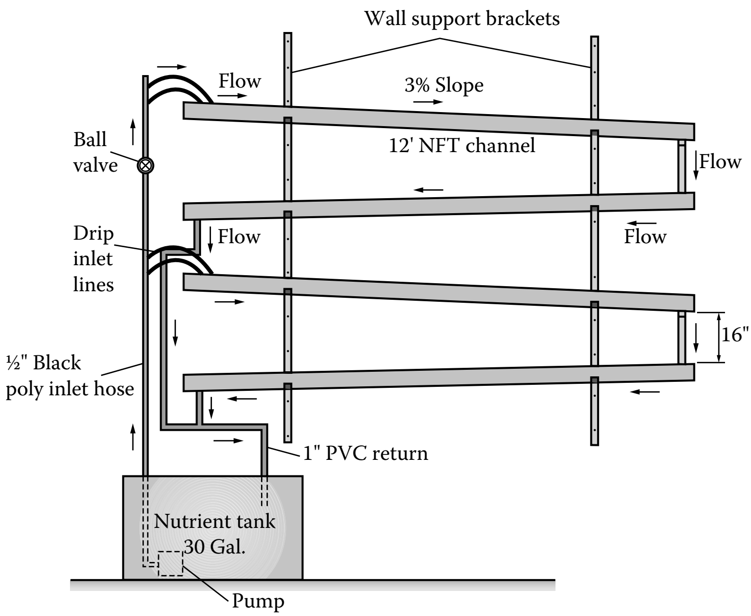


FIGURE 13.14 Wall garden NFT with two sections. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

The pump lifts the solution through a ½″ diameter black poly hose from the reservoir to the inlet end of the highest grow channel. Do not use more than two to three channels hooked together or the solution temperature may rise and oxygen deficit may occur to the plant roots. Connecting three 12-ft gutters together in one section is an NFT solution flow through 36 ft. That is very long for growing under high light intensity summer weather. It would be better to use two sections with two channels each for a total of four, providing the height of the wall is sufficient. Each channel must be a minimum of 16″ apart to give adequate light to the one immediately below.

If constructing two separate sections of NFT, use the same inlet header, but install a ball valve before the inlet hose enters the upper gully. This will balance the flow to the two sections. Collect the drainage from the second channel (lower one) and direct the return pipe from each section back to the nutrient tank as shown in Figure 13.14. In effect there are two separate systems but one common inlet header with two individually regulated outlets.

A-FRAME NFT SYSTEM

This design again is suited only to low-profile plants. The concept is the same as that for the wall garden NFT systems, but instead of attaching the growing channels to a vertical surface, they are supported on an A-frame. The length of the A-frame should be 11½ ft to support 12-ft long channels. The size of the A-frame can be varied to fit any length of NFT gullies. I recommend a minimum of 8–10 ft to justify the amount of work needed in constructing the A-frame. Make the framing 6″ shorter than the gullies to enable placement of inlet and return pipes.

Construct the A-frame in the form of an isosceles triangle having two equal sides (Figure 13.15). Locate the first channel 16″ above the floor level so there is enough height to enter the reservoir. Other channels have 10″ between them to reduce any mutual shading by mature plants.

This spacing is sufficient for six channels on each side to give a total of 12 channels on the A-frame as shown in Figures 13.15 and 13.16. The slope of the sides of the A-frame should be shallow enough to permit adjacent channels from overlapping in their horizontal space. Each channel ideally should be offset 4″ horizontally from the adjacent ones next to it. With the sides 75½″ and the base 48″ each channel has a space of 48″/12 = 4″. The altitude of the A-frame is 6 ft. A horizontal bench would contain eight channels in a 4 ft width. The result is an additional four channels or 50% increase in the number of plants. A 12 ft × 4 ft A-frame with 12 gullies has a total of 12 × 18 plants/gully = 216 plant sites.

Materials

1. The A-frame is to be constructed of ¾″ square or 1″ diameter round galvanized steel tubing. Calculate the length according to the dimensions. The frame members may be welded or bolted. The A-frame may be covered with ¼″ thick white plastic sheeting or a Mylar reflective cover to get more efficient use of light. However, that is not essential.

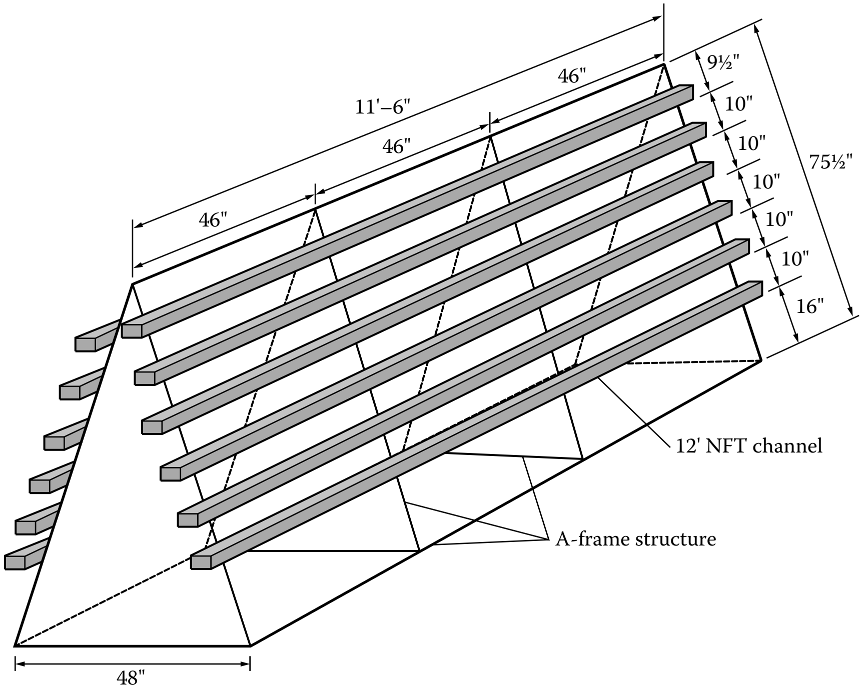


FIGURE 13.15 A-frame with six NFT channels on each side. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

2. The reservoir should be 100 gallons for a 12 ft long system or 50–60 gallons for a 6–8 ft long system. Due to the cost and labor in building the A-frame, I recommend to plan on a 12 ft system.
3. A submersible pump with a ¾″ outlet, minimum volume of 10 gpm with a head of 15 ft.
4. One filter of 100 mesh by ¾″ diameter.
5. Inlet piping fittings of ¾″ diameter include male adapters, ball valves, tees, 90° elbows, and ½″ barbed adaptors for ½″ black poly hose and figure "8" caps.
6. Other fittings include drip lines (two per gully), about 30 ft, 24 compensating emitters of 1 gph, and twelve 90° elbows (1″) for drain spouts from the end of the channels to the collection pipe.
7. Twelve 12-ft NFT gullies with covers, end caps, and drain spout. These have holes spaced at 8″ centers. It is best to use channels that have separate covers that can be removed for cleaning.
8. One collection pipe of 2″ diameter—about 10 ft.
9. Collection/return pipe fittings (2″) including caps, 90° elbows, and tees or cross fits with 1″ × 2″ reduced bushings. Follow the diagram plan of Figure 13.16.

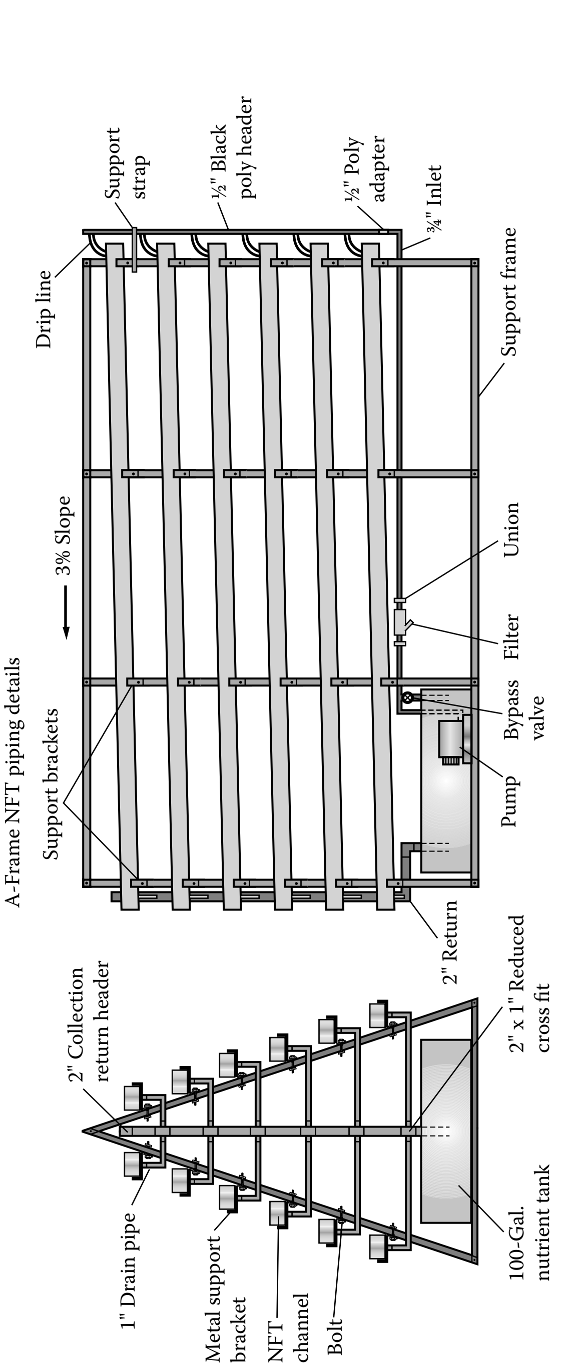


FIGURE 13.16 Details of pump and irrigation system to NFT channels. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

10. Support brackets to hold the NFT channels on the A-frame. Use four per channel, so that is a total of 48 brackets. These are bolted to the A-frame bars. Make the brackets from 1″ wide by ⅛″ thick steel. Form their shape to fit the bottom of the NFT gullies similar as shown in the diagram.

Assembly

Construct the A-frame first and later mount the NFT channels onto it after covering the A-frame with sheets of plastic or Mylar, if it is being used. Locate the solution reservoir at the drain end of the A-frame. Install the pump with fittings, a union above the lid of the reservoir and then the bypass and filter. Then, with a tee, make a header to each side of the A-frame under the first NFT gully and then up to the inlet location using a ¾″ × ½″ slip-thread female adapter where the ½″ poly adapter is attached to convert to the ½″ black poly hose. This will be at the base of the first NFT channel on each side. Punch the holes for the emitters; install them and the drip lines to the top of the channels (two per channel).

Mount the 2″ collection pipe header in the middle of the A-frame at the drain ends of the NFT gullies. Use several 90° elbows with a short 4″ piece of pipe at the lower end of the collection pipes to enable making a bend from the angle of the A-frame to the horizontal section joining the two collection pipes just above the nutrient reservoir as shown in Figure 13.16. Use a 90° elbow to enter the nutrient tank. You may put a short spout at the end of the elbow, but do not glue it so that you can remove it when accessing the reservoir for cleaning. Place a cap on the top end of the 2″ collection pipe, but do not glue it in case access to clean the pipe is necessary. Attach the 1″ drain pipes from all of the NFT gutters to the 2″ collection pipe header with tees or a cross fitting. Use only silicone to seal the entrance of this spout into the collection pipe as at times the gullies may have to be removed. Just a note here that when cleaning the gullies after a crop, use a piece of towel soaked in a 10% Clorox solution and scrub the channels. If you have other plants still in the other channels, plug the drain line in the gully with another towel before using the bleach solution to prevent the bleach solution from going back to the nutrient tank. After cleaning, dry the gully with a towel and let the channels air dry before placing in your seedlings.

Drill holes in the nutrient reservoir lid to accommodate the pipe from the pump, the bypass line, and the return drain line.

