Chapter Outcomes

After studying this chapter, you will be able to:

• Explain how various hydroponic systems work.
• Describe aquaponic systems.
• Describe rooftop gardens.
• Discuss vertical gardening systems.
• Discuss raised bed gardening.
• List careers related to nontraditional gardening systems.

Words to Know

aeroponic system
drip system
aggregate
ebb and flow system
aquaponics
effluent
biofilm
intensive green roof system
biopharming
extensive green roof system
culling
ground level ozone
deep water culture (DWC)
heat island effect
hydroponics
lasagna composting
nutrient film technique
(vertical)
square foot gardening
(CFM)
vertical gardening
water culture system

Before You Read

After reading each section (separated by main headings), stop and write a three- to four-sentence summary of what you just read. Be sure to paraphrase and use your own words.
While studying this chapter, look for the activity icon to:

- **Practice** vocabulary terms with e-flash cards and matching activities.
- **Expand** learning with the Corner Questions and interactive activities.
- **Reinforce** what you learn by completing the end-of-chapter questions.

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As our world population continues to grow and more land is lost to development, the agriculture industry is faced with the task of producing more food and fiber in less space and on poorer quality land. In order to meet these needs and overcome so many obstacles, growers have turned to new, innovative growing systems, often located in the most unlikely places. Crops are currently being cultivated in places such as abandoned mines, WWII bomb shelters, and growth chambers located deep in the earth. These nontraditional growing areas require alternative growing methods such as hydroponics with water and artificial lighting in place of soil and natural daylight. Other nontraditional growing systems that have become increasingly popular include rooftop gardening, vertical gardening, green roofs or walls, and aquaponics.

In this chapter, you will learn about nontraditional growing systems as well as biotechnology applications being used to help growers meet the needs of an increasing population and decreasing land availability.

**Hydroponics**

*Hydroponics*, a water-based, soilless growing method, is the fastest-growing sector of the green industry. This technology provides a means of growing plants in places with poor soils or limited land availability. It also allows food to be cultivated near consumers and delivered fresh on a daily basis—often the same day it is harvested. This is especially true in urban areas where growers have installed hydroponic systems on rooftops and in repurposed buildings, *Figure 20-1*.

The initial investment for a hydroponic system is high because the grower must acquire a location, equipment, power source, and possibly a water treatment system. If water quality is low, the water must be treated (which is extremely expensive) or brought in. The grower must also provide aeration, nutrients, light, temperature control, appropriate pH balance, and pest control. Growers have control over every facet of the growing process and must fully understand their crops’ needs and carefully monitor their system to keep plants healthy and productive. If not properly monitored, diseases can spread quickly from sick plants to healthy plants through contaminated water.

**History of Hydroponics**

Hydroponic gardening is not a new concept. Early forms of hydroponics date to around 600 BCE. For example, the Hanging Gardens of Babylon (one of the seven wonders of the ancient world) were elaborately engineered and contained many types of trees, shrubs, and vines. These gardens are

**Did You Know?**

London’s underground bomb shelters are being used to house a subterranean hydroponic farm that will produce 11,000–44,000 lb of crops annually.

*Figure 20-1.* Plants can be grown indoors, hydroponically, using various light systems.
said to have flourished in the arid, desert-like climate due to a hydroponic-type system supplied with water from the Euphrates River. 

During the 10th and 11th centuries, the Aztecs developed a floating garden that resembled hydroponic systems used today. They built rafts with roots and reeds, topped them with soil, and floated them on Lake Texcoco. Crops were sown in the soil and grew as the rafts drifted around the lake, **Figure 20-2**.

During the early 1600s, British scientist Sir Francis Bacon formally researched hydroponic, or soilless, gardening. His research was published in 1627 and propelled a surge of hydroponic research and advancement. Another British scientist, John Woodward, conducted hydroponic experiments in the late 1600s. Many of his experiments focused on determining the source of plant nutrition.

The twentieth century experienced a wax and wane of hydroponic research and advances.

- In 1925, researchers at agricultural experiment stations began to search for solutions to the problem of replacing soils within greenhouses. The idea of using a nutrient or water solution began to be studied.
- Between 1925 and 1935, university experiment stations in states such as New Jersey, Indiana, and California began to test sand and gravel culture.
- William Gericke, a University of California Berkeley scientist, promoted hydroponics using the term *aquaculture*. Later, he found this term already in use to describe the study of aquatic organisms and coined the term *hydroponics*.
- In 1940, two other scientists from Berkeley, Dennis Hoagland and Daniel Arnon, published *The Water Culture Method for Growing Plants without Soil*. This text, considered one of the most important hydroponic resources, is still used today.
- During World War II, the armed forces grew plants hydroponically on barren Pacific Islands to feed the troops.
- Starting in 1973, the rising cost of petroleum led to increased costs of plastic. This inflation in price led many growers to abandon the idea of hydroponics.
- Disney’s EPCOT Center Land Pavilion showcased various methods of hydroponics as the way to grow crops in the future. In 1982, innovators at Disney forecasted a need for this growing technique as a way to solve agricultural problems associated with conventional farming practices.
- A former Sony semiconductor factory now houses the largest hydroponic facility in Japan. Mirai grows 10,000 heads of lettuce under 17,500 LED lights in the 25,000 ft² building. Plants grow 2 1/2 times faster and use 1% of the water used in conventional outdoor lettuce cultivation.
Hydroponic Systems

There are seven main types of hydroponic systems. Each method of hydroponics has advantages and disadvantages. Growers must evaluate the system’s setup, maintenance, yield, cost, and reliability to determine which would work best for them. Some methods use a misting system, some use a growing substrate, and others use only liquids. However, all methods grow plants without the use of soil. Each method must provide oxygen to plant roots, a nutrient solution, and the proper pH to ensure optimum plant growth and quality. Types of hydroponic systems include wick, ebb and flow, drip, nutrient film technique (NFT), water culture, deep water culture, and aeroponics.

