

An Introduction to Small-Scale Soilless and Hydroponic Vegetable Production

July 2019

Natalie Bumgarner, Assistant Professor and Extension Specialist, Department of Plant Sciences, University of Tennessee
Robert Hochmuth, Regional Specialized Agent and Center Director, University of Florida Extension

Residential and small-scale commercial food production can take many forms. Traditional home gardens that utilize native soil may be the most common, but interest in growing vegetables is not limited to those with suitable outdoor and in-ground sites. In many cases, a gardener may not have access to a plot of soil, or the soil may be of such poor quality that growing in the ground is not an option. Soilless production and hydroponics are options for many and enable small-scale vegetable production where traditional gardens would be impossible.

The growing systems and techniques involved in soilless growing can enable those in urban areas with small spaces, a sunny patio, or a range of other locations and situations to enjoy growing their own food. Growing plants without using soil has been done for many years, but the science and practice of these methods continues to develop and expand opportunities for commercial growers and gardeners alike.

This educational publication has been prepared in a cooperative efforts between University of Tennessee Extension and University of Florida Cooperative Extension systems to provide information and an introduction to these hydroponic practices and techniques specifically for gardeners, students, youth and other non-commercial growers.

Growing Food Without Soil

What is soilless and hydroponic production?

Most crops are grown in outdoor locations with adequate sunlight where native soil and appropriate irrigation and fertilization practices can provide for plant needs. Soil plays many vital roles for plants including: supplying physical support, providing water holding capacity, supplying many of the nutrient needs of plants, as well as supporting the biological activity necessary for nutrient cycling. Soilless production is a method of growing plants that provides for many of the same functions as the soil by supporting the plant physically while providing a rooting environment that gives access to optimum levels of water and nutrients.

Soilless production can take place in naturally occurring sand, peat moss, coconut husks (coir), as well as materials made from rocks or minerals through industrial processes (perlite, vermiculite, rockwool). In many locations, locally available materials such as composted pine bark, rice hulls and other products are used in soilless culture. Some soilless

production also takes place in foam substrates. These materials will be discussed in more detail in the later sections (Figure 1).

Soilless production can be done in several ways. Sometimes plants are grown in a **substrate** (simply meaning the material where the plant roots live) that mimics the physical support and water and nutrient supplying roles of native soil but is not actually soil. An example would be poinsettias, bedding plants, vegetable transplants and other crops grown in a greenhouse in a peat-based substrate. These plants are watered, fertilized and managed to optimize growth through management of physical properties of the substrate and providing water and nutrition for the plant.



Figure 1. Lettuce seedlings in different types of soilless growing media. Bumgarner image, use courtesy of CropKing Inc.

Soilless production can also include roots that are not grown in a substrate. In these solution-based systems, nutrients are dissolved in water, and plant roots are directly bathed in a nutrient solution.

For the purposes of this publication, the authors consider using the terms “soilless production” and “hydroponics” to be interchangeable. Both terms are used to describe plant production systems where the

native soil is not used. In this publication there are two subcategories within soilless production or hydroponics. Those two subcategories are: 1. Systems using a soilless media or substrate to grow the crop, and 2. Systems using only a nutrient solution to grow the crop with no media or substrate other than to grow the transplant plug. Products sold as “hydroponic” in stores may use either a soilless media or nutrient solution type of production system. In no case would a crop be considered to be grown hydroponically if grown in a native soil.

Why use soilless systems?

While soil supports many areas of our lives (food, clothing, housing), there are challenges in managing crops in soils. Soil may have poor physical structure, poor drainage or low nutrition, all of which limit plant growth. Soils may harbor plant pathogens, insects or nematodes that can infect or feed on plants. Soils may have been contaminated with other materials or chemicals that can reduce growth and yield or present safety hazards for humans. Additionally, there are many urban and suburban areas where soil is not even accessible or land is so valuable that gardening or agriculture cannot realistically be practiced in those soils. Plants grown in soil are generally outdoors where low or high ambient temperatures, low or excess moisture, pests and pathogens can negatively impact crop growth and quality. All of these potentially negative factors can be condensed into three key reasons why soilless production may be a solution:

- Soilless production can tailor the physical, chemical and even biological aspects of the growing substrate and environment to exact crop needs to enhance growth and productivity.
- Soilless production can be practiced more easily in controlled environments, such as greenhouses or even indoors with proper lighting, to enable the most efficient use of these high capital production areas.
- Soilless production in controlled environments can enable exclusion and efficient management of damaging pests and pathogens as well as environmental challenges.