If you want to place a covering over the A-frame do that now before securing the support brackets for the NFT channels. Remember to locate the support brackets to give a 3% slope to the gullies from the inlet end to the outlet end, that is, about 4″ of slope. The support brackets must be screwed, using self-drilling metal screws or bolts, into the vertical members of the A-frame. Secure the brackets at the inlet and outlet ends first, then attach those on the other frames to get their position accurately.

Position the NFT channels, make the inlet and drain connections, and put water in the reservoir to test the piping joints. Balance the ball valve at the bypass to get the correct flow into the gullies.

This is the most complex and difficult system to build, so do not be discouraged. There are many other more simple and equally productive hydroponic systems to construct as alternatives to the A-frame NFT system.

EBB AND FLOW SYSTEM

In a larger hobby ebb and flow hydroponic system use a series of trays sitting on a framework above a nutrient reservoir. This is a recycle system where the solution floods the substrate from below and then drains back to the reservoir awaiting the next irrigation cycle. A time clock or controller activates the pump several times a day to flood the growing beds. The frequency of irrigation cycles, as mentioned in the previous chapter, is dependent upon the crop, stage of plant growth, and substrate water retention.

The ebb and flow method is suitable to most crops including low-profile and vine crops. Since the substrate of choice must have good porosity, use some form of aggregate. In this case, we could also call it gravel culture. Use expanded clay, ¾″ crushed igneous rock, or ¼″ pea gravel.

In this system beds are constructed 2 ft wide by any length up to 20 ft by 10″ deep. Construct one or two beds with a 3 ft aisle between them for access. Make the beds in the same way as was done earlier for the raft culture raceway of the narrower 2 ft width as shown in Figures 13.2 and 13.3. Build the sides of the bed with 2″ × 10″ treated and/or painted cedar lumber. The bottom is ¾″ plywood. All lumber joints are screwed and glued. The beds are lined with a 20-mil vinyl as for the raceways using the same methods. Each bed must be supported on a wooden or steel framework.

Materials

1. Lumber of 2″ × 10″ dimension for all sides and ¾″ plywood for the bottom of the bed. Since plywood comes in 4 ft × 8 ft sheets, make the width of the bed(s) 2 ft outside dimensions to achieve optimum use of the plywood.
2. Swimming pool 20-mil thick vinyl.
3. Vinyl cement.
4. PVC pipe and fittings.
5. Lathes 1″ × ¼″ thick.
6. Submersible pump with a timer.
7. White oil-based paint and primer.
8. Nutrient reservoir. The volume depends upon the total volume of void spaces in the substrate of the bed(s).

   Calculate the total volume of the bed and multiply it by the percent of void spaces in the rock substrate. Typical crushed ¾″ rock has a void space of about 38%. Pea gravel would be less, closer to 25%. The finer the material the less void space is present. If you wish to test your substrate for its void space, place a given volume of gravel in a container such as a 5-gal bucket and add water to it until the water level just reaches the surface. Pour off the water into another bucket and measure this volume of water with a graduated cylinder. The fraction of that volume of water over the volume of the gravel gives you the percent of void spaces. To allow for some loss of water by the plants make the nutrient reservoir large enough to contain at least twice the void space of the substrate.

9. Metal frame to support the aggregate ebb and flow beds. This should be constructed of 1″ square tubing as the weight will be substantial, especially during an irrigation cycle when the bed is full of solution.
10. Use light weight expanded clay aggregate (LECA).

Volume Calculation

Here is an example to calculate the volume on aggregate needed: Volume = length × width × height (V = LWH). For a 10 ft long bed by 2 ft wide by 9″ deep: V = 10 ft × 2 ft × $\frac{9}{12}$ ft = 15 cubic ft. One cubic yard is equal to 27 cubic ft, therefore the number of cubic yards is: $\frac{15}{27}$ = 0.56. This is slightly over one-half a cubic yard. Order one cubic yard and there will extra for use later.

Weight Calculation

The LECA weighs 1200–1300 lbs/cu yd, whereas, ¾″ crushed gravel weighs about 2800 lbs/cu yd. The total weight for a 10 ft × 2 ft bed of LECA aggregate is therefore: 0.56 × 1200 lb = 670 lbs. Obviously, you need to make the bed and the supporting frame strong enough to withstand this weight.

Solution Volume Calculation (Using a 10 ft Bed with Expanded Clay)

V = 15 cu ft × 35% void space = 5.25 cu ft. Multiply by two for evaporation loss by plants: 5.25 × 2 = 10.5 cu ft. Convert to gallons: 1 cu ft = 7.48 U.S. gal; therefore: 10.5 × 7.48 = 78.5 gal. In this case, use a 100-gal nutrient reservoir to give adequate solution.

Assembly

First construct the bed(s) using 2″ × 10″ lumber for the sides and ¾″ plywood for the bottom. Be sure to use screws and glue in the joints. Install the vinyl liner as described earlier for the raft system raceway, but the plumbing will differ. Install a 1½″ diameter inlet pipe in the center of the bed in the middle lengthwise using bulk-head fittings to seal the pipe with the vinyl liner as discussed earlier for the raceway. An overflow pipe of the same size diameter and 8″ high is placed in the bed with similar bulk-head fittings within 12″ of the end of the bed nearest the nutrient reservoir. This maintains the solution level in the bed during an irrigation cycle.

Make the support frame next before the irrigation system from the pump and the drain line back to the reservoir. Using galvanized or chrome steel square tubing is preferred over wood for the bed framework. Be sure to make a separate frame for each bed. The top of the framework should be 30″ high to give sufficient height above the nutrient tank. The width should be about 1″ wider than that of the bed. Due to the weight of the aggregate and solution make cross supports every 3–4 ft. Tie the entire framework together at the base and top with bars both across and lengthwise as shown in Figure 13.3. At the edges of the top cross bars where the bed sits, extend the vertical tubes 1″ above to act as a guide to contain the bed.

After placing the bed on top of the framework start the plumbing. A submersible pump with a 1½″ outlet and capacity to fill the bed within 5 min will ensure rapid fill and drain of the bed. The volume of the void spaces in the bed in our example of a

10 ft long bed was 5.25 cubic ft or about 40 gal. The pump must be capable of filling the bed with 40 gal within 5 min so the pump outlet volume should be at least 8 gpm (40 gal/5 min). Assemble the piping from the pump in the following sequence: male adapter and bushing to 1½″ diameter pipe; 1½″ union; a bypass pipe with a 1½″ × 1″ tee (or 1½″ tee plus a 1½″ × 1″ reduced bushing); 1″ ball valve on a 1″ bypass line; 90° elbows to take the 1½″ inlet line from above the solution reservoir underneath the supporting framework for the bed and then entering the center of the bed. Within 2″ of the inlet to the bed install a 1½″ union so that the line can be dismantled if necessary. The return overflow line should be 1½″ diameter from one end of the bed closest to the nutrient reservoir. This also can be fastened to the underside of the bed framework. Drill holes in the cover of the nutrient tank for the bypass, main inlet, and return pipes. The piping differs somewhat from the raceway of Figures 13.3 and 13.4 in that an air pump is not needed and the ¾″ inlet line is replaced with the 1½″ main to the bed.

Fill the bed with the expanded clay aggregate to within ½″ of the top. Place a screen over the inlet and overflow pipes before filling with the aggregate. One day before transplanting, sterilize the aggregate with a Zerotol solution (hydrogen dioxide) of 1:100 concentration. This is equivalent to 1¼ fluid ounces per gallon. Water the medium with the Zerotol solution using a watering can from above. Alternatively, put 1 gal of Zerotol in the 100-gal solution tank and pump the solution into the bed several times keeping the pump on for half an hour each time to allow the solution to circulate through the substrate and overflow back to the reservoir. This process will kill most fungi.

ALTERNATIVE SYSTEM

There is one commercial ebb and flow system that uses a series of 5-gal pots, instead of beds, filled with lightweight aggregate. This system is described in detail with drawings (Figures 20.3 and 20.4) in Chapter 20. There is a 6-pot and a 12-pot system. The key components to the system are a 55-gal drum nutrient reservoir; a 5-gal controller bucket; 6 or 12 growing pots with felt liners to prevent debris entering the drain lines; two submersible pumps, fittings, and tubing; two timers; and a float valve.

A 400-gph pump is positioned in the solution reservoir that circulates solution to the controller bucket upon an irrigation cycle governed by one timer. The solution flows from the controller bucket by gravity to each of the grow buckets until they all reach a set fill level that is equivalent in all of the buckets and control bucket. A float valve in the control bucket then stops additional inflow of solution to the control bucket. When the timer for the main pump stops the irrigation cycle to the controller bucket, the second timer activates a smaller submersible pump of 160 gph in the control bucket to start pumping the solution back to the main reservoir. The two timers must be synchronized so that when one starts the other must be off. The solution from the grow pots drains back to the control bucket as the level in the control bucket is lowered by the pump sending the solution back up to the main 55-gal nutrient drum.

One timer is designated the “fill” timer and operates about 20 min during an irrigation cycle. The irrigation cycles are usually ever few hours according to the plant stage of growth and nature of the crop. The other timer called the “drain” timer activates the control bucket pump for about 40 min during a drain cycle as it takes more time for the solution to drain back from the grow buckets than it does to fill them.

This ebb and flow commercial hydroponic system costs about $450. For more information visit the website of "HTG Supply" listed in the Appendix.

You could construct this system yourself. The most challenging aspects would be to locate all of the various fittings needed to connect the distribution hoses, drain screens, and so on to the grow buckets. Each of the pots must be connected to the control bucket with special fittings (grommets) that will seal them to the buckets without leakage. Most are ½″ and ¾″ diameter poly hose fittings.

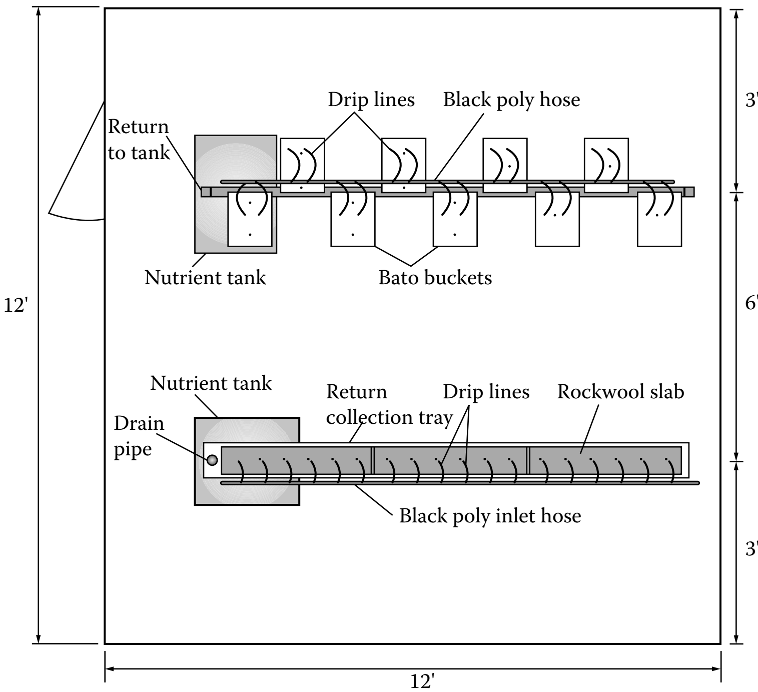
DRIP IRRIGATION SYSTEMS

Drip irrigation is central to all other hydroponic cultures with the exception of aeroponics. It is used with sand, perlite, vermiculite, small expanded clay, sawdust, rockwool, peatlite mixes, coco coir, rice hulls, and any combination of these as a mixture. Irrigation by a drip system is the common method of providing nutrient solution to the base of plants in all of these hydroponic cultures. Sand and sawdust cultures are contained in beds, whereas peatlite mixes, small expanded clay, and rice hull mixes are better in pots. Rockwool and coco coir cultures use plastic "slab" sleeves. Perlite may use slabs or special pots such as "bato buckets." All use drip irrigation. In the following example, re-cycled systems are used for one bench with bato buckets and the other with high-density rockwool slabs. The larger high-density slabs will support six tomato plants each providing they are V-cordon trained as explained in Chapter 24.

