W 844-B

Leafy Crop Production in Small-Scale Soilless and Hydroponic Systems

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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 effort 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 Systems

Overview

There are many choices in soilless growing systems for leafy crops, and those systems are covered in detail in the first publication in this series, W 844-A An Introduction to Small-Scale Soilless and Hydroponic Vegetable Production. It is important to make sure that your system choice fits the site, time available and preferred crops.

Recirculating and floating systems are the two most common growing systems used for leafy crops. Recirculating nutrient film technique (NFT) system and vertical, or tower, systems are all readily available. Additionally, floating or deep-water systems can be purchased or constructed in a range of sizes to fit varied budgets, locations and growing needs. Although there are other options, these two growing methods support rapid crop growth and relatively simple management for leafy crops when solution conditions (temperature, oxygen, electrical conductivity [EC], alkalinity/acidity [pH]) are well controlled.

Figure 1. *A low-cost floating hydroponic system that can be constructed simply for homes and schools. Bumgarner image, use courtesy of The Ohio State University Vegetable Production Systems Laboratory.*

A range of complete systems, often called hobby hydroponic kits, are available on the market. Benefits of small complete systems include the ease of setup and opportunity for customer support. However, the price does tend to be higher than do-it-yourself systems (Figure 1). Besides price and time in construction or assembly, other important considerations are the location, production potential, management requirements, food-safe materials and versatility of the system.

This discussion will not focus on the merits of specific systems and suppliers. Rather, the basics of nutrient solution management and leafy crop production are the focus because these practices will be needed regardless of the production system chosen.

Location

It is important to decide where your growing system will be located before purchase. Many small-scale hydroponic or soilless systems can produce well in backyard, educational or small commercial greenhouses. Additionally, outdoor production on porches or patios is possible for some systems that are more weather resistant. Whatever the location, natural light levels of six to eight hours will be needed for most vegetable crops, and more than eight hours is best for fruiting crops. Leafy crops can be grown under slightly lower levels of light, but they may take more time to reach harvestable size or the plants may stretch or have poor color. Air movement is also needed to support photosynthesis and reduce the infection potential for leaf diseases. Make sure the site does not experience high levels of reflected light and heat buildup that could stress plants and reduce productivity. The suitability of an outdoor or small greenhouse location will vary greatly by region and time of year. For instance, a fully exposed porch might produce an excellent crop of lettuce in Tennessee in the mid- to late spring, while partial shade may be needed at that same time of year in Florida.

Soilless and hydroponic production can also be practiced indoors with the use of supplemental lighting. However, production is more costly when lighting and ventilation systems are needed. It will also require knowledge of needed light levels and duration, and equipment. This discussion will focus on sites with natural light.

Production potentials

When investigating systems, consider the volume of leafy vegetable crops needed in relation to time, cost and space. Lettuces and many other leaf crops can be produced under optimum conditions in approximately six to eight weeks in soilless systems (two to three weeks in transplant stage and four to six afterwards). Mixed or baby leaf crops can be harvested sooner than mature crops. Although light and temperature that is too high or low can extend production time considerably, production estimates can be useful to help determine system needs and plan crop schedules.

Figure 2. *A simple, small-scale, vertical recirculating system that can fit a range of residential locations.*

Let's use as an example a hydroponic system that contains space for 36 plants and is growing a lettuce crop that takes four weeks to mature after transplant. Often a grower or gardener will have multiple ages of plants growing to provide steady harvest potential. If young lettuce was transplanted into one-quarter of the system weekly, then approximately eight heads of lettuce would be available for harvest each week under optimal conditions. Smaller systems with six to eight spaces in total would be able to produce only one to two head per week using the same staggered planting plan.

Ease of management

Ease of management is not always simple to predict, but it can be helpful to consider how nutrient solutions are managed and how the system is cleaned. Managing pH and fertilizer concentrations in the nutrient solution is essential, so the ease of accessing this solution for testing, pH or fertilizer adjustment or solution changes is important. Also consider the ease of system cleaning and changing the nutrient solution. For example, a small recirculating system tank could be emptied and cleaned in a few minutes, while a homemade floating bed with a plastic liner is much more difficult to change. It is best to clean systems periodically to prevent algae and pathogen buildup as well as mixing new nutrient solutions to prevent nutrient imbalances.