Background on soilless production and hydroponics

It has long been an interest of agriculture producers and researchers to better control all aspects of plant growth to maximize production. Thousands of years of history can attest to the fact that humans have been interested in improving the crop growing environment to increase food production or reduce land use. In the past century, key developments have expanded these efforts. First, a better understanding of plant mineral nutrition enabled the interaction of plants, soils and nutrients to be more closely replicated in soilless systems. Second, the use of plastics has enabled growers access to greenhouses, irrigation and plant management tools (twine, clips, etc.) that are more cost, time and space efficient.

Current use of controlled environments and hydroponics

Soilless production and precise environmental controls are often used together in commercial settings. One can maximize plant production by combining optimum rooting conditions through soilless culture and optimum “aboveground” environmental conditions.

While some commercial growers use soil to produce vegetables in greenhouses, most greenhouse producers rely on soilless systems to control quality and optimize production. Hydroponic and soilless production of vegetables has been actively investigated in the US since the early 1900s and was employed during World War II to provide food for troops in areas where soil production was a challenge. Since that time, commercial interest in hydroponics has advanced the industry to enable dependable production of soilless crops in many parts of the

world. The ability to efficiently use water and nutrients and introduce strict food safety practices means controlled environment soilless agriculture may be an important growing system for the future.

In addition to increases in large and medium scale greenhouse hydroponic production, personal and family-sized production of fresh vegetables is becoming more common and enables residents to contribute to their own fresh food supply. Often overlooked, another aspect of soilless production is that it can be a great tool for researchers and teachers. Growth chambers as well as greenhouses are the site of many experiments focused on understanding plant genetics and interactions with the environment. Soilless systems provide a means of scaling down the size of these studies and having the precise control needed for research. Lastly, but certainly not least is the potential of soilless systems to be used as a teaching tool. The scalability and versatility of these growing systems as well as their combination of science, technology, math and engineering make them a great tool for many educators.

What Crops Can Be Grown in Soilless or Hydroponic Systems?

With a proper understanding of nutrient needs, most crops can be grown hydroponically. A wide range of vegetable and herb crops can be produced, and both long- and short-term crops can be grown in soilless systems. Annual leafy and fruiting vegetables (Figure 2) are more often grown in soilless systems because of the return on time and system investment, ease of production, consistency of supply, high quality, and value to consumers.



Figure 2. *Tomatoes in soilless production in a small commercial greenhouse. Bumgarner image, use courtesy of CropKing Inc.*

A wide range of leafy vegetable crops, including lettuce (Figure 3), kale, mustard, spinach, endive, Swiss chard and many Asian greens are commonly grown in soilless systems because of their rapid growth rate and frequent consumption. Basil is the most commonly produced herb, but others may include chives, oregano, thyme, cilantro and rosemary. Many consumers also appreciate the ability of controlled environments and soilless systems to produce leafy crops with less pest and disease damage that can usually be grown with little or no pesticides.

Fruiting vegetable crops are also commonly grown in soilless systems. Tomatoes and cucumbers are most common because of their quality and productivity. A wide range of beefsteak, paste, cherry, cluster-harvest and grape tomatoes are grown in soilless systems. Generally, seedless cucumbers are produced in these systems, and they are valued for their thin skins as well as lack of seeds and bitterness. Two primary types of seedless cucumbers can be grown. The long, traditional types

that are 12 inches or longer are thin-skinned and dehydrate quickly and are usually shrink-wrapped. More recently, smaller-sized seedless cucumber fruit have become very popular. The smaller fruited types, referred to as mini cucumber or Beit alpha types, have all of the same attributes as the larger varieties, but do not dehydrate as fast and, therefore, are not typically shrink-wrapped. All seedless cucumber varieties have to be isolated from regular seeded varieties if pollinators are present. Sweet (especially colored) and hot peppers as well as eggplants are also possible. The quality of the pepper fruit can be outstanding, yet one thing to consider is that peppers are a slower growing crop.