Wick System

This simple, passive system uses a wick that is fed into a reservoir filled with a nutrient solution. The plants are suspended in a tray filled with a medium or aggregate of the grower’s choice. The nutrient solution transfers from the reservoir to the plant material suspended in an aggregate through the wick, Figure 20-3A. A wick works by capillary action (the ability of a liquid to flow in opposition to external forces such as gravity). The water is pulled up against the force of gravity through a process called adhesion. The edges of the droplets of water are forced up the surface of the wicking material (typically made from cotton). Growers may use an air pump to add oxygen to the nutrient solution.

Ebb and Flow System

Ebb and flow is a method of hydroponics in which the growing chamber or tray holding plants are periodically flooded with a nutrient solution and then drained, Figure 20-3B. The nutrient solution contains vital elements such as nitrogen, phosphorus, and potassium. A reservoir tank holds the nutrient solution and a growing chamber perches above the reservoir. The nutrient solution is pumped into this space. The nutrient solution rests in the tray where it can be absorbed by the roots and then drains back into the reservoir. This method, also known as flood and drain, is the most popular method used by both hobbyists and professional growers.
Drip System

A drip system uses a reservoir of liquid nutrient solution that is pumped into a series of thin tubes (drip lines) that slowly release the solution onto the base of each plant, Figure 20-3C. Recovery drip systems designed to collect and reuse the excess nutrient solution require more maintenance than nonrecovery systems due to variance in pH and nutrient strength levels in the reservoir. Drip systems are used in hydroponic systems as well as in other growing applications, including greenhouses, gardens, nurseries, and landscapes. Plants can be in growing trays, buckets, or baskets filled with an aggregate.

Nutrient Film Technique (NFT) System

The nutrient film technique (NFT) is a versatile hydroponic method that circulates a thin, constant stream of liquid nutrient solution over the plant roots. This system is commonly made with PVC pipe that has a series of holes across the top of the pipe. The plant material is suspended in baskets in this series of holes, Figure 20-3D. The baskets may be filled with aggregate, such as clay pellets or rockwool. (In hydroponics, aggregate is a solid, inert material that supports plant life. It is often referred to as a growing medium or substrate.) The roots of the plants hang down in the channel where the nutrient solution flows over the root tips. The nutrient solution must flow continuously or the roots will quickly dry out.

Figure 20-3. The various hydroponic systems
Water Culture System

In *water culture systems*, light plastic or foam trays containing plants float on a nutrient solution. The plant roots hang below the tray and are submerged in the nutrient solution, Figure 20-4. An air pump is used to supply oxygen to the roots through the nutrient solution. This system requires few mechanisms and is often a starter system for individuals attempting to grow hydroponically. Water culture may also be called floating hydroponics.

Deep Water Culture (DWC) System

*Deep water culture (DWC)* systems consist of a main reservoir and a series of buckets. The nutrient solution is pumped from the main reservoir to the buckets through tubing. The lid of each bucket holds a plant or plants and may or may not contain aggregate. The roots are suspended in the nutrient solution below the lid. An air pump or bubblers may be used to provide oxygen to the nutrient solution.

Aeroponic System

In an *aeroponic system*, plant roots are suspended in the air and misted intermittently with a nutrient solution, Figure 20-5. This system does not use any type of growing medium. This method requires a great deal of supervision by a grower and constant suspension or training of new plant growth.

System Components

Hydroponic systems use various components to create a functioning, soil-free system for cultivation. Equipment is needed to circulate water, turn equipment on or off, maintain water temperature, and add oxygen to the nutrient solution. Other important components include the aggregate used to support plants as well as the containers used to hold the plants and contain the nutrient solution. Some of the pieces of equipment that work together to hold, circulate, or aerate the liquid solution are listed and described in Figure 20-6. (This equipment will vary by individual systems and grower preferences.)
Additional devices and systems that make a hydroponic system work more efficiently or effectively include:

- Climate controls—used to maintain growing area temperatures at optimum levels for plant growth. Climate controls may be used to add and/or remove heat from the growing area.
- Carbon dioxide (CO₂) systems—used to increase the level of carbon dioxide in growing areas to supplement and promote photosynthetic output.
- Lighting systems—artificial light source used to provide sufficient or supplemental light at optimal quality and in appropriate quantity.
- Nutrient solutions—countless solutions available that may be used to create a nutritional program suited to specific systems and crops.
- Pest control—integrated pest management (IPM) that may include organic and synthetic forms of pest controls using biological, cultural, and chemical means.
- pH meters—monitoring and adjustment of nutrient solution/water pH is vital to ensure plants receive sufficient nutrients.
- Timers—automatically turn controls on and off at appropriate intervals to maintain such factors as temperature (water and air), oxygen, and water levels.

Without these implements, growing hydroponically could be quite cumbersome and much less profitable.

Corner Question

Why does a hydroponic system benefit from a chiller?
Aggregate Forms

Hydroponic systems do not use soil but may use an aggregate (growing medium) to support the plant roots and help hold up the plants, Figure 20-7. The medium should not amend or change the chemical makeup of the nutrient solution. It should be coarse and porous, which will allow plant roots to access nutrients and oxygen easily. The growing media may be organic or inorganic and can come from a multitude of different sources. Some growing aggregates include:

- Coconut coir—a lightweight organic material made of coconut husks.
- Hydronor—–a pelleted expanded clay material.
- Oasis cubes—a lightweight, synthetic material often used as a floral design substrate.
- Perlite—a white, volcanic rock material.
- Pine bark—an organic material made of chipped tree bark.
- River rock—rocks with rounded edges.
- Rockwool—an expanded basaltic rock fiber material.
- Vermiculite—a lightweight, metallic, mica material.

Crops

The cost of establishing a hydroponic system makes it important to choose crops with high returns. Crops commonly grown using hydroponics include tomatoes, peppers, herbs, cucumbers, lettuce, and microgreens. Many of these crops have short life spans and produce a significant yield which allows growers to quickly recoup the costs of implementing the hydroponic systems. Growers are continuously expanding crop selections and attempting to grow new crops for consumers.