Common Leafy Crops

Types of head lettuce

Iceberg lettuce is not a common hydroponic crop because it takes more space and a longer time period with fairly specific conditions to mature. The most common leafy crop grown in most soilless systems is bibb or butterhead lettuce. The softer leaves on bibb lettuce do not ship as well as iceberg and romaine and are less common in field lettuce production, but bibb lettuce flavor is often preferred for home production. Another reason may be that most lettuce breeding for hydroponics and greenhouses has been targeted at bibb lettuce, so there are several consistent cultivars with good resistance for common diseases. Further discussions on crops and cultivars can be found in other publications in this series.

Romaine lettuce is becoming more popular in soilless production, but it can be challenging because of increased risk of quality issues such as tipburn (death of young leaf edges). Romaine cultivars grown in hydroponic systems frequently have more open heads than romaine hearts often purchased at the grocery store. Oakleaf and other leaf lettuces can be a good option because they are less susceptible to tipburn and produce an attractive, reasonably consistent and timely crop. Leaf lettuce cultivars can be grown to a more mature stage as well. Green leaf lettuces and the smaller serrated leaf lettuces, such as lolla rossa, can also be grown. However, the lolla rossa type lettuces typically grow slower and often produce less total yield than other types of head lettuce, but offer benefits in novel leaf shapes and colors (Figure 3).

Mixed Lettuce

Lettuce commonly referred to as baby lettuce is often simply harvested at an immature stage. Many romaine, leaf and oakleaf cultivars can be successfully produced for immature harvest. When plants are harvested young, several seeds are placed in one growing space so they will fill in quickly. These mixed cubes are essentially a mixed bag salad grown and harvested together. The opportunities for mixing colors and leaf shapes creates a tasty and visually appealing crop that can be harvested at a range of sizes.

Figure 3*. A mixed cube of hydroponic lettuce where multiple seeds of different cultivars (green and red lolla rossa) were planted in the same cube. Bumgarner image, use courtesy of CropKing Inc.*

Basil

After lettuce, basil is the second most widely grown leafy crop in hydroponic systems. While most lettuce crops are harvested once at maturity, basil is often harvested multiple times. Growing points and young leaves are harvested, encouraging more branching and growth to produce more harvestable leaves and tender stems. Often basil plants can be grown and harvested for many weeks or months. Basil is a warm-season crop and prefers warmer temperatures and higher light levels than are typical for lettuce production. In fact, basil can also be grown in fruiting crop systems with fertilizer levels similar to those used for tomatoes and cucumbers.

Kale and other Brassica crops

Kale, mustard, pak choy and mizuna are examples of other leafy crops that grow well in hydroponic systems. While many lettuces were bred and developed for soilless production, many crops and cultivars used in hydroponic systems were actually developed for use in soil. So, trying a range of crops and cultivars is one of the best means of determining what works well in the site and system because some do not remain as compact as needed and may require harvesting at smaller stages.

The Basics of Nutrient Solutions

Source of water

Well water and municipal water can both be successfully used, but it is best to send a water sample to a public or commercial lab to determine the levels of sodium, chloride and micro- and macronutrients. Poor water quality can be more damaging in hydroponics because there is no soil to act as a buffer, and the plant roots are often directly bathed in the solution.

High levels of sodium and chloride can be a concern due to salt stress (75 parts per million is often used as a general upper limit). For this reason, do not use water that has gone through a water softener because softeners remove minerals that cause hardness (e.g., calcium, magnesium) and replace those nutrients with sodium. A water source with high salt levels may need to be treated (reverse osmosis) or diluted with another source.