The following components make up a drip irrigation system. The materials listed are for an indoor drip system irrigating two 10-ft rows of pots with two plants each or 8″ wide slabs with six plants each. If these are vine crops, each plant requires 4 sq ft of floor space. Therefore, a growing room of dimensions 12 ft long by 12 ft wide has a total area of 144 sq ft. The maximum number of vine crops in that area is 144/4 = 36 total plants of tomatoes, peppers, or eggplants. European cucumbers must have a minimum of 9 sq ft so the area would contain only 16 plants. You will, however, grow a combination of these crops, for example, 4 cucumbers, 18 tomatoes, 6 peppers, and 4 eggplants. Space the rows 6 ft apart. The first row is 3 ft from the wall and there is 6 ft between it and the next one, making it also 3 ft from the other wall. In our example, (Figure 13.17), the first row with the bato bucket system has 6 peppers, 4 eggplants, and 4 cucumbers and row two in the rockwool slabs has 18 tomato plants.

Materials

1. A submersible or centrifugal self-priming pump with timer.
2. A 35-gal tank with cover.
3. Compensating emitters of 0.5 gph.
4. Drip line of 0.160–0.220″ diameter (36 plant drip lines × 18″ = 54 ft).
5. Barbed stakes: 36
6. Two figure "8" end stops or 3″ × 1″ PVC.
7. Schedule 40, ¾″ PVC pipe: 10 ft
8. Various ¾″ PVC fittings including male adapters, tees, 90° elbows, ball valves, ¾″ × ½″ slip-thread reduced bushings (2).
9. 20 ft of ½″ black poly hose with ½″ barbed adapters (2), 1″ hose clamps (2).



Note: Systems are supported on a frame above tanks.

FIGURE 13.17 Drip irrigation system plan. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

10. PVC glue and cleaner.
11. A poly punch tool to make the holes for the emitters in the poly hose.
12. 100 mesh filter.
13. Lumber or ¾″ steel square tubing for supporting the pots on frames or slabs in trays.
14. Lumber to construct trays for slabs.

Assembly

Here only the assembly of the drip irrigation system is discussed as the remaining growing systems explain the various substrates in pots or slabs and any supporting structure. Starting from the pump, attach a ¾″ main inlet line with a male adapter, then above the tank make a bypass line using a tee, ball valve, and 90° elbow. Above the bypass put a 100-mesh filter in the main line then continue with 90° elbows and the line to a header at the front of the plant rows.

Then use two elbows and a reduced slip-thread busing in each to adapt to the ½″ poly adapters. The ½″ black poly hose is attached to each adapter and runs to the end of each row where a figure "8" end stop is placed. Punch holes for the emitters at the location of the plants and insert an emitter in each. Attach a drip line to each emitter at one end and a barbed stake at the other that sits at the base of each plant.

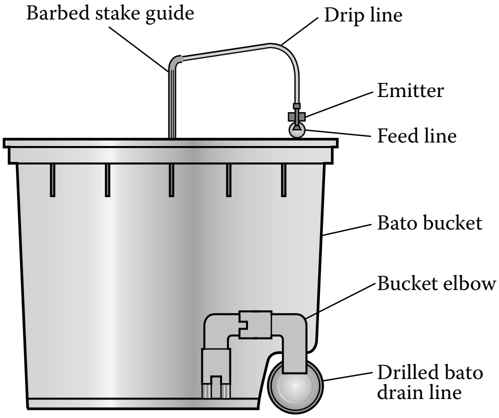


FIGURE 13.18 Bato bucket with drainage siphon at bottom. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

PERLITE BATO BUCKET SYSTEM

Bato buckets are special pots designed for using coarse substrates such as perlite and expanded clay. I do not recommend them for finer substrates since the buckets retain a small reserve of solution at the bottom of the pot. Also, any recirculation of the leachate with a fine medium would be more complex in managing due to potential salt build-up. The buckets have an indentation at the back to enable them to sit on a 1½″ drain pipe. A ¾″ diameter double elbow forms a siphon to drain from the pot to the drain pipe (Figure 13.18). This siphon keeps about 1″ of solution in the bottom of the bucket. This persistent reservoir of solution in the bucket is important with coarse substrates.

They are made by a company in Holland and hence are also referred to as "Dutch" bato buckets. These buckets are suitable for vine crops. They are made of rigid plastic, measuring 12″ × 10″ × 9″ deep (Figure 13.18). The bato buckets are placed on a 1½″ or 2″ PVC drain pipe to enable recirculation of the nutrient solution. The rows are spaced 6 ft apart and the bato buckets are staggered at 14–16″ centers within the rows. Some hobby units are available as a self-contained supporting structure, pots, and irrigation system in compact configuration (Figure 13.19). As long as the plants are V-cordon trained to optimum spacing at the top of the crop, the narrow spacing of the pots is functional. Two plants are grown in the buckets, with the exception of one for European cucumbers to obtain the correct growing area per plant. Irrigation is by a drip system.

In an indoor bato bucket system, the pots will have to be raised above a solution tank with a framework of steel or wood. The frame has to be just high enough to permit gravity flow of the recycled solution to the tank as shown in the diagram of a commercially available hobby system (Figure 13.20).

Materials

The following materials list is to build a system of two 10-ft rows of bato buckets with the same irrigation system as described previously under "Drip Irrigation

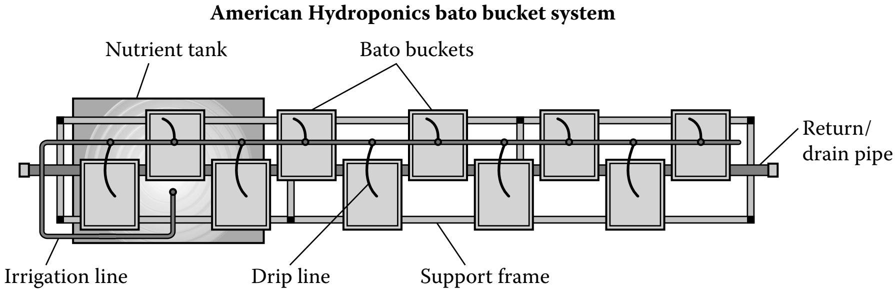


FIGURE 13.19 Bato bucket layout (plain view). (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

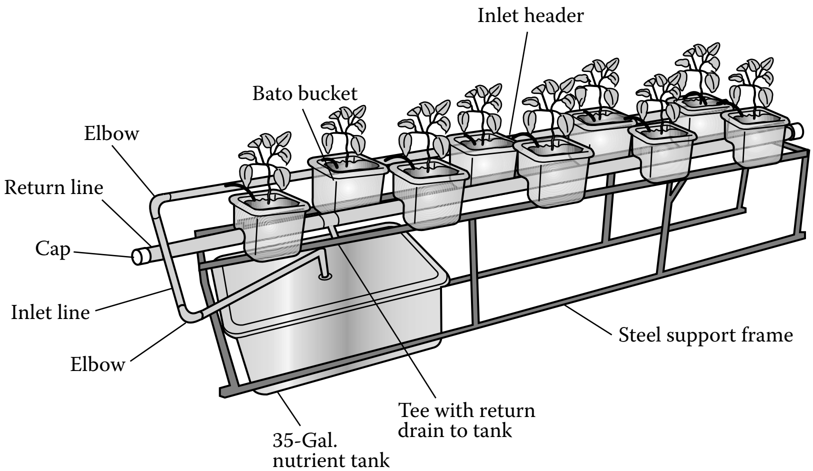


FIGURE 13.20 Side view of supporting frame and layout of a bato bucket. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

System." The irrigation system is exactly as outlined; therefore the materials for that portion include all items 1–13 listed earlier with a 50-gal tank. The additional materials needed are listed in the following text:

1. There are nine bato buckets per row, so a total of 18 bato buckets.
2. Thirty feet of PVC pipe of 1½″ diameter for the drain collection lines.
3. Various 1½″ PVC fittings for the drain return to the solution tank include 90° elbows (3), female adapter plus threaded plugs (2), and one tee.

Assembly

Construct the supporting framework as shown in Figures 13.19 and 13.20. Make two individual benches, one for each row of pots. You may place ½″ thick plywood on

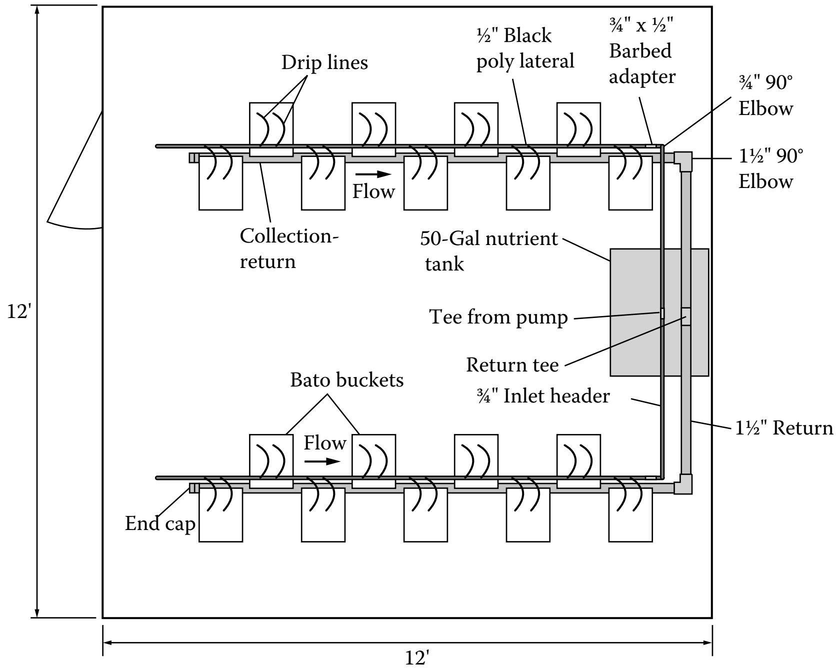


FIGURE 13.21 Details of drainage and irrigation systems for two tables of bato buckets. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

the top of the benches, but it is not necessary for bato buckets as they are supported at their drain end by the drain pipe. Once the framework is completed make up the drip irrigation system as described earlier. Then, secure the drain pipe system on the frame under the drain end of the bato buckets. Cut 1″ diameter holes along the top of the drain pipe at the positions of the pots (14″ centers starting 8″ in for the first one). Join the two drain pipes with elbows and a tee to a common header that then enters the top of the solution tank. Locate the nutrient tank between the rows at the back wall. Connect all of the inlet pipes, bypass, filter to the pump and make up the header with risers up to the top of the first bato bucket in each row and connect, with an elbow and adapter, the black poly hose with the emitters and drip lines as shown in Figure 13.21.

One day prior to placing the pots with the perlite, moisten the perlite and flush the substrate with Zerotol (1¼ fl oz per gal). Upon positioning the bato buckets, place the black poly hose along the top of the pots. The pots are now ready to transplant. During transplanting put one drip line with a barbed stake at the base of each plant. Irrigate 4–5 times per day with 5 min duration per cycle. Adjust the frequency of cycles with the stage of plant growth and cycle duration for 20% leachate.

ROCKWOOL CULTURE

Start seedlings in rockwool cubes that are transplanted to rockwool blocks before a second transplant (about 5–6 weeks after sowing for most vine crops except cucumbers about 2 weeks) to rockwool slabs. Rockwool properties and products were discussed in Chapter 11.

For consistency in description of materials and components, the same size of rockwool system as for perlite bato buckets is presented that grows 36 vine crops in an area of 12 ft × 12 ft. There are two rows of plants, but instead of bato buckets, use 8″ wide rockwool slabs. The supporting framework for each bed differs somewhat in that it should slope 3% toward the solution tank.