With a highly controlled environment, hydroponics is also an ideal method of growing plants for biopharming. Biopharming is growing plants that have been altered, often via genetic engineering, for medicinal uses. These biotechnological strategies are not without controversy. Although the growth of these crops takes place in enclosed environments to decrease the possibility of contaminating other crops, critics are still very wary of these agricultural methods.

Aquaponics

Hydroponics is growing plants without the use of soil while aquaculture is growing fish. Aquaponics is the combination of these two systems. Aquaponics is a system of growing plants in water that has been or is being used to grow fish, snails, crayfish, or other aquatic creatures. Growers harvest the aquatic creatures, most commonly fish, and the plants.

The effluent (waste) produced by fish can be toxic to the fish, especially if they are being raised in a confined space. Aquaponics uses the effluent to contribute to the plant’s nitrogen cycle. Nitrogen-fixing bacteria fix the ammonia into nitrates and then nitrites (which are used by plants as nutrients). Once nutrients have been used by the plants, the water is recirculated to the fish tank and the cycle begins again, Figure 20-8.
Aquaculture farming systems range in size, complexity, and crops grown just as any other farming ventures do. Many growers consider aquaculture one of the solutions to dwindling land availability and an increasing need for food by a growing population.

**History of Aquaponics**

Aquaculture has been around for centuries. However, aquaponics and the cultivation practices used today rest on the research of the 1970s. Several institutions pioneered science and practices that enable aquaponics to thrive today.

**Corner Question**

What is a Brix scale?
New Alchemy Institute

The New Alchemy Institute was a research center in Hatchesville, Massachusetts. The center was a dairy farm converted to an aquaculture facility. The institute experimented with growing fish in bioshelters and reported on the use of aboveground, translucent tanks. The tanks were operated using solar power. The pond water, rich with fish waste, was used to irrigate crops in greenhouses.

North Carolina State University

In the 1980s, a graduate student (Mark McMurtry) at North Carolina State University in Raleigh, North Carolina, developed a research project to grow tilapia fish and vegetables. Mark McMurtry’s experiment resulted in a new system with high fish protein production, water recirculation, water waste reduction, and high yields of vegetable crops. The S & S Aqua Farm near West Plains, Missouri, modified the North Carolina State University system to create a more efficient method called the Speraneo System. Tilapia fish were raised in 500-gallon tanks from which the water was circulated to vegetables grown in gravel inside a greenhouse.

The University of Virgin Islands System

A research team at the University of Virgin Islands team revolutionized the deep water culture (DWC) system of hydroponics, merging the growth of tilapia in rearing tanks as a fertilizer source. The fish tanks are linked together with a floating raft that acts as a stage for basil, Swiss chard, lettuce, and other crops. This system recirculates water through tubing with pumps. It has operated continuously for over a decade, allowing for harvests of fish every six weeks and lettuce and other crops weekly.
System Components

The same components used in hydroponic operations are used for the plant-growing portion of an aquaponic operation. These components, referred to as the hydroponic subsystem, will vary depending on the method being used and the grower’s preferences. Aquaponic operations also use equipment specifically for the fish or other aquatic creatures being raised. Equipment and devices used for the aquaculture portion of an aquaponic system include:

- Electric sump pump—the mechanism that pumps water from one point to another in the system.
- Biofilter—an element that provides a habitat for bacteria to grow and convert ammonium (fish waste) into nitrates (a form usable by plants).
- Settling basin—a unit that catches waste and filters suspended solids.
- Rearing tank—the location where the fish are raised.

Growing in an Aquaponic System

The three main classes of organisms grown in an aquaponic system are the plant crop, the fish (or other aquatic creatures), and bacteria. Each of the organisms is an integral part of the system and each contributes and uses various elements to continue the cycle.

Plants

Leafy greens and herbs are commonly cultivated by aquaponic growers using the effluent water that is rich with nutrients from fish and bacteria. Plants grown using aquaponics include kohlrabi, cabbage, basil, dill, parsley, lettuce, and cilantro, Figure 20-9. Other plants that growers choose vary but may include tomatoes, cucumbers, peppers, eggplant, radishes, taro, melons, and peas. The hydroponic method used varies by operation, but is usually limited to the following:

- Ebb and flow.
- Drip.
- Nutrient film technique (NFT).
- Deep water culture (DWC).

After the water passes through the hydroponic portion of the system, it is filtered and oxygenated before returning to the fish-rearing tanks.

Aquatic Creatures

Not all aquatic creatures thrive in an aquaponic system. For example, saltwater fish do not work with plant systems due to the high concentrations of salt used in the water. There are several freshwater fish that can be grown. However, some fish statistically grow faster and are healthier in aquaculture facilities than others. Tilapia is the number one fish used in commercial aquaponics, Figure 20-10. Other fish used include perch, catfish, cod, and barramundi. Some systems also grow snails, prawns, or crayfish.

Corner Question

What is the world’s largest aquaponic system?
Career Connection

Rebecca Nelson and John Pade

Nelson and Pade Aquaponics

In 1984, Rebecca Nelson and John Pade constructed a hobby greenhouse in California. They followed with the construction of two commercial tomato hydroponic greenhouses. Later that decade, the company expanded into aquaponics. Today, Nelson and Pade, Inc., is housed in Montello, Wisconsin, and hobbyists and experts consider Nelson and Pade, Inc., a premiere aquaponic design, engineering, and supply company.

The company designs and engineers aquaponic systems, supplies aquaponic equipment, and helps hobbyists and professionals develop their knowledge in aquaponics. In 1997, the company began publishing Aquaponics Journal and began directing all of its efforts into this sector of agriculture. Today, the company is still growing. It currently has a 14,000 ft² demonstration greenhouse and 17,000 square feet of shop and warehouse space housed on 12 acres. The company offers courses affiliated with the University of Wisconsin-Stevens Point.