Nutrient solutions for soilless systems are often based on the source water, which can contain a range of dissolved minerals. Some of these minerals are plant nutrients that can be used, but nutrients could be present in larger quantities than plants require. High levels of some minerals, such as calcium and carbonate, can interfere with solution formulation, pH management or nutrient uptake by the plant.

Fertilizer materials

Use only fertilizers designed for hydroponic systems because fertilizers vary based on the growing system. For example, calcium and magnesium may be present in higher quantities in a hydroponic fertilizer than in fertilizers for use in soil or potted greenhouse crops. Also, most hydroponic fertilizers contain all micronutrients, which is less common in fertilizers for soil growing. To prevent clogging in pumps and irrigation systems, it is also important to use greenhouse grade fertilizers because they are completely soluble and do not contain filler materials common in fertilizers designed for soil.

Hydroponic fertilizers are generally in either a dry/granular or liquid form. Dry fertilizers are often the most cost effective. They can be purchased as a premixed product or as individual fertilizers that are combined in specific ratios based on source water. Liquid fertilizers are often premixed and not specific for source water. They are simple to use in small hydroponic systems, but they are difficult to adjust to specific source water conditions. If you have poor water quality, such as high pH or carbonates, a custom mix is an option, but often such mixes are not required on a small scale. While mixing your own fertilizer can be cost effective, most small-scale producers use premixed products for convenience.

Managing Nutrient Solutions

Fertilizer use in soilless systems

Dry or granular fertilizers can be used in one of two ways in soilless systems. They can be added in known quantities directly to a known volume of water to create a nutrient solution provided to and used directly by plants. This process would be similar to mixing a soluble fertilizer like Miracle-Gro (which is NOT recommended alone for hydroponic systems) with water. We often refer to this as a feed strength solution.

Fertilizers can also be used to mix concentrated solutions. Using dry or granular fertilizers to create liquid fertilizer concentrates is essentially creating a mixture similar to the liquid fertilizers discussed below. Mixing concentrates that can be used over and over can be a time- and cost-efficient method that can also be more accurate than using dry fertilizers directly (liquid volumes can be measured more quickly and accurately than weights). Many fertilizers will have instructions for either method.

Premixed, liquid fertilizers are very common in the hydroponics marketplace. They contain dissolved minerals and are added to source water in precise amounts. Instructions can be given in volume of fertilizer liquid added per volume of source water, such as ounces per gallon. Liquid fertilizers can also be mixed based on dilution ratios. An example would be a 1:100 dilution ratio of concentrate to water. This would mean that 1 gallon of fertilizer concentrate added to 99 gallons of source water would create 100 gallons of nutrient solution.

Managing electrical conductivity (EC) in soilless leafy crop nutrient solutions

Small-scale hydroponic growers often mix nutrient solutions based on fertilizer label directions without being able to test the concentration of the final solution. This practice can work, but keep in mind that fertilizer instructions are based on average crops and source water. If the water has many dissolved minerals already present, mixes can be far from ideal.

So, it can be quite useful to be able to test the concentration of all minerals and nutrients in solution. There are two common methods. First, samples can be tested in a lab to determine the levels of each nutrient in solution. It can be a good practice to periodically send a solution sample to a lab, but the time and expense often prevents this from being done frequently. The second common method to describe the total amount of dissolved ions in solutions (from fertilizers and source water) is to measure electrical conductivity (EC). Measuring EC provides a good sense of the overall fertilizer strength and can provide a simple way to make sure nutrient solutions are mixed correctly.

Figure 4. *These are small handheld pH and electrical conductivity, or EC, meters that can be a useful addition to a residential or educational hydroponics growing system.*

Handheld devices can be purchased to measure EC in solutions (Figure 4). Often these units are combined with pH probes (discussed below) to provide multiple-use handheld tools. With proper testing and confirmation, fertilizers can be mixed to target ECs that provide specific nutrients based on the ratio of nutrients in the fertilizer. So, while EC does not tell us exactly the level of an individual nutrient at a given moment, it can be used to prevent serious errors in mixing and guide management of solution strength during growth.