Figure 3. Mature head of greenhouse bibb lettuce ('Rex') in NFT system. Bumgarner image, use courtesy of CropKing Inc.

How Are Plant Nutrients Provided?

In traditional soil growing, plant roots take up most essential nutrients from the water that fills the spaces between soil particles. The soil particles themselves contribute to plant nutrition by holding nutrients added as fertilizer, contributing to nutrient cycling, or even slowly breaking down to provide nutrients from soil minerals or organic matter. In hydroponic systems, the supply of plant nutrients can be more exacting because there is not a soil 'middle man.' Plants still take up most nutrients from a water solution, but there is no soil reservoir to hold or provide nutrient. In soilless production, the soilless substrate is used to hold the nutrient-rich solution, but in most cases, the soilless substrate does not contribute to the nutrient supply itself. Plants grown in soilless and hydroponic systems require the same macro and micronutrients as plants grown in the soil, and these nutrients are provided in the form of fertilizer salts. The positively charged (+) cations and negatively charged (-) anions dissolve in water to provide needed nutrients (Table 1).

Growers select fertilizer materials and prepare solutions that provide all the nutrients needed. Specific fertilizer salts are used in nutrient solutions to ensure that they are soluble in water and that dissolved salts do not become unavailable for plant uptake. These nutrients are calculated to be available in appropriate concentrations to provide what plants need without over or undersupply. Maintaining appropriate pH levels is also important in ensuring nutrient availability. Plants may show signs of a nutrient deficiency if essential nutrients are not available to the plant.

Table 1. Description of essential nutrients for plant growth and fertilizers that provide them

Classification	Name	Chemical forms commonly taken up by plants	Common fertilizers used to provide these nutrients
Macronutrients	Nitrogen (N)	NO_3^- , NH_4^+	Calcium nitrate — $\text{Ca}(\text{NO}_3)_2$ Potassium nitrate — KNO_3
	Phosphorus (P)	H_2PO_4^- , HPO_4^{2-}	Monopotassium Phosphate — KH_2PO_4
	Potassium (K)	K^+	Monopotassium Phosphate — KH_2PO_4 Potassium nitrate — KNO_3 Potassium sulfate — K_2SO_4 Potassium chloride — KCl
	Calcium (Ca)	Ca^{2+}	Calcium nitrate — $\text{Ca}(\text{NO}_3)_2$
	Magnesium (Mg)	Mg^{2+}	Magnesium sulfate — $\text{MgSO}_4 \cdot x\text{H}_2\text{O}$
	Sulfur (S)	SO_4^{2-}	Potassium sulfate — K_2SO_4 Magnesium sulfate — $\text{MgSO}_4 \cdot x\text{H}_2\text{O}$
Micronutrients	Boron (B)	BO_3^{3-}	H_3BO_3
	Chloride (Cl)	Cl^-	Not often added through fertilizers Potassium chloride — KCl
	Copper (Cu)	Cu^{2+}	CuSO_4 , $\text{Cu}(\text{NO}_3)_2$
	Iron (Fe)	Fe^{2+}	Chelated Iron
	Manganese (Mn)	Mn^{2+}	MnSO_4
	Molybdenum (Mo)	MoO_4^{2-}	Na_2MoO_4
	Zinc (Zn)	Zn^{2+}	ZnSO_4
	Nickel (Ni)	Ni^{2+}	Not often added through fertilizers

Small-Scale Hydroponic Growing Systems

The type of growing system for soilless production should be selected based on the mature size of the crop being produced as well as cost, management time, and many other factors. Size of plants and time in production are both important in determining the growing system. Large vining crops not only require more space for stems, leaves and fruit, but also have a larger root mass and higher nutrient needs over a longer period of time. Smaller leafy crops require less space for leaves and roots and occupy the growing system for less time.