Bacteria

Have you ever had a goldfish and wondered what happened when you found it floating in its glass bowl? The goldfish may have died from a high level of ammonium. Fish constantly release ammonium into the water as a by-product of their metabolism. In an aquaponic system, the ammonia is converted into a usable form of nitrogen by various bacteria and then absorbed by the plants.

- Nitrosomonas is a bacteria that converts ammonia into nitrites.
- Nitrobacter and nitrospira further the nitrogen cycle by converting nitrites into nitrates, a nutrient easily used by plants.

Bacteria housed in the aquaponic system form a biofilm over surfaces. A biofilm is a group of microorganisms that stick together on a surface. The coating formed by these groups of beneficial microorganisms is the thin, slimy coating found on the rocks, filters, and roots in an aquaponic system. Biofiltering units in aquaponic systems promote the growth of these microorganisms. Solid waste (uneaten food and waste) is removed from the tank containing the bacteria and is often treated for use as plant fertilizer. Once the solids are removed and effluent has been converted to nitrate, the water containing the nutrients is pumped to the hydroponic system.

Safety Note

Biofilms can grow on the vegetables harvested from an aquaponic operation. Biofilms can contain beneficial bacteria as well as harmful bacteria, such as listeria and E. coli. Therefore, vegetables should always be washed before consumption. Careful sanitation procedures must be part of good agricultural practices at aquaponic facilities to prevent food contamination.
Rooftop Gardening

Rooftop gardens are yet another form of gardening that has been in use for centuries. Evidence of rooftop gardens and elevated terraces has been found in ruins dating back to earlier than 600 BCE. These ancient gardens provided food, recreational areas, and shade to the inhabitants of many urban areas, much in the same manner that they do today.

Techniques

A variety of gardening techniques can be situated on top of buildings. The type of gardening technique used for a rooftop garden may range from simple container plantings to an elaborate, intensive roof system. The type of gardening technique used often depends on the structural capability of the building.

Container Gardening

Container gardens are the simplest form of rooftop gardening. Container plantings are usually low in cost and fairly easy to maintain. The main elements of container gardens are the containers, growing medium, plants, a method for watering the plants, and a method of adding nutrients for plants. Container plantings allow the gardener flexibility in choice of containers, plant materials, and planning or arrangement. Growers may also more easily move seasonal plants indoors when needed.

Green Roof Systems

A green roof system is a carefully designed rooftop garden that requires professional design and installation. The garden is designed not only to cultivate plant materials, but to function as the roofing material for the structure. There are two methods of green roof systems:

- **Extensive green roof system**—a live, planted garden that forms a matting and helps to increase insulation, reduce runoff, and increase a roof’s lifespan. It has vigorous and hardy plants that require little maintenance, such as sedums and other succulents or prairie plants, Figure 20-11A.

- **Intensive green roof system**—a landscape on top of a roof similar to a typical garden planted at ground level. Intensive roof systems may have complex or elaborate plantings. They usually require more extensive maintenance that involves fertilization, irrigation, pruning, and harvesting, Figure 20-11B.

Figure 20-11. A—Succulents are commonly used in extensive green roof systems. B—Small trees may be grown with an assortment of other plant materials in an intensive green roof system.
Thinking Green

Riverbend Nursery

Riverbend Nursery in Riner, Virginia, grows many plants and prides itself on cultivating plant systems specifically meant for green roofs. The company is a licensed grower for a company called LiveRoof®. The nursery produce sedums and other hardy materials meant for green roof systems.

Kelly Connoley-Phillips, the Sales and Marketing Manager at Riverbend Nursery, approaches architects, landscape architects, and engineers to introduce them to Riverbend's green roof products. Once LiveRoof is specified as the green roof system on a project, she works with the nursery staff to select a plant mix for the project based on the client's needs. Once the selection is finalized, growers set the 12- to 16-week growing process in motion. The green roof materials are shipped to the certified installer for same-day installation.

Kelly emphasizes the benefits of incorporating a green roof into new construction. There are several benefits aside from the aesthetic beauty. One of the most important financial benefits is that this will “extend the roof’s life by 200%, skipping two replacement cycles.” It can also help to decrease a building’s heating and cooling costs. These benefits, coupled with the impact of decreasing the heat island effect and reducing runoff, should help architects and business owners realize the importance of going green, especially when constructing a roof.

These systems significantly increase insulation for the building, which reduces energy needs and costs. The green roof system commissioned depends upon the objectives of the building owner, projected maintenance needs, and the structural capability of the building.

Planning a Rooftop Garden

Several factors must be considered when planning a rooftop garden.

- Consider the engineering of the roof. Is it stable enough to hold a garden? What load can be supported? What is the overall condition of the roof? What access is there to the roof?
- Determine the objectives for this garden. What types of plants will be used? Will this space be used for leisure or food production? What is the budget of the project? What shadows are cast by surrounding buildings?
- Design the system to meet the needs of the objectives. What material will be used as a growing medium? What plant species will be grown? What irrigation system will be installed? What maintenance will be associated with the plant species used?
- Obtain the proper permitting. Will there be a need for new electrical, building, or other permits? What windbreaks will be needed?

Structural Capability

The best time to install a rooftop garden is during new construction. Working with an existing roof presents several obstacles that can be costly, although not impossible, to overcome. Installing a green roof system on new construction is easier and more cost effective because all structural requirements and access points can be included in the original design. If an existing structure is to be modified to accommodate a rooftop garden, a licensed structural engineer or architect must first evaluate the structure.
The engineer or architect will determine the structure’s load-bearing capability and whether additional supports are needed. The total load (weight) of the garden includes heating and cooling equipment, plants, media, water (including snow or ice), any equipment or materials, and the people who may visit or work on the roof.

Prior to construction, permits from city or other local governments must be obtained. Plans created by licensed engineers or architects must also be submitted for review.