For example, most leafy crops are produced with EC levels in the nutrient solution of 1.5 to 2.0 milli-Siemens per centimeter. During plant growth, nutrients are taken up by the plant and EC levels may drop. This would signal that more fertilizer should be added to replace the nutrients taken up by the plant. These fertilizer materials would be added to the reservoir until the EC again reached the target level. If warm conditions caused the plant to use large amounts of water in transpiration, the EC might rise in the reservoir. The grower could add source water to lower the EC back down to the target level. These examples illustrate how EC can be used to manage crop growth.

Electrical conductivity is a measure of the concentration of all dissolved nutrients in a solution. It is also possible over time for the EC value to remain on target while the specific levels of key nutrients (most often nitrogen and potassium) may be insufficient. In the absence of equipment to measure specific nutrients, the most common approach is a change of the majority of the nutrient solution volume in the reservoir tank (often referred to as a tank change). The combination of fresh source water and nutrients will restore the optimum balance of nutrients and promote crop growth and productivity. The time between nutrient tank changes varies by crop, season and size of container. It is common to change the solution at one- to two-week intervals for many actively growing crops in the main part of the season.

Assessing pH in soilless systems

The pH is a measurement that determines the acidity or alkalinity of a solution. Maintaining appropriate pH levels enables nutrients to be used most efficiently by plants. Measurement and management of pH is an area that is critical to successful soilless production.

Two common methods are suggested to monitor pH:

- Handheld pH meter. These small electronic meters contain electrodes that can assess the pH of a solution quickly and efficiently (FIgure 4). However, they can be a bit costly ($80 and up) and are only accurate as long as they are properly calibrated.
- Colorimetric (color changing) indicator solutions. Dyes can be purchased that turn specific colors at given pH levels (Figure 5). Adding a few drops of these indicator solutions to a sample of nutrient solution and correlating the color to a pH chart can be a simple and inexpensive system of assessing pH (if you are not red-green color blind). Litmus paper is another colorimetric option that can be useful for beginners to cost effectively assess pH. It may not be as precise, but can be useful for small hobby systems where tools are limited.

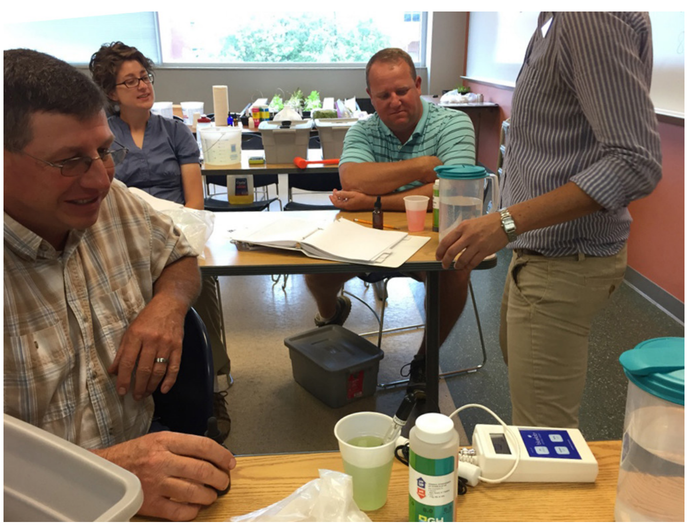

Figure 5. *Colorimetric dyes can be a tool for monitoring pH as well as teaching chemistry as these teachers are discussing.*

Managing pH in soilless leafy crop nutrient solutions

Nutrient solution pH is kept in a range (often 5.5 to 6.0 pH) that will maintain nutrients in the most available forms for plant uptake. Additionally, appropriate pH levels will keep nutrients from precipitating and clogging lines or building up on pumps. Depending on the source water, acidic or basic materials may need to be added to reach the appropriate pH. Dilute acid or base solutions can be used to raise and lower pH.