A tray under the rockwool slabs collects the leachate from the rockwool slabs and returns it to the nutrient reservoir. To contain 8″ wide slabs construct watertight trays 10″ wide by 4″ high by 10 ft. Each tray has three slabs each with six plants of tomatoes, peppers, or eggplants as shown in Figure 13.17. Grow only three European cucumbers per slab to meet spacing demands of the plants. V-cordon train the plants as outlined in Chapter 24. To make the return tray waterproof, line it with 20 mil vinyl, folding and gluing it as was shown in the raceway construction in raft culture. A 1½″ diameter drain pipe is installed at the lower end within 2″ of the tray end in the same way as described for the raceway. The drains of the two trays are attached with a union to the collection pipe header going to the solution tank. The irrigation system is the same design as for the bato bucket perlite system shown in Figure 13.21. Items 1 through 13 of the materials for the drip irrigation system with a 50-gal tank are used in addition to the following.

Materials

1. Six rockwool slabs 4″ thick by 8″ wide by 39″ long.
2. Fifteen feet of PVC pipe of 1½″ diameter for the drain collection lines.
3. Various 1½″ PVC fittings for the drain return to the solution tank include 90° elbows (5), unions (2), bulk-head fittings (2), and one tee.
4. 1″ Styrofoam to insulate the slabs.
5. ¾″ thick plywood.
6. Fifty feet of 1″ × 4″ lumber for tray sides and ends.
7. Two pieces of 20-mil vinyl swimming pool liner 2 ft wide by 12 ft.
8. Vinyl cement.
9. White oil-based paint.

Assembly

The benches for the slab trays are constructed the same as for the bato buckets with the exception of the 3% slope to the solution tank. The inner dimensions of the trays are 10″ × 10 ft × 3½″ high. Cut the plywood to 10 ft 4″ long by 11½″ wide. This is the bottom of the tray. Screw and glue the 1″ × 4″ boards around the perimeter of the plywood. Paint the wood after assembly, but before placing the vinyl liner. Drill the drain hole within 2″ of the end of the tray to get a snug fit for the 1½″ diameter pipe and seal it with bulk-head fittings as described in the construction of raceways earlier and as shown in Figure 13.22.

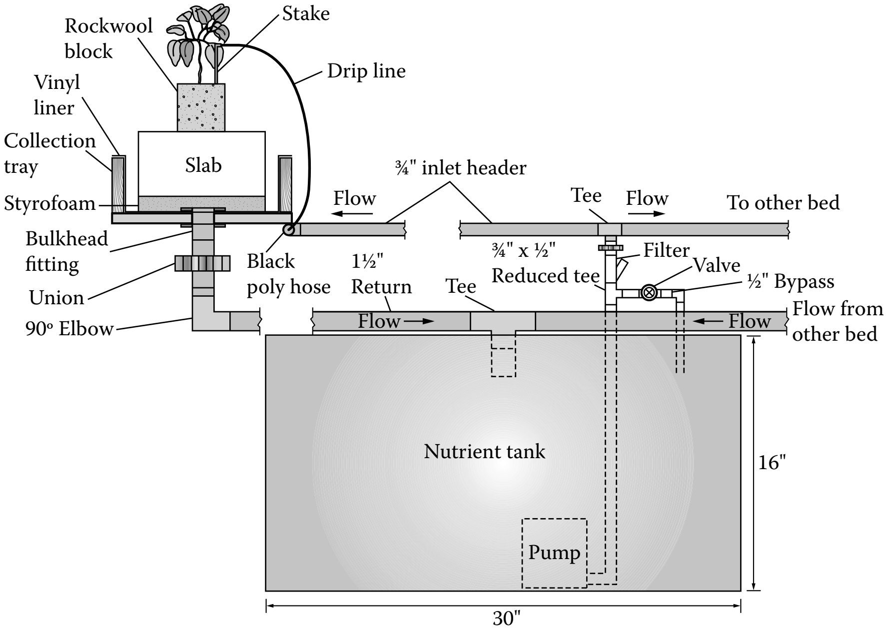


FIGURE 13.22 Rockwool culture layout. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

Once the collection trays are completed, put them in place and make up all of the return lines and attach the header to the trays with a union so that they can be dismantled for cleaning and/or repair. Then, fabricate the drip irrigation lines with the inlet pipe, bypass, and so on from the pump.

Test all of the irrigation and drainage systems with raw water in the solution tank to detect any leaks.

A key component is the 1″ thick Styrofoam. Use the high-density "Roofmate" type of Styrofoam. Cut the Styrofoam strips 8″ wide and a total length of 9 ft 8″ long so that they do not cover the drain as shown in Figure 13.22. The Styrofoam strips are placed immediately underneath the slabs. The Styrofoam between the bottom of the return tray and the slabs has two important functions. First, it insulates the slab keeping the roots warm. Second, it raises the slabs up slightly and away from the sides of the tray to permit easy flow of the leachate. After the slabs have been presoaked for several hours, cut drainage slits 1″ long on a 45-degree angle from the base of the slab liner at the level of the Styrofoam underneath. These drainage cuts are positioned between the plants. Three cuts are sufficient. Cut them on the same side (only one side) of each slab.

Seedlings are sown in 1½″ rockwool cubes, transplanted to 3″ blocks, and finally to the slabs after 5–6 weeks from sowing. Remember to presoak the slabs with a half strength nutrient solution prior to transplanting the seedlings in the blocks. At that time make up the nutrient solution in the tank.

Frequency of irrigation cycles is dependent upon stage of plant growth and the crop. Make the duration of any given cycle long enough to get at least 20% leachate.

COCO COIR CULTURE

The entire setup for coco coir culture is the same as for rockwool culture. The slabs for coco coir are the same dimensions as those for rockwool; however, they also make “mini” slabs that are shorter than the normal ones and are good for two plants only.

The only difference between these two cultures is the frequency and duration of irrigation cycles. Coco coir retains much more water than rockwool, so fewer irrigation cycles are needed. Leachate can be reduced to about 15% maximum with a shorter duration of any cycle.

Seedlings may be started in coco coir cubes and blocks such as those sold by Jiffy Products, but most growers still use the rockwool cubes and blocks and transplant to the coco coir slabs by setting them on top of the slabs as is done with rockwool slabs.

AUTOPOT SYSTEM

This is basically a wick type of system of a series of pots, but a patent system due to a special “AQUAvalve” that regulates the irrigation to the pots. For details visit their website (see Appendix) and Figures 13.23 and 13.24. They recommend using substrate 50/50 mixes such as coco/perlite, coco/expanded clay, and rockwool/expanded clay.

The AutoPot requires no power, pumps, or timers to operate. It functions on the gravity of solution from a tank. This flow of solution to the pots is regulated by the AQUAvalve through gravity from the solution tank. It fills a tray under two pots to about ¾″ in depth and does not fill it again until the solution is used up by the plants in the pots. Each tray holds two pots. A capillary-like disc is set in the tray under the pots. A black “matrix” disc is set in the bottom of the pots before filling with a substrate. This also acts in bringing the solution in contact uniformly with the substrate.

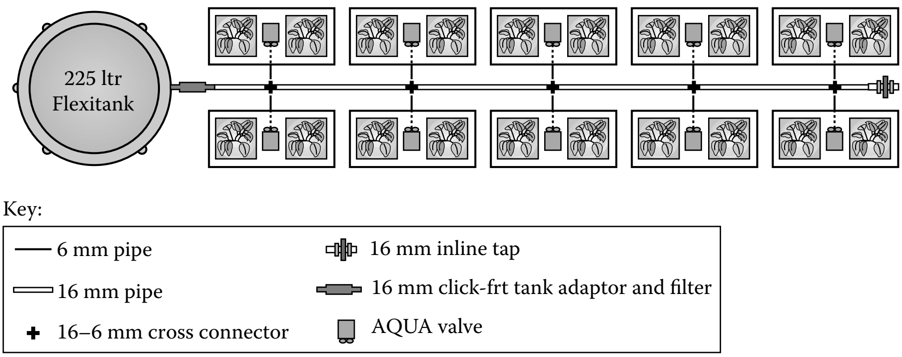


FIGURE 13.23 AutoPot system layout with 20 pots. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

FIGURE 13.24 AutoPot system of 20 pots. (Courtesy of AutoPot Global, Ltd., Paddington, Oxfordshire, United Kingdom.)

AEROPONICS

This culture is not feasible on a larger scale than the small indoor units that were described in Chapter 12. A somewhat larger unit may be constructed as an A-frame. In this system make an A-frame of 1¼″ diameter PVC pipe and secure 1″ thick Styrofoam on the outside to hold the plants. The frame must sit above a nutrient tank. The width of the base should be a few inches narrower than the nutrient reservoir so that the solution will drain back to the reservoir. The system can grow low profile crops and medicinal plants whose roots are harvested for vitamins or drugs.

The following list of materials is for an A-frame of 3 ft wide base and 4 ft long. The height of the sides is 4 ft. The sides are therefore 4 ft × 4 ft with the bottom edge sitting on top of the nutrient reservoir that is 3 ft × 4 ft × 9″ deep. Construct the nutrient reservoir of wood and line it with 20-mil vinyl as was done for the raceway system.

Materials

1. Lumber for the reservoir includes 14 ft of 2″ × 10″ and ¾″ thick plywood for the bottom.
2. A piece of 20-mil vinyl liner 6 ft × 8 ft.
3. A-frame materials include: 1¼″ diameter schedule 40 PVC pipe, 90° elbows, and tees.

4. A high pressure submersible pump with 200-mesh filter.
5. PVC pipe of ¾″ diameter schedule 80 supporting and connecting to the mist nozzles.
6. Various PVC fittings for the mist distribution pipe.
7. A 24-h timer with minute intervals.
8. Two sheets of 4 ft × 8 ft × 1″ thick Roofmate Styrofoam.
9. Various hardware of bolts, plastic electrical ties, screws, glue, and so on.

Assembly

Construct the nutrient reservoir with outside dimensions of 4 ft × 3 ft. Be sure to use screws and glue on all joints including the plywood bottom. Fold in the vinyl liner as described for the raceways previously. Paint the reservoir with white oil-based paint before lining it. This reservoir has no drain.

Once the reservoir is completed build the A-frame to fit onto it. Assuming that the exact outside dimensions are 48″ × 36″, make the A-frame slightly smaller to allow for the 1″ Styrofoam that will cover the sides and ends of the A-frame. The inside of the Styrofoam must overlap the reservoir frame by ½″ to permit the moisture when irrigating to run back into it. Refer to the drawings of Figure 13.25 for details. The outside dimensions of the A-frame without the Styrofoam then is as follows: width: 33″ less ½″ on each side = 32″; length: 48″ less ½″ on each end = 47″. First, construct the two ends using 1¼″ PVC pipe as shown in Figure 13.25. The lower base cross member is 36″ long in order to rest on top of the nutrient reservoir sides. One horizontal 1¼″ pipe (47″) going lengthwise is attached by stainless steel screws or bolts in the corners of each "A" to complete the frame.

Fit the two 36″ cross members of 1¼″ diameter PVC with a 90° elbow on each end at exactly the outside width of the nutrient reservoir so that these supports will fit snugly against the outside wall of the reservoir to strengthen it. These are attached to the top sides of the tank using 2″ self-tapping stainless steel screws. Fasten with self-trapping stainless steel screws the peak of the frames together using the horizontal member at the top angle.

Cut the Styrofoam to fit the sides and ends securing them to the A-frame with stainless steel self-tapping screws. Be careful that your measurements are correct so that the insides overlap into the solution reservoir about ½″ to allow drainage back to the solution tank to prevent leakage outside. Refer to the diagrams of Figure 13.25 for details. Cut ¾″ diameter holes in the side Styrofoam boards at 6″ × 6″ for lettuce, arugula, basil, and some herbs or 4″ × 4″ centers for smaller herbs. This is similar to the spacing for boards of raft culture so the 4 ft × 4 ft board would hold 64 plants at 6″ × 6″ spacing. Leave the Styrofoam ends of the A-frame off until the irrigation system is completed.