**Access**

Access to the rooftop garden should be a primary concern during the planning stage. If the space is open to the public, two or more ways to access the site may be required. Multiple access points may be included in new construction and may include both indoor and outdoor entry points. Access usually includes stairs or a fire escape.

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**STEM Connection**

**Urban Heat Island Effect**

During warmer months, cities often experience a phenomenon known as heat island effect. **Heat island effect** is an increase in temperature of urban areas due to a variety of environmental factors, including the radiant energy trapped by dark surfaces (roofs and asphalt pavement primarily) and the heat produced by increased air conditioner use. The higher temperatures, combined with air pollution, contribute to higher levels of smog and ground level ozone. **Ground level ozone** is a harmful air pollutant that is formed from chemical reactions of other pollutants near Earth’s surface. Smog and ground level ozone are both harmful to human health and may cause problems such as eye irritation, asthma aggravation, and permanent lung damage. The heat island effect also negatively impacts the quality of the environment and building operating costs.

Increasing the amount of growing vegetation in a city is an excellent means of reducing the heat island effect and improving air quality. Plants provide heat absorption while also cooling the surrounding air through evapotranspiration. With limited land space available, rooftop gardens are a logical and practical solution. Rooftop gardens have additional benefits, including:

- Reducing energy costs as the plants and soil acts as insulators for both heating and cooling.
- Reducing rainfall runoff from buildings. Rainwater would otherwise run off the building, collect additional pollutants, and add polluted water to sewer systems.
- Filtering and cooling rainwater before releasing excess water into the sewer systems.
- Filtering the air by taking in carbon dioxide and producing oxygen through photosynthesis.
- Providing recreational areas for a building’s inhabitants.
- Providing space for food production and enhancing the city skyline.
Cost

The initial cost of a rooftop garden depends on the type of garden and whether structural modifications must be made. The cost of a container garden may be the least expensive but will vary depending on the materials (plant, media, and containers) used. Green roof systems cost about 50% more than conventional roofs. An extensive green roof system usually costs less than an intensive green roof system. Both systems, however, can increase the life of a roof by more than 50%, offsetting the initial investment.

Materials

The materials used in a green roof system must be installed to create an environment that will foster plant growth and maintain the roof’s integrity. The materials are installed in layers in the following order (Figure 20-12):

- The bottom layer is composed of a lightweight but sturdy insulation.
- A waterproof membrane is placed on the insulation layer. The waterproof membrane protects the building from moisture. This membrane is designed to withstand acidity released by roots.
- A root barrier is placed on the waterproof membrane to prevent roots from penetrating the membrane and insulation.
- A drainage layer made of a gravel, clay, or plastic comes next. This layer diverts excess water and aerates growing media. Additional drainage points or tiles should also be incorporated into the garden design. Some products used in the drainage layer are also designed to store water for later plant use.

Figure 20-12. Green roof systems use layers of materials to create a growing environment conducive to plant growth.
Irrigation and Drainage

When planning a rooftop garden, the water supply and storage system must be an integral part of the design. The garden design must include an irrigation system for water distribution, a drainage system to control excess water flow, and a means of storing excess water for later use. Although water from the city supply system may be used for irrigation, rainwater should be the primary source of water. Green roof systems are designed to take in rainwater as it falls and may also retain excess water for later use by plants. Excess rainwater may also be stored in rooftop cisterns, Figure 20-13. A drip system should also be installed to distribute water throughout the garden when needed.

Rooftop gardens reduce runoff by absorbing rainwater and diverting the excess to another system. The excess water must be dealt with using a drainage system. Water not absorbed by plants or media can be diverted to a cistern, and additional water directed to the sewer system. If too much water stays on the rooftop, there will be excessive weight added and plant root systems may suffer. Drainage systems can include gutters, downspouts, tiles, and drains. Screens or barriers may be used to prevent obstruction of the drainage system.

Growing Media

Natural soils made of clay, sand, and silt are extremely heavy. Growing media well suited for rooftop gardens include compost, organic matter, and recycled materials. The media must allow water to be held while also being permeable. In addition, the media ingredients must resist heat, tolerate frosts and thaws, provide a space for rooting and holding nutrients, and be resistant to fire. The media must secure plants in a manner that will prevent them from falling over due to wind. (Wind speed doubles for every ten stories of building height.)

Plants

Plants suitable for rooftop gardening vary, but they must be hardy. Generally, plants that do well in this environment also perform well in poor soils. Plants must be able to withstand harsh environmental conditions, as extreme weather conditions are magnified on rooftops. Insulation for roots helps with continuous freezing and thawing cycles that are encountered on many rooftops in the United States. Windy conditions also increase desiccation or extreme drying of plant material. Landscape architects and gardeners typically choose drought-tolerant and native species for successful rooftop gardens.
Maintenance

Rooftop gardens require the same degree of maintenance as other garden spaces. Rooftop gardens require irrigation, weeding, pruning, fertilizing, harvesting, culling (removal of dead or old plants), replanting, and the addition of soil amendments. Additional maintenance tasks include supporting windbreaks, cleaning drainage pipes, and winterizing irrigation equipment.

Vertical Gardening

As space for gardening becomes more limited, gardeners search for new ways or places to grow plants. Many people live in urban areas or take up residency in apartments and townhomes with little or no green space. Gardeners can grow plants without a great deal of space by planting a vertical garden. Vertical gardening is a method of growing plants on a vertical surface, such as a wall or trellis, rather than on a horizontal surface, Figure 20-14. Growers might also use vertical garden elements to add beauty or variety to a space. Methods of vertical gardening that people find successful for ornamental plants or food production include using pockets, trays, pot hangers, found objects, planters, and green walls.