Leafy vegetable crops

There are a variety of soilless growing systems that can be used to produce leafy vegetable crops. Most are some type of recirculating hydroponic system, and a few non-recirculating systems can be effective growing leafy greens hydroponically as well. A recirculating hydroponic system means that the nutrient solution is continuously or intermittently (with the use of a timer) moving past plant roots. Sometimes the pH and target nutrient levels are continuously maintained by automated equipment. Other systems require manual adjustment by the grower or gardener.

Most leafy crops are started close together in a nursery and then transplanted into a growing system where they are grown until harvest. This conserves space in the main growing system while the plants are small. The two most common growing systems are nutrient film and floating raft, also known as a deep-water culture system. Another recirculating hydroponic option is an aeroponic system, where roots are misted with nutrient solution or solution is intermittently dripped over the roots.

Recirculating nutrient film technique

The nutrient film technique (NFT) is scalable and flexible for a range of leafy vegetable crops. NFT systems come in a range of sizes to fit large or small greenhouses, on porches or even indoors (Figure 4). These systems typically consist of plastic channels containing a thin film of nutrient solution flowing through them. This nutrient solution is generally pumped from a reservoir located below the channels. Irrigation lines deliver the nutrient solution directly to the feed end of each channel. The channels are installed with a slight (1-2 percent) slope to allow nutrient solution to drain down the channel from the higher feed end and out a drain line at the other end to then be returned to the reservoir by gravity.



Figure 4. Leafy crops growing in channels in a nutrient film technique (NFT) system indoors with supplemental LED lighting. Bumgarner image, use courtesy of CropKing Inc.

Channels can be of varied length and design. Some are two-piece with a top cap that snaps over the bottom channel, while others are one piece with holes punched or drilled in the top (or sides). Regardless of the design, channels typically have holes at set distances that provide consistent plant spacing. Channels are supported by metal or wooden benches or support racks that provide the needed slope. Solid pipes, open channels or flexible lines are used to drain the nutrient solution from the channels back into the reservoir.

Within the channel, plant roots are bathed in a thin, continuously moving film of nutrient solution on the bottom of the channel. Because of the shallow depth of the solution, there is still space in the channel for roots to be in contact with air. Most light is blocked from reaching the flowing nutrient solution to prevent algae growth. The shallow depth of the nutrient solution also means that solution temperatures are similar to air temperatures, which can be a challenge in small systems in warm seasons. Also, small aboveground reservoirs heat up more quickly than larger, buried tanks.

Recirculating vertical systems



Figure 5. Vertical, self-contained hydroponics system appropriate for residential or educational settings. Bumgarner image.

Vertical hydroponic systems have plants in structures in an upright arrangement to be more space efficient. Some systems have channels arranged vertically with constantly flowing solution. Others, such as the tower systems (Figure 5) have no channels, but are recirculating because solution is typically pumped to the top of the tower and allowed to drain through the plant roots to the reservoir beneath. In many tower systems, the water is not pumped continuously. Intermittent solution flow can reduce prolific root growth in the system by encouraging some root pruning by the air. Even with some of these differences in system management, the main principles of supplying plants with nutrients through flowing, dripping or spraying nutrient solutions are similar across NFT and vertical systems.

Floating culture or deep-water systems

Floating or deep-water hydroponic systems have a reservoir of nutrient solution on which crops are floated or suspended while the roots hang freely in the solution. Floating systems can be constructed cost efficiently for the home grower from wooden frames lined with plastic or using other containers that are water tight (buckets, tubs, small swimming or kiddie pools). Lightweight plastics (expanded polystyrene, Styrofoam) with holes drilled at intervals are used to support the plants in plastic mesh pots.

Since plants are floating on the solution, pumping of the solution as described in the NFT system is not necessary. One of the key differences between NFT and deep-water systems is often the volume of water and the depth of solution. Unlike the NFT system where there is a thin film of solution and a large air space, most of the roots in deep-water systems are directly submerged. A small portion of the roots are above the solution and are exposed to the air around the soilless substrate used to grow the transplant. Maintaining oxygen in the nutrient solution of these systems may require bubblers or even oxygen injectors on a large scale. However, on a small scale, leafy greens can be successful in a non-re-

circulating deep water system so long as the roots have some space for air. A benefit of floating systems is that the larger water volume tends to have a moderating impact on solution temperatures and other conditions. Another benefit to home gardeners is the floating systems do not require any pumping systems and are easy to construct. More details on crop production appropriate to both of these systems will be covered in other publications in the series.