Make up the irrigation system using ¾″ diameter Schedule 40 PVC from the pump. Install the 200-mesh filter at the front of the header. Place the header with the mist nozzles on top of 1″ PVC frame cross members at 12″ above the nutrient reservoir. Install four mist fogger heads at 12″ centers in line along the top of the pipe. The position of the first mister is 6″ from the end and the other three are at 12″

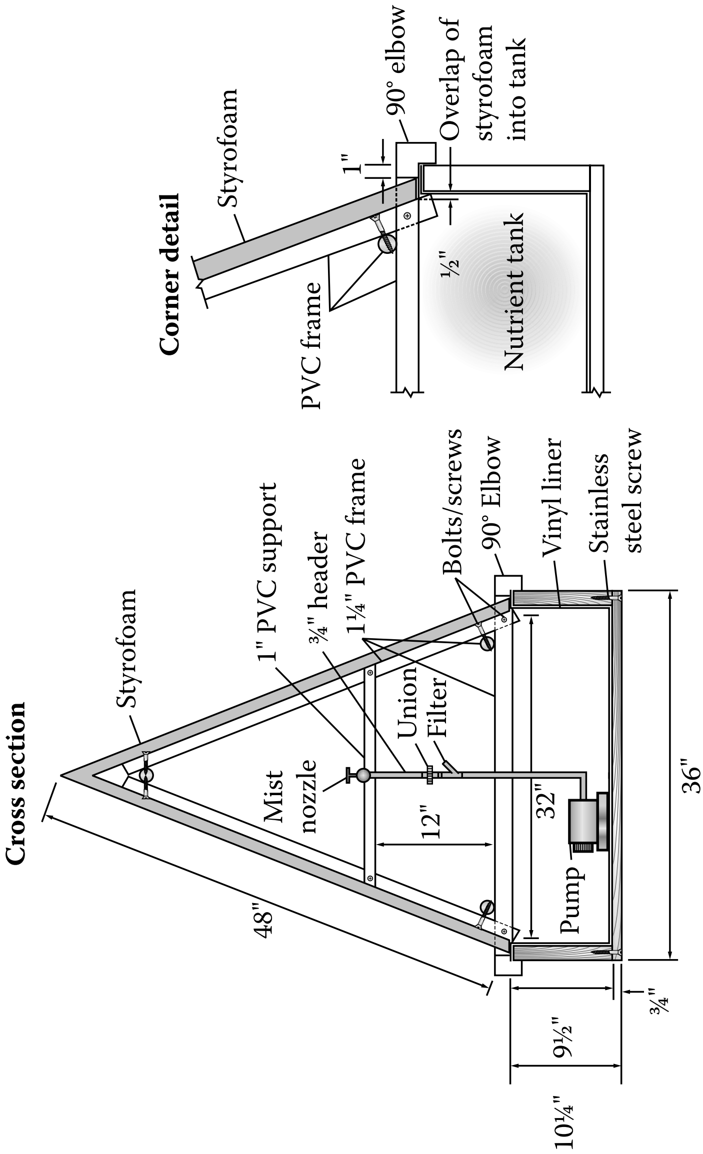


FIGURE 13.25 Aeroponic A-frame cross section with details. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

centers making the fourth one 6″ from the opposite end. A timer activates the pump to operate the mist cycles. The frequency and duration of the cycles depends upon the crop and its stage of growth, but as a guideline fog every few minutes for 5 sec, day and night.

PLANT TOWERS

This is a system developed to increase the number of plants in a unit area occupied. This system is for low-profile plants and is particularly suitable to most herbs and strawberries. Plant towers need about 10–12 sq ft of floor area to allow for adequate light. The best method of construction is with the use of special Styrofoam pots available in the marketplace (see Appendix for suppliers). While in some cases you can grow bush tomatoes, peppers, or eggplants, light must be sufficient to penetrate the whole crop canopy. With those crops put only half the number of plants in a tower. With the square pots that are available, plant in the corners of the pots. The plant towers must be supported with a central pipe and be secured above by a cable or other bracket to the ceiling. The towers use a drip irrigation system, two drip tubes in the top pot and one in the middle pot of the tower. The towers must sit on top of a collection pots connected to piping that will conduct the solution back to a nutrient reservoir. I do not recommend using polyethylene sacks as they break with age. You can also construct a column from large diameter PVC pipes such as 8″ diameter. But, again the square Styrofoam pots are better to make transplanting or seeding with subsequent plant support easier than will be the case with pipe columns or sacks.

In the previous example for the bato buckets in a 12 × 12 ft growing space, we can fit about 10–12 plant towers. Here is a list of supplies needed for 10 plant towers. Seven pots per tower are sufficient as the pots are 9″ × 9″ × 8″ tall. Seven pots is a height of 56″. In addition to the pots is the height of the collection pot, at least 10″, plus the support frame height of 20″ for a total tower height of 86″. That height will just fit in a normal house ceiling height of 8 ft with some room above for the irrigation system, tower supports, and so on.

The towers are at 24″ centers with the first located 18″ from the wall. There are five plant towers per row and two rows spaced at 3 ft – 6 ft – 3 ft distances starting from the side wall of the room as shown in Figure 13.26. A 2″ diameter PVC collection pipe at the base of the plant towers returns the solution to the nutrient tank.

Materials

1. For up to 10 plant towers use a plastic storage bin of 50 gal as a nutrient tank.
2. If the plant towers are seven pots high you need 70 pots for 10 towers.
3. Thirty feet of 2″ PVC schedule 40 pipe for the drainage return pipe.
4. Fifty feet of drip line.
5. Thirty compensating emitters of 1–2 gph.
6. Time-clock controller with 24-h and 60-min increments.
7. One submersible pump having a lift capacity of 10 ft with 30 psi pressure.

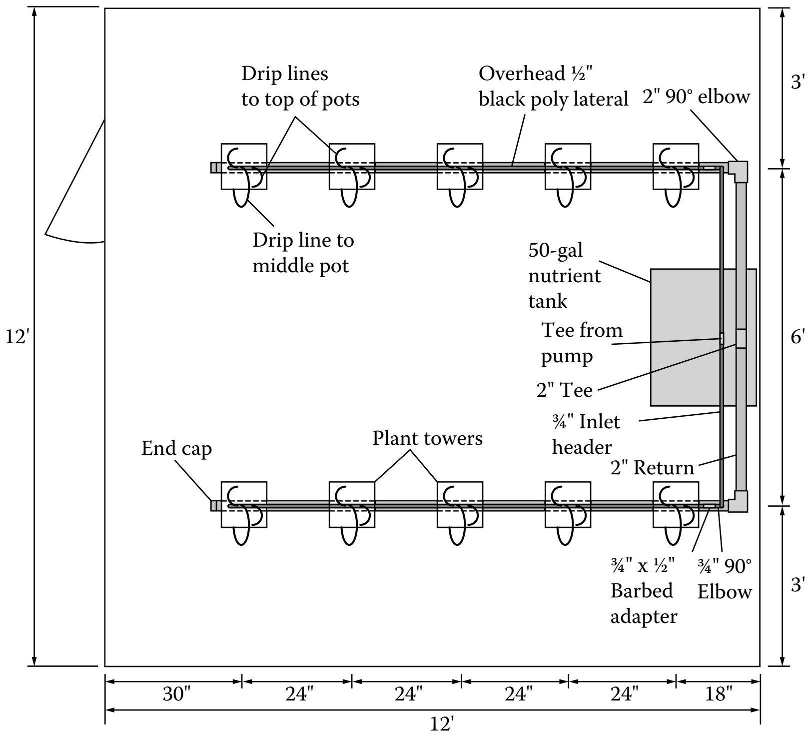


FIGURE 13.26 Layout of plant tower system with all components. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

8. Twenty feet of ¾″ PVC Schedule 40 pipe as the main to the height of the plant towers.
9. Thirty feet of ½″ black poly tubing.
10. Various PVC fittings including a ¾″ bypass ball valve, four ¾″ male adapters, six 90° elbows (¾″), two ½″ slip-thread reduced bushing, and two ½″ male barbed adapter to poly tubing.
11. Punch tool for making the holes for the emitters for the black poly lateral tubing.
12. Ten collection pots for the base of the plant towers.
13. One hundred feet of ¾″ diameter galvanized electrical conduit to support the plant towers.
14. Various lumber or ¾″ square steel tubing to build a support stand for the towers to keep them above the level of the nutrient reservoir.
15. One hundred feet of 1″ thin wall PVC for the sleeve over the conduit pipe to permit easy rotation of the plant tower.
16. Ten rotation disks of ¼″ thick by 3″ × 3″ square plastic plate. Drill ¾″ hole in center to permit conduit to pass through it.
17. Bulk-head sealed fitting for each collection pot or tray to connect ½″ black poly line to return pipe.

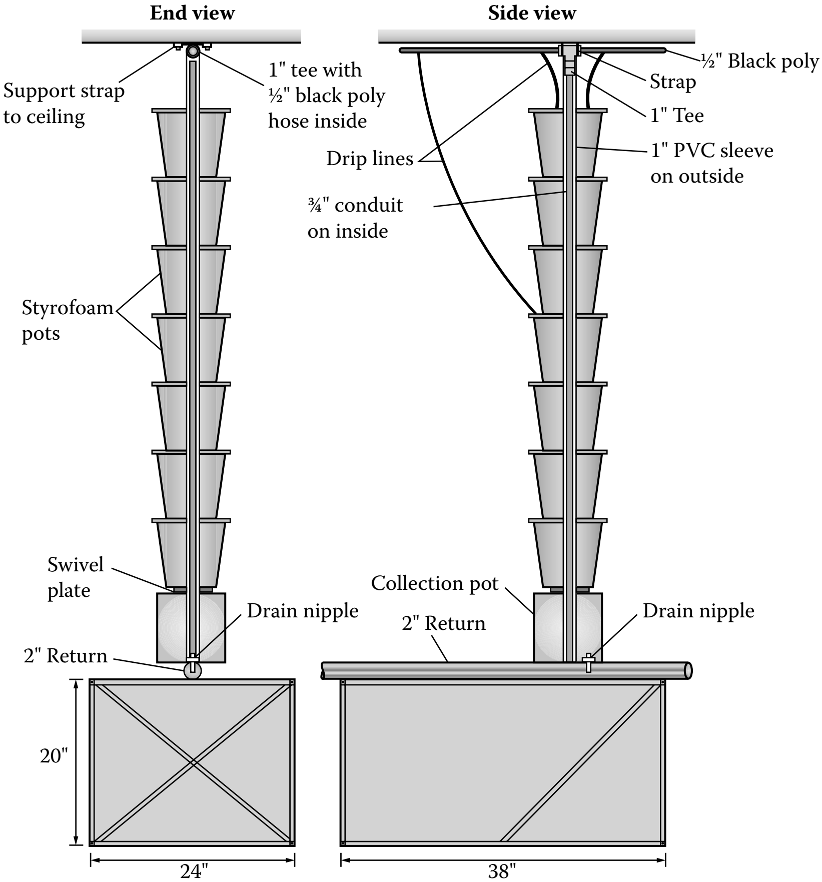


FIGURE 13.27 Irrigation piping from the pump to the top of the plant tower. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

Assembly

First construct a supporting frame 24″ wide by 20″ high by 114″ long for the plant towers with the nutrient reservoir positioned underneath or in the center as shown in Figure 13.26. Attach a vertical member every 38″ along the length. Put braces on the end portions of the frame as shown in Figure 13.3 for the raceway system. The plant tower can be either set on top of the drain pipe as shown in Figure 13.27, or it can be set beside the drain pipe with a small hose line attached from the collection pot to the return pipe. If the plant tower is set beside the return pipe, cover the top of the frame with ¾″ plywood. Placing the collection bucket on top of the return pipe requires a sealed drain nipple from the bucket to enter the return pipe. Place the bottom end of the conduit in the collection pot to the side of the drain nipple after sliding the swivel plate and a 10″ long 1″ diameter PVC sleeve over the conduit as shown in Figure 13.27. This piece of pipe must be the same length as the height of the collection pot or one inch shorter so that the tower will drain into the collection pot. Assemble the plant towers using the steel conduit and the 1″ PVC sleeve. Then, slide the special (Vertigro) Styrofoam pots over the conduit with its sleeve.