Pockets

Several companies make products with a pocket design to hold plants. Pockets composed of a recycled felt material can be constructed as individual pockets or in rows of pockets. The pockets are filled with a potting soil and then plants are added. Pockets work especially well for growing edibles, such as herbs and strawberries. They are also excellent for houseplants and can add a touch of green to any wall in a building or home. Grommets or other methods are used to hang the material on a vertical surface. The pockets can be watered by hand or a drip tube or soaker hose can be attached to irrigate the plants.

Trays

Trays used for vertical gardening are similar to greenhouse or nursery trays. They are typically constructed of plastic or a decay-resistant wood, such as cedar. The trays are usually divided into planting cells. The planting cells range in size depending on the type of plant material used. For these systems, it is best to use shallow-rooted material. The trays are mounted with a bracket and rest at a 30° angle to promote drainage and aeration, Figure 20-15.
Pot Hangers
A pot hanger is a device made of polypropylene that supports containers. The hidden hanger can support up to 100 pounds and tolerate high winds. The device supports any device that has a lip for it to clamp onto. It can then be attached to any surface, Figure 20-16.

Found Objects
Salvaged or recycled materials can be used for growing plants and make attractive additions to the landscape. Gutters, troughs, pallets, shutters, old shoes, and soda bottles can all be modified or fitted to suit a vertical garden. Gardeners must ensure that these planters have adequate drainage and are near a readily available source of water. The plants can be watered by hand or a drip tube or soaker hose can be attached to irrigate the plants.
Planting tubes are made of plastic or another fiber. They act as a hanging basket with holes distributed evenly around the tube. Soil fills the container and plants are placed in the holes.

Stacked containers can create a tower effect. Some are sold as a system; others are created by gardeners. These towers are easy to maintain, use less horizontal space, and are aesthetically pleasing, Figure 20-17.

Barrels can be modified to provide spaces for plants to grow. Slots are made in these upright containers where plants can be inserted. Usually, up to 40 plants can be grown in a fifty-gallon barrel.

Green Walls

Green walls (often referred to as living walls) blanket the interior or exterior sides of buildings and structures with plant materials, Figure 20-18. Most walls incorporate an irrigation system into their design. A landscape architect professor, named Stanley Hart, patented the idea in 1938.

Green walls offer several benefits:

- Reduction in temperature surrounding the living wall. This helps to counteract the heat island effect found in urban areas.
- Reuse of non-potable water (water that is not fit for drinking). In recirculating systems, the plants can help to absorb some contaminants from the water.
- Use of a surface that would otherwise go unused. Areas that lack horizontal space for plants or are arid and cannot support plant life can benefit from green walls.
- Beautify the exterior and interior of buildings. Studies have shown that green spaces indoors promote a more productive work environment.

Before installing a green wall space, several factors should be considered. The factors include:

- How the wall will be constructed.
- The direction of the sun’s rays and where they travel throughout the day.
- The media that will be used for this mode of vertical gardening: loose media, mat media, or structural media.
Loose Media

Systems that use loose media have potting soil placed in a package and attached to a wall, Figure 20-19. These systems must have media replaced annually when planted outdoors and biennially when planted indoors. These systems tend to erode and should not be used in applications over eight feet high. Additionally, these systems should not be used in areas where there is a great deal of public interaction as watering can be difficult and untidy.

Mat Media

A mat made of coconut coir or a felt-like product can be used to line a wall. This system is best for the interior of a building. These systems do not support mature or aggressive root growth. They mat will need to be replaced about every three to five years because the material will be covered with roots and plants will overwhelm the material.

Structural Media

Structural media systems have a life span of ten to fifteen years. Blocks of material with precise pH levels, water holding capacity, and aeration are manufactured into various sizes, shapes, and thicknesses. This strong material withstands continual watering, fertilization, heat, seismic activity, and wind.

Figure 20-19. Loose media systems do not last as long as other vertical systems and can be difficult to water or maintain.
Raised Bed Gardening

Raised bed gardens elevate the surface of the cultivation area 12” to 30” above ground level. A raised bed is the perfect option for a gardener faced with a poor soil situation or for a container-type roof garden, Figure 20-20. The raised bed may be built from new or recycled products and can be filled with topsoil or compost to create optimal growing conditions. Soil in the beds is typically deep, loose, and fertile and has good aeration, drainage, and permeability.

Gardeners with physical disabilities or difficulty bending can garden more easily with raised garden beds. Raised bed gardens can be easily weeded, irrigated, mulched, and generally maintained. To accommodate those with physical challenges, raised bed gardens should be constructed at least 30” tall and no more than 4” across. Raised bed gardening works well in urban and suburban situations where soil surrounding buildings is of poor quality and in areas where construction once took place or heavy foot traffic has impeded the soil’s health.

Raised Bed Media

Gardeners can choose how to compose the growing media in their raised bed garden. The quickest and simplest method is to simply add organic matter to the needed depth, width, and length. Adding compost, aged manures, and leaves to the soil can help quickly fill the bed. Gardeners may use lasagna or sheet composting to fill raised beds.

Figure 20-20. Raised beds with drip irrigation are situated on this intensive rooftop garden.
**Lasagna composting** is a system of building layers of organic matter to construct the growing media in a raised bed. The following steps are used in lasagna composting.

1. Cut the grass in the area to be gardened as close to the soil level as possible.
2. Cover the area with 8 to 10 layers of newspaper and/or a layer of cardboard and apply water until the material is saturated. Be sure to overlap the edges of the paper and/or cardboard.
3. If you are using a frame, place it on top of the newspaper/cardboard layer.
4. Pile layers of chopped grass, vegetation, mulch, soil, or compost on top of the newspaper or cardboard. Apply water to saturate the material.
5. Cover with more newspaper and/or cardboard and then again with organic matter, watering each time. Use a mixture of organic brown and green materials, such as grass clippings, kitchen scraps, sawdust, seaweed, and used potting soil.
6. Allow the material to decompose so that the material looks like earth and smells like good, sweet soil. This process will take several months depending on the temperature and moisture level of the pile. Continue the process until the raised bed garden has the appropriate dimensions.