Fruiting vegetable crops

Fruiting vegetable crops differ from leafy vegetable crops in crop duration (often several months instead of several weeks), mature crop size, and nutrient needs. Therefore, growing systems for fruiting crops generally have more rooting space and physical support.

Production systems for fruiting vegetables typically use a single pass or feed to drain system of nutrient management rather than a recirculating nutrient solution. A recirculating system may pose more risk of spreading pathogens to longer term crops or having an imbalance in the nutrient solution for larger crops that are taking up more nutrients at varying levels. In smaller, noncommercial systems, it is common for fruiting crops to be grown in recirculating systems because of the small plant number and the simpler management.

Unlike the NFT and floating systems described above, most fruiting crops are grown in a soilless substrate. They typically have a larger root mass that is best grown in a larger space than is present in channels. Aeration is important for these large root masses and a porous substrate can better provide oxygen to roots than floating systems. Two common systems for fruiting crop production are upright containers and lay-flat bags, also known as slabs. Less commonly, soilless media vertical systems can also be used.

Upright container culture

The upright container systems may include upright plastic bags, nursery pots, or buckets. The upright containers may have drainage holes in the bottom of the container or have a higher drainage system to allow a reservoir of nutrient solution in the bottom of the container. Upright container systems are similar to a soilless production systems for many potted crops, although substrates differ (Figure 6). In a reservoir container system (e.g., Dutch buckets or Bato buckets), young plants are transplanted into a container of porous substrate, commonly perlite or clay pebbles. Other upright containers with drainage in the bottom may use a wider range of soilless media such as peat mixes, composted pine bark, coconut fiber (coir), sawdust, perlite, etc. A balanced nutrient solution is delivered using drip lines at intervals throughout the day. The containers with reservoirs are designed to have a reservoir in the bottom to enable a large portion of the bucket to drain and provide good aeration to the roots while also providing a small storage area for the roots to reach a more consistent supply of nutrient solution. Other upright containers have a small reservoir in the bottom along with a pump that enables the system to be self-contained. Some upright containers, like reservoir buckets, are washed and used for many years.

Lay-flat bag or slab culture

Fruiting crop production in lay-flat grow bags or slabs is similar to several of the upright containers because a nutrient solution is dripped by plant roots and allowed to drain from the bottom. Perlite is the most common substrate in reservoir buckets, while rockwool, perlite, coconut fiber (coir) or sawdust can all be used in bags or slabs. Bags or slabs are not typically reused (or only reused once). Since the nutrient solution is not being recycled, the leachate should be minimized and collected to protect groundwater quality. The nutrient concentration in the leachate is often similar to the incoming solution and therefore, once collected, can be used for fertilizing many other plants in the yard or farm. Managing leachate collection can be challenging in many of these systems, so growers must have a reasonable plan to collect the nutrient solution leachate.



Figure 6. A young tomato transplant being placed in perlite in a growing bucket. The drip line to deliver nutrient solution can also be clearly observed. Bumgarner image, use courtesy of CropKing Inc.

Conclusion

This concludes the overview and introduction to small-scale soilless or hydroponic growing systems. With this summary of the background and different types of systems, it is our hope that those considering these systems will be better prepared to select a growing system that best fits their preferred crops and site. For more detailed information on leafy and fruiting crops as well as troubleshooting and cultivar selection, we encourage gardeners, teachers and small-scale growers to utilize other publications in this series:

[W 844-B Leafy Crop Production in Small-Scale Soilless and Hydroponic Systems](#)

[W 844-C Tomatoes, Peppers, and Cucumbers in Small-Scale Soilless and Hydroponics Systems](#)



AG.TENNESSEE.EDU

Real. Life. Solutions.™