Stack the pots so that each is rotated by 45° to the one below and set them in the special locking indentations. Use a maximum of seven pots per tower. Put a 1″ diameter PVC tee at the top of the conduit and fasten the tee to ceiling with pipe strapping or other type of bracket. To permit disassembly of the plant tower remove the bracket holding the tee and slide out the remaining plant tower assembly. Once all of the plant towers have been placed at 2 ft centers, start on the irrigation and drainage system.

From the pump in the solution reservoir attach a ¾″ main using the male adapter, tees, and elbows to a bypass line as was shown in rockwool culture (Figure 13.22). Past the bypass return line with the ball valve, continue the header up to within 2″ of the ceiling where a ¾″ × ½″ slip-thread adapter is connected to a tee at the top. Connect ½″ black poly hose to the ½″ barbed adapters of the tee going both directions to the plant tower rows. Support the PVC tee with a pipe strap or other bracket to the ceiling. The black poly hose attached to the barbed adapters passes through the 1″ tees at the top of each plant tower support pipe and is then plugged at the end using a figure “8” adapter or a short piece of 1″ pipe. Punch three holes in the black poly hose close to each tower and insert the emitters and then the drip lines to them. Two lines go to the top pot and the other one goes to the center pot of each tower.

Attach the bulk-head fitting to the lower side of each collection pan and connect it with a short piece of ½″ black poly hose to the 2″ return pipe to the solution tank. Be sure that the return pipe is lower than the base of the collection pan so that all solution will drain back from the pan to the return pipe by gravity. Alternatively, use a sealed ½″ or ¾″ PVC nipple on the bottom of the collection pot to enter the return pipe located immediately below as shown in Figure 13.27. The return pipe is plumbed back to the top of the solution reservoir as shown in Figure 13.26.

Fill the pots to within 1″ of the base of the adjacent upper pot with substrate of your choice depending upon the crop grown as outlined in the table of Chapter 15. Start herbs by seeding directly into the substrate of the pots. When seeding herbs be sure to use 8–10 seeds per corner planting site. With basil, bok choy, and arugula start the seeds in growing cubes and transplant to the pots after a few weeks. With strawberries you must purchase pre-chilled plants or bring in runners from your garden in the fall or early spring as they must go through a dormancy period. Start up the system to check for any leaks if these plant towers are located in your house as all solution must be contained to prevent damage to your floors.

14 How to Start Your Plants

SEED VIABILITY AND PERCENT GERMINATION

For the growing of hydroponic vegetable crops start your plants from seed. All seeds have a certain life expectancy called viability. The viability is dependent upon the seed itself as well as age and conditions under which it was stored. To lengthen viability keep the seeds in a refrigerator at about 40°F (4.5–5°C) or slightly higher. Do not put them in the freezer section. In general, large seeds retain their viability longer than small seeds. Lettuce, for example, loses viability after 6 months. As viability falls, so does the percentage germination. This is the percent of seed that will germinate under normal sowing conditions of a moistened medium. Every seed package will give percentage germination at the time of packaging the seed. The date tested is given on the seed package. Tomatoes will retain viability for about 3 years when stored in a cool, dry location. However, the percentage germination will decrease over this time period.

You may test the seed germination quite easily. Put 100 seeds on top of two to three layers of moistened paper towels. Then, cover them with another two to three layers of moistened paper towels. Keep them at about 70°F to 75°F (21–24°C) or whatever germination temperature is recommended on the seed package. Inspect the seed after several days, or after the expected length of time indicated on the seed package for the seed to germinate, and count how many of them have broken the seed coat and started to grow. Take that number of germinated seeds and divide by the total of 100 to get the germination percentage.

This percent of expected germination is important for you to determine how many seeds to sow. For example, if 70% of the seeds germinated, then you know you must sow at least 30% more seeds to get the number of plants you want. As an example, if you want 20 tomato seedlings and you found a 70% germination, then multiply the 20 by the percent you want (100%) and divide by the percentage germination (70%): $20 \times 100/70 = 29$. Sow 30 seeds to obtain more seedlings than needed. In that way, you can select the most vigorous seedlings to transplant.

SEED SOURCE AND VARIETY

Another important factor is to get the best seed available. You may order through many seed distributors such as those listed in the Appendix. The next thing to consider is the choice of variety. In most cases, greenhouse varieties will do best with indoor hydroponics. Do not collect seeds from your plants and volunteer them for the following crop as most varieties are F1 hybrids and will not produce the same plant in the next generation. The choice of varieties is discussed in more detail in Chapter 22.

PLANT HABIT/FORM

The form of the plant is also important in your choice. When growing indoors you may use bush varieties, but staking ones are more productive. These are also termed "indeterminate." Bush or "determinate" varieties grow to a certain height and then stop, whereas the staking types continue to grow upward. This applies to vine crops like tomatoes, peppers, eggplants, and European cucumbers and not to low-profile crops.

SEEDLING GROWING SUBSTRATES

When starting seedlings for hydroponic culture we use a soilless medium. The easiest method of sowing seeds is to use growing cubes. There are many available in the market. If you want to grow in peatlite mixture or coco coir in pots, you may use peat pellets or compact cell trays that you fill with a peatlite or vermiculite substrate. For lettuce, arugula, bok choy, basil, and herbs, it is best to start the seeds in either rockwool or Oasis cubes as shown in Figures 11.3 and 23.8. There are a number of different sizes of these products to choose from. Use the smaller ones, usually 1″ × 1″ × 1½″ rockwool cubes or 1″ × 1″ × 1½″ Oasis "Horticubes" for lettuce, arugula, and so on. With vine crops use the 1½″ × 1½″ × 1½″ rockwool cubes.

When growing vine crops, the seedlings in the rockwool or other cubes are transplanted to rockwool blocks before later placing them in the final growing substrate. The advantage of starting the seed in growing cubes is that you may select the best plants later to be transplanted to the rockwool blocks. This is another reason to sow at least 10% more seeds than the number of plants needed. Growing cubes and blocks must be thoroughly saturated and flushed with raw water prior to sowing or transplanting. Rockwool has a pH between 7 and 8.5 and hence is very basic. Reduce it to optimum levels between 6.0 and 6.5 by using a slightly acid solution after saturating the cubes. This can be done by adding vinegar or acetic acid to water to adjust the pH within this optimum range and soaking the cubes again before sowing the seeds. When preparing the blocks for transplanting, soak them with a half strength nutrient solution having a pH between 6.0 and 6.5.

Rockwool blocks come in various sizes: 3″ × 3″ × 2.5″, 3″ × 3″ × 4″, 4″ × 4″ × 2.5″, and 4″ × 4″ × 3″. The choice of size is a function of the plant grown, the size of the vtransplant, and the stage at which you wish to transplant to the final growing area. The longer the plant is held before the final transplant stage, the larger the block. Place the seedlings in the growing cubes or blocks in plastic mesh trays to permit rapid drainage. The trays should sit on a propagation table of wood or galvanized steel with either wire mesh top or lumber with 1½″ spaces between each cross member. This promotes rapid draining and allows aerial pruning of the plant roots that may grow from the cubes or blocks. Do not allow a root mass to form under the cubes or blocks as damage to the roots will occur during transplanting that will predispose the plants to diseases.

PROPAGATION BENCH

If you wish to contain the drain water from the seedlings after irrigation, build an ebb and flow bench that sits on top of a ¾″ steel square tubing framework, as described earlier in Chapter 13, Figures 13.2 and 13.3, and Figure 14.1. However, make the dimensions different from those described in Figures 13.2 and 13.3. Make the inside width 49–50″ by 4 ft 2″ or greater in length, depending upon the number of seedling trays, by 3″ deep. Each seedling tray is 1 ft × 2 ft, so a 4 ft × 4 ft bed would fit eight trays. To get complete drainage away from the trays and allow air pruning of roots, place 1″ of igneous rocks in the base of the bed to support the trays above any drainage water (Figure 14.1). Use rocks of ¾″ diameter. This will give large spaces among them that will dry between irrigations.

Alternatively, make a support frame of 1″ PVC pipe as shown in Figure 14.1. This support frame would keep the mesh trays above the drainage level of the ebb and flow tray. A 2″ high overflow pipe similar to that shown in Figure 13.3 would regulate the maximum solution height at 2″ enabling the solution to moisten the seedlings from below. The overflow pipe, drain pipe, nutrient tank, and plumbing are not shown in Figure 14.1 as they are shown in detail in Figures 13.2 and 13.3. The only difference is that the pump is directly connected to the drain pipe in the bed to fill and drain the bed. Use a 1″ feed/drain pipe from the pump. When the pump shuts off the water will flow back to the nutrient tank below through the pump.

The seedling mesh trays are 12″ × 22″, therefore orient the support frame below so that the trays will be placed perpendicular to the frame. The ebb and flow bed can be 25″ wide by a multiple of 1 ft in length to fit the trays most efficiently. If you need a larger area, make the ebb and flow bench 49″ wide by a multiple of 2 ft (such as 4 ft × 6 ft or 8 ft). Add an extra 1–2″ to the length to give ample room for the seedling trays. The irrigation cycles are automated with a timer operated pump in the nutrient tank below the bench.

During the initial seeding of the cubes, the cubes could be placed immediately on the surface of the ebb and flow bench, but it is better to use the mesh trays as that allows complete drainage. This method would also be fine for low-profile plants that are not transplanted to rockwool blocks. The placement of the layer of rocks or the

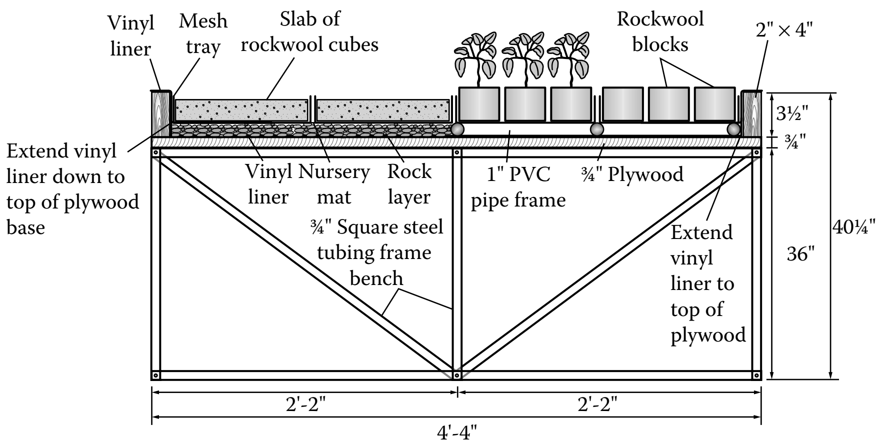


FIGURE 14.1 Propagation ebb and flow bench. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

support frame will reduce algae growth in the bottom of the ebb and flow bench due to the exposure to light to a wet surface containing nutrients.

When using the ebb and flow system for the rockwool blocks, keep them in mesh trays and cover the surface of the bed with rock or something else to prevent algae growth. Several layers of black nursery weed matting on top of the rock layer will further discourage algae growth.

Specific details of sowing and transplanting for each crop are given in Chapter 23.

15 Choosing Hydroponic Systems for Specific Crops

The choice of not only the hydroponic system but also the substrate is determined by the crop grown. When making this decision, consider the expected growth of the plant during its cropping period and the form of the crop (low-profile vs. vine-crop) stature. Small plants have less extensive root systems and can hence grow in smaller containers. Many plants simply do not like to grow in a nutrient solution alone but must have a medium into which to spread their roots. These include many herbs such as sage, rosemary, thyme, and oregano that are accustomed to a dry medium around their bases (crowns). Long-term crops that grow for many months cannot tolerate a water solution as they soon develop an oxygen deficit that causes their roots to die.