**Intensive Gardening**

Intensive gardening uses several horticultural techniques to yield the greatest harvests for a raised bed. Plants are carefully placed to promote growth. An example may include planting corn, beans, and squash together. The tall corn stalks act as a trellis for bean vines to grow on. The squash leaves provide shade around the base of the corn and bean plants to help cool the soil and prevent weeds from growing. Gardeners spend a great deal of time planning for every season’s planting. Plants that are harvested are quickly replaced. Gardeners often exercise a method known as **square foot gardening**, Figure 20-21. Plants are placed every foot and are planted in a staggered pattern where leaves overlap to prohibit weed growth. Gardeners use certain compact varieties and species of plants to conserve valuable growing space. Harvests from this method are usually 4 to 10 times higher than conventional gardening methods.

**Straw Bale Gardening**

A raised bed garden does not have to be permanent nor use a frame. Straw bale gardens use composted straw bales as a planting medium. Straw bales are usually about 4’ long and 18” to 24” wide. When the straw bale is placed on the ground, it is nearly 24” tall. A bale will turn into a block of compost over time and can act as a platform for plant growth, Figure 20-22.
Gardeners can speed the process of decomposition by using high nitrogen fertilizers or blood meal and applying water. To check whether the bale has decomposed sufficiently, insert a trowel into the bale to examine the material. It should be cool to the touch and smell like sweet soil. The interior of the bale should also look darkened and no longer resemble straw.

The decomposed bale will house between three to four vegetable plants. Some plants, such as tomatoes, should be planted in a bush variety. Two tomato plants may be housed in each bale. The plants must be adequately watered. Soaker hoses or a drip irrigation system work well. Additionally, plants must be heavily fertilized to ensure that they are receiving the appropriate amount of nitrogen. The carbon from the straw bales will lock up a great deal of the fertilizer, so additional nitrogen fertilizer must be applied. A good organic source is blood meal that is 12% nitrogen.

**Careers**

Each of the gardening techniques discussed in this chapter offer countless career and entrepreneurial opportunities. Aside from growers, many other personnel are needed to design, install, and maintain equipment.

**Aquaponic System Manager**

An aquaponic system manager possesses agricultural training and education—at least a bachelor’s degree. This person develops crop and fish management programs at an aquaponic facility, Figure 20-23. He or she ensures proper planting, cultivation, and harvesting of fish and plants. The aquaponic manager provides technical expertise for daily crop production operations. He or she determines the types, quantities, projected sales volumes, and budgets for all crops. In addition, the manager may hire, train, and supervise all other workers.

**Living Wall Designer**

When envisioning an artist, most people picture a painter or a sculptor, not a horticulturist. A living wall or green wall designer is an artist who uses plants as a medium and walls or other vertical spaces as his or her canvas. Vertical landscape designers create beautiful, living art that also provides environmental benefits. A living wall designer has a plant science background coupled with an emphasis in art. Living wall designers may also be landscape architects or designers, botanists, or agronomists.

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*Did You Know?*

The decomposition of a straw bale is an exothermic reaction. This means that as the microbes decompose the straw bale, heat is given off. A decomposing straw bale can reach temperatures in excess of 140°F (60°C).

*Figure 20-23. An aquaponic manager cares for the fish in his operation.*
In New York City and Chicago, Gotham Greens grows hydroponic crops on the rooftops of warehouses and grocery stores. Gotham Greens designs, builds, and operates urban greenhouses for hydroponic vegetable and herb production. They cultivate their plants in a pesticide-free, ecologically sustainable environment year round to supply reliable, safe, and wholesome produce to the local community.

The chief agricultural officer, Jennifer Nelkin Frymark, learned how to grow plants hydroponically at Arizona State University. She has also worked in places such as Antarctica growing fresh produce for scientists in a continent covered with ice. She has a strong background in plant physiology and expertise in greenhouse system design, hydroponic systems and controls, integrated pest management, plant nutrition, and staff training.

Frymark is passionate about sustaining the environment and bettering her world. She uses hydroponic systems for her business for several reasons. Hydroponic systems recirculate water and produce crops with 20 times less water than conventional agriculture. Hydroponic systems also yield 20 to 30 times more than conventional agriculture. There is very little usable land in metropolitan areas, and hydroponics provides a more efficient avenue for plant growth. With urban locations, Gotham Greens sells locally and eliminates long-distance travel for crops. The shipping reduction provides fresher produce, reduces fuel consumption, and prevents additional carbon emissions. In addition, Gotham Greens employs local community members.

Gotham Greens was recently named to the “Coolest New Businesses in America” list by Business Insider. This did not happen by chance. Frymark and her partners’ efforts have made her company stand out and expand. Their work with companies such as Whole Foods has also helped Gotham Greens gain recognition in urban markets.
Chapter Summary

- Hydroponic growers cultivate plants using water and nutrients without soil.
- British scientist Sir Francis Bacon formally researched hydroponic gardening in the seventeenth century. Advances in hydroponics have continued to the present day.
- Types of hydroponic systems include ebb and flow, water culture, deep water culture, aeroponics, nutrient film technique, drip system, and wick system.
- Crops grown using hydroponics include tomatoes, peppers, herbs, cucumbers, lettuce, and microgreens.
- Aquaponics is a system of growing plants with water that has been used to grow fish, snails, or other aquatic creatures.
- An aquaponic system uses a hydroponic subsystem for the plant portion of its operation as well as specific equipment (sump pump, biofilter, settling basin, rearing tank) for the aquatic creature portion.
- Plants grown using aquaponics include lettuce, kohlrabi, cabbage, basil, dill, parsley, and cilantro.
- Rooftop gardens are situated on top of buildings. They are an excellent way to reduce the heat island effect in urban areas. Plants provide heat absorption while also cooling the surrounding air.
- Rooftop gardens come in a variety of forms. Both container plantings and entire rooftop systems can add beauty to an area and provide cost savings for heating and cooling.
- Factors that should be considered when planning a rooftop garden include the load-bearing ability of the structure, the objectives for the garden, and the permits needed for construction.
- Vertical gardening is a method of growing plants on an upright surface, such as a wall or trellis. Methods of vertical gardening include using pockets, trays, pot hangers, found objects, planters, and green walls to grow ornamental plants or food.
- Raised bed gardens create an elevated gardening area.
- Career opportunities associated with nontraditional gardening systems include chief agricultural officer for a hydroponic facility, an aquaponic system manager, and vertical garden wall designer.
Words to Know

Match the key terms from the chapter to the correct definition.

<table>
<thead>
<tr>
<th>A. aeroponic system</th>
<th>H. drip system</th>
<th>O. intensive green roof system</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. aggregate</td>
<td>I. ebb and flow system</td>
<td>P. lasagna composting</td>
</tr>
<tr>
<td>C. aquaponics</td>
<td>J. effluent</td>
<td>Q. nutrient film technique (NFT)</td>
</tr>
<tr>
<td>D. biofilm</td>
<td>K. extensive green roof system</td>
<td>R. square foot gardening</td>
</tr>
<tr>
<td>E. biopharming</td>
<td>L. ground level ozone</td>
<td>S. vertical gardening</td>
</tr>
<tr>
<td>F. culling</td>
<td>M. heat island effect</td>
<td>T. water culture system</td>
</tr>
<tr>
<td>G. deep water culture (DWC)</td>
<td>N. hydroponics</td>
<td></td>
</tr>
</tbody>
</table>

1. A harmful air pollutant that is formed from chemical reactions of other pollutants near Earth’s surface.
2. A hydroponic growing method in which plant roots are suspended in the air and misted intermittently with a nutrient solution.
3. A method of hydroponics in which the nutrient solution is pumped from a main reservoir and circulated through an attached system of buckets containing plants.
4. A landscape on top of a roof similar to a typical garden planted at ground level.
5. A media that is used to cultivate plants in a hydroponic system.
6. A method of hydroponics in which the containers holding plants are periodically flooded with a nutrient solution and then drained.
7. A method of hydroponics in which plants in trays float with their roots submerged in a nutrient solution.
8. A hydroponic method in which a liquid nutrient solution is slowly released onto the base of each plant through a series of thin tubes.
9. The increase in temperature of urban areas due to a variety of environmental factors.
10. A system of growing plants in water that has been used to grow fish, snails, or other aquatic creatures.
11. A hydroponic method that circulates a thin stream of water containing nutrients over the roots of plants.
12. A method of growing plants on an upright surface, such as a wall or trellis.
13. A system of gardening in which every plant is allotted a specific amount space in a garden.
14. Growing plants that have been altered, often via genetic engineering, for medicinal uses.
15. The waste from living creatures.
16. A group of microorganisms that stick together on a surface and form a thin, slimy coating.
17. Removing dead or old plants.
19. A live, planted garden on top of a structure that forms a matting and helps to increase insulation, reduce runoff, and increase a roof’s lifespan.
20. A system of building layers of organic matter to construct the growing media in a raised bed.
Know and Understand

Answer the following questions using the information provided in this chapter.

1. What are some problems associated with growing hydroponically?
2. What was Sir Francis Bacon’s contribution to hydroponics?
3. What are the types of hydroponic growing systems discussed in this chapter?
4. What are some types of aggregates used in hydroponic systems?
5. What are some crops that are grown using hydroponics?
6. Why are some people wary of biopharming methods?
7. How does aquaponics differ from hydroponics?
8. What role do bacteria play in an aquaponic system?
9. What are the main elements used in an aquaponic system for the production of plants and fish?
10. What are the main elements of container gardens?
11. What is a green roof system?
12. What are some benefits of a rooftop garden?
13. What are some factors that should be considered when designing a rooftop garden?
14. What are the elements or materials that make up a green roof system for a rooftop garden?
15. Why might growers choose to plant a vertical garden?
16. What are some methods of vertical gardening that people find successful for ornamental plants or food production?
17. What is a green wall and what are some benefits offered by green walls?
18. Describe a raised bed garden.
19. Describe the education needed for and job duties of an aquaponic system manager.

Thinking Critically

1. You recently started an aquaponic system to grow tilapia. You are using city water. Within the first 48 hours, 75% of your fish died. Hypothesize the reasons for their sudden death.
2. You visited a vertical wall that was constructed almost three years ago using pockets on the interior of a building. The plants did very well for the first year and a half. They have been watered, fertilized, and exposed to the correct amount of light. Now, these once vibrant plants look sick and weak. What could be the reason for their decline?
STEM and Academic Activities

1. **Science.** Find a building that has a green roof system and compare the engineering required of this building to your home or school.
2. **Science.** Design a living wall for a space in your school. Select the appropriate plant materials.
3. **Engineering.** Design and construct a vertical garden using a recycled plastic barrel.
4. **Social Science.** Contact a company that offers hydroponic systems for urban areas. Ask questions about its workforce and who it employs to operate the business. Create a short video or marketing announcement about this company and what it provides for its employees or consumers.
5. **Language Arts.** Write a position paper outlining the advantages and disadvantages of green roofs.

Communicating about Horticulture

1. **Reading and Writing.** Compare and contrast three types of hydroponic growing aggregates. Create a chart with the pros and cons of each type.
2. **Reading and Writing.** Research aquaponics and write a two-page report explaining the benefits of using this technology.

SAE Opportunities

1. **Exploratory.** Job shadow a hydroponic grower.
2. **Experimental.** Compare different growing media on one hydroponic growing system that uses an aggregate culture.
3. **Exploratory.** Research how hydroponic or aquaponic systems can positively impact urban communities around the world.
4. **Entrepreneurship.** Design and construct vertical garden systems using recycled materials such as pallets and sell them to the public.
5. **Entrepreneurship.** Grow plants hydroponically and sell the produce.