Plants that can tolerate a water culture system include lettuce, basil, watercress, mint, chives, arugula, and bok choy. Lettuce, arugula, basil, and bok choy have a relatively short cropping cycle of less than 2 months. For this reason, they will grow well in water culture systems such as the floating raft system or nutrient film technique (NFT). Most herbs, if grown on a short cycle, especially for "live" herbs, are happy in water culture systems. "Live" herbs are those that are harvested with their growing cube and roots intact and marketed in small plastic bags or sleeves as "living" plants. This method of harvesting prolongs their shelf life. It is very popular for basil, arugula, and lettuce. Even for your own use, keep the roots on these plants if you are not going to use the entire plant at one preparation. You will be aware of the lettuce in the supermarkets that are packaged in semi-rigid (clam-shell) containers with a lid and a small reservoir in the bottom to contain the roots in their growing cube. The most popular method of growing "live" herbs is in NFT channels, as they can easily be removed at harvesting without damaging a lot of their roots.

Long-term crops growing more than several months must have a substrate and be containerized or grown in beds. These include all vine crops and melons. Rockwool and coco coir slabs are the most common systems of hydroponics with these types of crops. They all use drip irrigation. The advantage of the drip irrigation system is to apply the solution near the base of the plants bringing oxygen with it as it percolates through the substrate. With the moisture homogeneously distributed within the substrate, the roots can spread around to seek water, nutrients, and oxygen. With any open or re-circulating system, it is critical to get good drainage that conducts the leachate away from the plant substrate and container so that oxygenation is not restricted to the plant roots. With ebb and flow systems, this complete drainage between irrigation cycles is one factor that will determine the success or failure of the crop. While small-scale systems of ebb and flow crops will do well as drainage is fairly rapid, with much larger systems of ebb and flow it is more difficult to get adequate and complete drainage in order to avoid restricting plant growth and production. For that reason, with long-term crops I do not recommend using ebb and flow systems. If crops are stressed by environmental limitations, they become more susceptible to pests and diseases. This is another reason to select the correct growing system for the specific crop.

Certain plants have preferences for specific substrates. Some plants like a higher water-holding capacity, while others need very rapid drainage and less moisture contained within the medium. Most vine crops thrive in most media, providing the medium has good drainage with available oxygen to the plants' roots. A few herbs such as rosemary and sage like very good drainage so do best in a coarse well-drained substrate like perlite, vermiculite, or mixtures of these with peat or coco coir at a 1:1 ratio. Knowledge of the type of soil these plants prefer will indicate the nature of medium to use with hydroponics. For example, if the plants do best in a sandy soil, they prefer a substrate with very good drainage, so we would use perlite, vermiculite, or the mixtures of these with some peat or coco coir.

Table 15.1 summarizes the most suitable hydroponic systems and substrates that some commonly grown hydroponic crops prefer. The raft culture system is not suitable to many crops due to the logistics of harvesting. It is used only for one-time harvest plants, so even though some low-profile plants may thrive in the water culture it is not feasible from a labor stand point to grow them as the boards would have to be taken out to harvest and then replaced again with the mature plants intact. This is difficult to do without damaging the boards or the plants. The roots of the plants could become broken or infected with disease organisms during the removing and replacing of the boards into the pond or raceways. Also, with a single harvest crop the boards are then sterilized before placing them back into the raceways for transplanting.

Aeroponics can grow most plants well, but due to the cost of such a system and the inconvenience of supporting vine crops, it is not used for vine crops. It is feasible from a growing point of view for low-profile plants, including strawberries, lettuce, arugula, basil, and many herbs, but again it may not be the correct choice due to capital costs. Aeroponics is the culture of preference for any crop whose harvestable portion is high value roots or tubers. For example, to produce medicinal products from some herb plant roots, aeroponics is both practical and economically feasible. Another very specific application is the growing of seed potatoes as they must be kept free of any disease. This system of aeroponics is used in the International Potato Research Center at Universidad de La Molina in Lima, Peru (Figures 15.1 and 15.2). That center ships certified potato seed tubers to all parts of the world in establishing mother plants for local planting. These seed potatoes are a very high-value crop with strict control of introducing seed stock certified free of diseases to various countries.

Table 15.1 shows that vine crops of tomatoes, peppers, European cucumbers, and eggplants grow in most hydroponic systems with the exception of water culture and aeroponics. They also do well in most substrates that offer good drainage. While melons are included in the list of crops, they normally are not grown unless they can be trained vertically by support strings. Their production is usually limited to five to six fruits per vine over the cropping period. For this reason, they are not economically feasible to grow commercially except in countries such as Japan, where they demand a very high price in the marketplace (up to $30–40 per fruit).

TABLE 15.1
Crops and Suitable Hydroponic Systems and Substrates

	Hydroponic system									Substrates						
	Water			Ebb and Flow		Drip Irrigation										
Plant	NFT	Raft	Wick	Rock	Exp. clay	Rock wool	Coco coir	Bato buck	Aeroponics	Rock	Exp. clay	Perlite	Vermiculite	Rice hulls	Coco coir	Mixes
Lettuce	x	x	x						x							
Arugula	x	x	x						x							
Basil	x	x	x						x							
Cilantro	x		x									x			x	x
Chervil	x		x									x			x	x
Chives	x		x									x			x	x
Dill	x		x									x			x	x
Marjoram	x		x									x			x	x
Mint	x	x	x						x			x			x	x
Oregano	x		x									x			x	x
Parsley	x		x									x			x	x
Rosemary										x	x	x	x			
Sage	x									x	x	x	x			
Tarragon										x	x	x	x			x
Thyme	x									x	x	x	x			x
Watercress	x	x	x						x							
Bok Choy	x	x	x						x	x	x	x	x	x	x	x
Chard	x	x	x						x	x	x	x	x	x	x	x
Spinach	x	x	x						x	x	x	x	x	x	x	x
Tomatoes			x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cucumber				x	x	x	x	x		x	x	x	x	x	x	x
Eggplant				x	x	x	x	x		x	x	x	x	x	x	x
Pepper				x	x	x	x	x		x	x	x	x	x	x	x
Melons				x	x	x	x	x		x	x	x	x	x	x	x
Radish				x	x							x	x	x	x	x
Strawberry	x								x			x	x	x	x	x

FIGURE 15.1 Aeroponic growing of seed potatoes. (Courtesy of the Potato Research Center, Universidad de La Molina, Lima, Peru.)

FIGURE 15.2 Aeroponic seed potatoes. Note the small tubers on the roots. (Courtesy of the Potato Research Center, Universidad de La Molina, Lima, Peru.)

Radish is also a very unique crop that is not grown commercially with hydroponic culture. It is a relatively low-value crop and grows well with soil. Radish will grow in many substrates and in ebb and flow systems, so for home use it would be a feasible crop to grow.

Strawberries grow well in many hydroponic systems including NFT and aeroponics. To increase production, they can be grown in an A-frame system of NFT. They are particularly suitable to growing in plant towers with many types of substrates. The plant towers increase the plant density by about 6 times that expected in beds. They are spaced 3 ft apart within rows and 4 ft between rows. There are a number of commercial operations in Florida and even in Colombia and Peru that grow strawberries in plant towers or vertical sacks. Strawberries require good drainage so the substrate and the hydroponic system must meet this need. Plant towers are easy to construct in your home. The design and construction of plant towers was described in Chapter 13.

Herbs also are very productive in plant towers using most substrates. Most will grow for 4–6 months and some, like rosemary, chives, parsley, mint, marjoram, and oregano, will last up to 10–12 months (Figure 15.3). Again, production is increased

FIGURE 15.3 Various herbs in plant towers. (Courtesy of CuisinArt Golf Resort and Spa, Anguilla.)

6–8 times that of normal bed systems. The key to good production and long-lasting crops in plant towers is good light and adequate drainage. The leachate from the towers can be recycled or it can be an open system. For your home, it is best to recirculate the solution for up to a month before changing it.

16 Environmental Control Components for Hydroponic Systems

Environmental conditions must be maintained at optimum levels to achieve success with any indoor growing. These factors have to be monitored and regulated with equipment having sufficient capacity for the growing area (Figure 16.1). The following factors are controlled: temperature, air circulation, carbon dioxide (CO_2), light, water quality and temperature, nutrient solution pH and electrical conductivity (EC), and oxygenation of the nutrient solution when using water culture systems. The following discussion looks at each environmental factor to control and equipment that can fulfill that need.

TEMPERATURE

Most plants grow well under specific temperature ranges. They require minimum and maximum levels. In general, night temperatures should be cooler than day temperatures. This differential may be as high as 10°F (5.5°C) or more. For cool-season crops such as lettuce, night temperatures should be about 55°F (13°C) and from 60° to 65°F (15.5–18°C) during the day. With warm-season crops such as tomatoes, peppers, cucumbers, and eggplants, suitable temperatures are 65°F (18°C) at night and 75°F (24°C) during the day. Herbs withstand a wider range of temperatures.

To control temperatures, a heating and cooling system is required. In most cases, in your home the normal temperatures you maintain in the house are within the desired temperature ranges of plants. If growing in a cool basement, a supplementary heating system may be a requisite. Electrical space heaters will meet the plant temperature demands. Use a 220-volt heater to save on the electrical demand. Baseboard heaters would also be good. These could be installed together with your house heating system. Artificial lights for providing light will also generate heat, so they may provide more than what is necessary to maintain optimum temperatures. In such a case, a cooling system will have to be installed to extract the air from the growing room.

Cooling by exhaust fan(s) is the standard method. The exhaust fans are installed in the wall with an outlet to the outside. Any such fan needs automatic shutters that close when not operating to assist in preventing insects from entering the growing room. The size of the fans is calculated on the volume of air in the growing room and the temperature differential that must be reduced within the room. An air exchange of the total volume should be at least one per minute if a significant number of lights

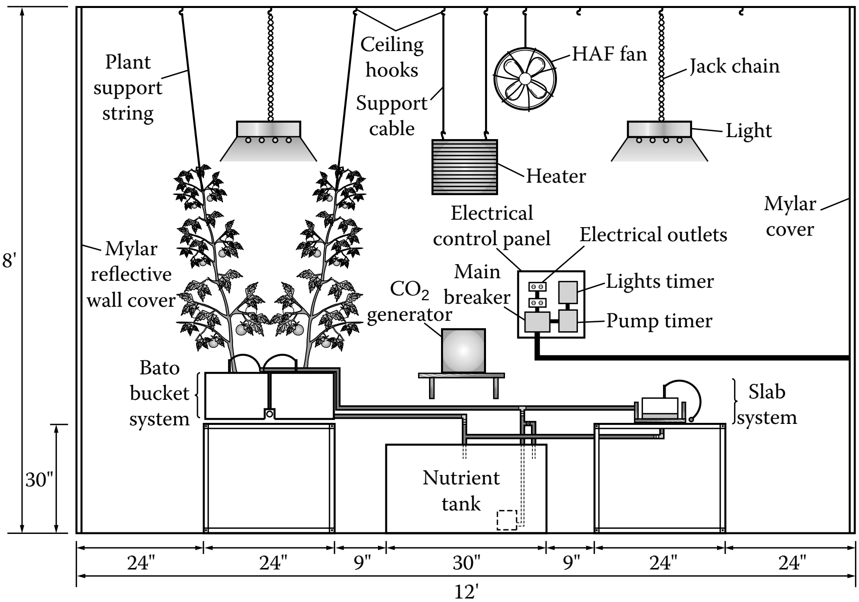


FIGURE 16.1 Cross-sectional view of growing room with all components. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

are installed. It is useful to have two-speed fans so that if a small amount of cooling is needed, the lower fan speed operates, but if further cooling is demanded the second faster speed is activated by a thermostat.

It is a good idea to purchase a thermograph that will record temperatures on a 24-hour basis. Some have charts that are good for a week of monitoring before replacing. The thermograph is much better than a max-min thermometer as the thermometer tells you only the maximum and minimum temperatures reached at an undesignated time. It does not tell you temperature fluctuations over time as does the thermograph.

AIR CIRCULATION

Air temperature must be uniform throughout the crop canopy for optimum growth. As the plants grow vertically in the room, they block the circulation of air and cause large temperature differences from the bottom to the top of the plants. This, of course, is especially noticeable with vine crops. The ideal source of heat for the plants is to have floor or bottom heating pipes. Alternatively, a unit heater connected to convection tubes that are located between the rows of vine crops will make hot air rise up through the crop. However, with space heaters a convection tube cannot be used due to the fire hazard. If you mount a gas fired unit heater at one end of the room near the ceiling and install a housing that will distribute the heated air down through convection tubes to the base of the plants, you will get more efficient use of the heat than a space heater. This will also help mix the air and create good circulation making the air temperature throughout the crop more uniform.

The mixing of the air is also important in exchanging the air at the boundary layer immediately in contact with the plant leaves. This movement of air past the leaves brings in fresh air high in CO_2 in contact with the stomates of the leaves where the CO_2 can enter the plant. Another helpful piece of equipment is a horizontal air flow fan (HAF) that is mounted near the ceiling. The HAF fan blows the air down the length of the room causing turbulent flow that mixes the air. This improved air circulation gives more uniform temperature and increases CO_2 exchange at the leaves. Refer to the Appendix for suppliers of this equipment.

CO_2 ENRICHMENT

Normal CO_2 levels in the ambient atmosphere are now approaching 400 mg/L or ppm. Research over the years has established that enrichment of CO_2 to 2–3 times ambient levels (800–1200 ppm) greatly increase the production of vegetable crops by as much as 20%, especially under low light conditions. The ambient CO_2 levels vary with your location. Cities have higher levels of CO_2 due to automobiles and industries. There are a number of small CO_2 generators available for home growers (Figure 16.2). You can use bottled CO_2 in tanks similar to propane tanks, but such a system is awkward and heavy to move for refilling. Also, when using tanks, a system of distribution tubes must be located between and underneath the rows of plants. Another system is a natural gas combustion unit that generates CO_2. This CO_2 generator also gives off heat that may have to be extracted as it operates only during the day period. The operation of the unit is governed by a timer.

The level of CO_2 in the grow room must be monitored and regulated. Many of the generators have a monitor-controller that activates the enrichment system according to preset levels and turns it off if this level is exceeded. You may also purchase a hand-held tester for CO_2 levels.

FIGURE 16.2 Natural gas or liquid propane (LP)-fired carbon dioxide generator. (Courtesy of Green Air Products, Inc., Gresham, Oregon.)

FIGURE 16.3 Carbon dioxide Boost Bucket kit compost generator. (Courtesy of CO2Boost LLC, Landenberg, Pennsylvania.)

One of the least expensive and natural methods of generating CO_2 is with a special CO_2 composting pot that releases CO_2 from the decomposition of mushroom compost (Figure 16.3). One bucket will enrich a 10 ft × 10 ft × 10 ft room at levels between 1200 and 1500 ppm for 60–90 days. This is available commercially as a small bucket and is renewable with the purchase of refills (see Appendix for supplier).

LIGHT

Most plants indoors will grow relatively well under a light intensity of 5500 lux (510-foot candles) for a period of 14–16 hours per day. The function of light in photosynthesis and its measurement related to photosynthesis was explained in Chapter 5. In the past, cool-white fluorescent lighting was the type of light used for plant supplementary lighting. Now there are more energy-efficient and better quality lights sold such as the high-intensity discharge (HID) and compact fluorescent. There are two types of HID lights: high-pressure sodium (HPS) and metal halide (MH). A combination of both gives best results. The HPS lights promote blooming and fruiting, whereas, the MH light causes more rapid vegetative growth. Compact fluorescents save electricity. They are now available for growing plants (Figure 16.4). Again, a mixture of the red for flowering and blue for vegetative growing is best.

Today, light emitting diode (LED) lights are gaining popularity due to their energy efficiency. There are a number of types available for growing plants that mix red and blue lights in reflectors to maximize their efficiency in photosynthesis. While these lights last up to 50,000 hours, they are expensive.

All lights are placed in reflective fixtures to maximize the reflection and distribution of the light. There are three shapes of reflectors: parabolic, horizontal, and conical. Parabolic reflectors focus light on the plants by directing the light below

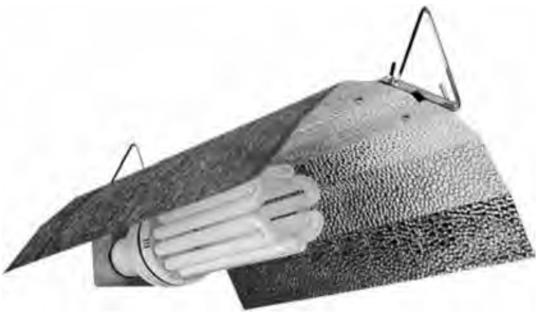


FIGURE 16.4 Compact fluorescent light with light reflector. (Courtesy of Sunlight Supply, Inc., Vancouver, Washington.)

the horizontal plane and thus reducing glare to your eyes. Conical reflectors give more side light. Square-shaped reflectors are effective for square growing areas. Horizontal reflectors are recommended for HPS systems.

Ballasts for HPS lights should be located away from your plants to reduce heat build-up within the crop. Ballasts are not needed for compact fluorescent and LED lights. Keep ballasts off the floor as water could splash onto them. Lights must be mounted above the crop by hooks or jack chains from the ceiling. If you use jack chains, you can raise the lights as the plants grow keeping the lights at least 2–3 ft above the crop. If the lights are too close, the heat they give off will promote rapid vegetative growth.

There are also circular and linear light movers that move the lights above the crop over a period of time to more evenly distribute the light intensity over the crop (Figure 16.5). Linear movers are best for narrow growing areas, whereas circular movers are better for square areas. Light movers do not allow you to plant your crop at higher densities; they improve the light distribution and therefore produce a more even growth of all the plants (Figure 16.6).

Use a Mylar reflective covering on the walls surrounding the hydroponic systems to reflect light back into the sides of the plants.

Refer to the Appendix for suppliers of lights and their accessories.

WATER QUALITY AND TEMPERATURE

Water quality and temperature are important factors for successfully growing plants. Water quality is a measure of the types and concentrations of minerals present in the raw water. Most city waters are of acceptable quality, unless they are very “hard.” Hardness is a measure of the amount of calcium and magnesium carbonate present in the water. Hard waters are quite suitable for hydroponics. The only thing you must determine is which elements and at what concentrations they are present so that you may adjust your nutrient solution formulation accordingly. If you purchase a ready-made formulation, ask for one that is for hard water. If you make up your own formulation, hard water may provide most of your calcium and magnesium needs, so will actually save on the use of the fertilizer salts required.

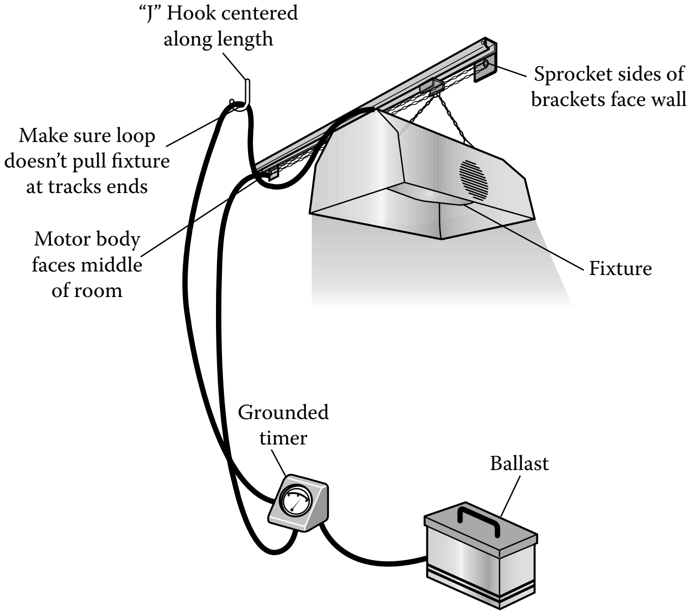


FIGURE 16.5 Linear light mover with components. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

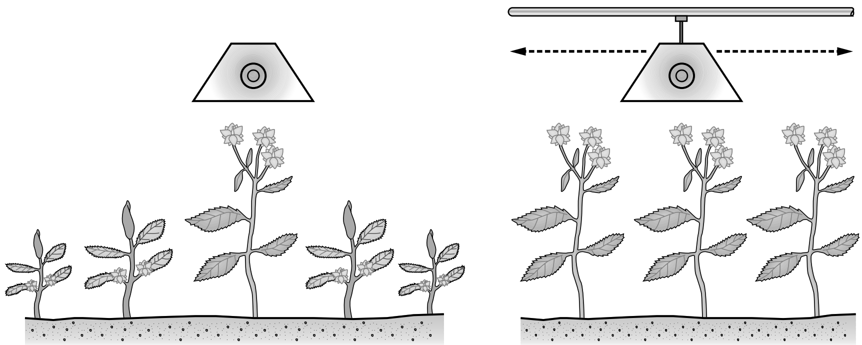


FIGURE 16.6 Comparison of plant growth with and without a moving light source. (Drawing courtesy of George Barile, Accurate Art, Inc., Holbrook, New York.)

The best approach is to get a water analysis of the raw water by a laboratory that does such tests. Test for all of the plant essential elements. Once you know the levels, you can adjust the nutrient formulation to take those into account. When the analysis of the trace elements indicates some are high, reduce or even exclude those from the formulation. For example, optimum boron concentration for the plants is about 0.3 mg/L, so if the test shows boron in excess of that leave out any addition of it in the formulation. Most plants will tolerate boron levels twice or three times the optimum level before any reduction in growth occurs. Often information on water quality may be obtained from the city offices that regulate domestic water supply.

The temperature of the raw water is also a factor that affects plant growth. Everyone is aware that you do not start your soil garden too early in the spring when the soil and groundwater are very cold as the plants will not grow and often just survive without any new growth until the weather heats up the soil. With hydroponics, water temperature is also important for rapid growth. If the water is too cold, purchase an immersion heater. This type of heater is generally electric for small nutrient tanks. They should be available at local hydroponic shops (see Appendix). The immersion heater is placed in the nutrient tank. Temperature is controlled with a thermostat on the immersion heater.

Keep the nutrient solution between 65 and 70°F (18–21°C). Water may also be too high in temperature. In that case, use a water chiller to lower the nutrient solution temperature. For example, lettuce likes a cooler water temperature of 65–68°F (18–20°C). If raw water enters at 80°F (27°C) or more, it is best to lower the temperature to prevent bolting (lettuce going to seed grows a shoot rapidly) and fungal activity in the roots that will damage the plants causing them to wilt during high-light conditions of mid-day. Water holds more oxygen at lower temperature so this also affects plant roots and growth. Alternatively, an ozone generator may be used to add oxygen to water, which will prevent diseases and slow any bolting of lettuce.

Controlling nutrient solution temperature is critical in growing crops in nutrient film technique (NFT) and raft culture systems, especially cool-season crops such as lettuce and spinach. Sources for these components are listed in the Appendix.

EC AND PH OF NUTRIENT SOLUTION

To monitor the concentration of nutrients in the nutrient solution use an EC meter (Figure 16.7). Hand-held "pen" type EC meters are also available (Figure 16.8). These meters tell the total dissolved solutes in the solution and therefore indicate when the

FIGURE 16.7 An electrical conductivity meter.

solution is being depleted of its elements. The addition of elements can be calculated and a "top-up" solution used to increase the elements. However, on a small scale it is much easier to simply replace the nutrient solution making up a new solution every few weeks. Plants use more water than nutrients, so the addition of water is needed every few days (depending upon the ratio of volume of water to each plant). With a

FIGURE 16.8 A "pen" type hand-held electrical conductivity and ppm tester. (Courtesy of Bluelab Corporation Ltd., Tauranga, New Zealand.)

FIGURE 16.9 pH indicator paper.