When mixing nutrient solutions, initial adjustment of pH is usually not sufficient to maintain optimum pH over the entire growth of the plant. Therefore, regular attention is needed to maintain pH levels because nutrient uptake by the plant and interaction of the solution with air can all rapidly change pH. The ability to resist changes in pH is known as the buffer capacity, and source water differs in its buffer capacity due to dissolved elements. Some source water may react quickly to acid or bases that change pH while others may react slowly. So, when adjusting pH, it is important to add acidic or basic materials slowly to prevent overshooting the target. With time and practice, adjustments of pH in hydroponic systems will become easier to approximate.

Growing Transplants

Substrates

Most leafy crops are started in cubes or plugs and grown for 10 to 20 days before being placed in the growing system. This is the most space-efficient method since early stages of growth take up valuable space in the main system. Additionally, smaller transplant areas can be managed better to support germination than larger growing systems. Substrates (simply the material where plant roots live) for soilless systems are manufactured to be consistent and easy to use. For instance, each cube will have a dibble (indentation in the surface of the cube) to securely hold the seed during germination (Figure 6). This indentation also provides high moisture and humidity immediately around the seed and reduces the chance of the seed drying out. Most seeds are not covered as is common in soil or greenhouse mixes.

Figure 6. *Foam cubes with indent for lettuce seed. These are Oasis foam cubes that have 276 cubes per 10-by-20-inch sheet. Bumgarner image, use courtesy of CropKing Inc.*

Substrates provide roots access to moisture, nutrients and air in proper amounts. Some are made from organic materials, such as peat and coconut husks (coir). Some of these materials have a polymer binder in them to enable the cube to retain its shape. Others may have a thin mesh or fabric shell to prevent loose particles in both recirculating and floating systems.

Other substrates are made from synthetic polymers or inorganic materials. The most common inorganic materials are rockwool (made from super-heated basalt rock) and foam cubes (Figure 6). Both of these materials can be engineered to provide air pore sizes that are ideal. These materials also come in a range of sizes to fit different types of growing systems. Larger cubes are typically more expensive, but they can be used to grow a larger transplant and may provide more buffer against fluctuating solution conditions.

Seeds and seeding

Seeds can be purchased as raw or pelleted. Pelleted seeds are more expensive, but can be easier to handle and seed by hand (Figure 6). They can be an asset to small-scale producers because most seeding is done by hand. Try to avoid the risk of reduced germination by using what you purchase within 6-12 months.

Most often cubes or plugs are placed in solid seeding trays for germination allowing water solution to be delivered from the bottom. It is best to seed into evenly moist cubes or plugs. For the first few days after seeding, you can use pH-balanced clear water or dilute nutrient solution.

Over seeding by 10 to 15 percent will compensate for uneven or failed germination. This strategy also ensures transplanting of only the most uniform seedlings. Place individual seeds in the cube for head lettuce or multiple seeds for mixed lettuces. If baby lettuce with many (greater than three to four) plants per cube is desired, raw seed may have to be used because multiple pelleted seeds quickly fill up the dibble in the cubes.

Figure 7. *Young lettuce seedlings with leaf and root growth appropriate for transplanting. Bumgarner image, use courtesy of CropKing Inc.*

Germination conditions

After placing seeds in the cubes, ensure that the cubes are evenly moist but not saturated. Transplants can be started in seedling trays (with solid bottoms) not connected to the growing system. Usually ¼ inch of water in the tray is sufficient. Using clear water for the first few days after seeding can be fine, but using nutrient solution is important as soon as germination occurs. This water or solution will need to be frequently checked for pH levels as those can change quickly and lead to poor growth in seedlings. Germination and seedling production can also be carried out in a nursery area connected to the growing system. This method can reduce the need to manage the solution in a separate tray, but it is important that proper temperatures can be maintained. For lettuce and many leafy crops, ideal germination conditions are around 70-75 F. Follow recommendations for the crop and cultivar you are using. Heat mats can be used to increase temperatures if needed. Also keep in mind that high temperatures can reduce germination. Cool-season crops (lettuce, spinach, mustard, kale) can have reduced germination above 85 F. Do not allow trays or pads to receive direct sunlight in excessively warm seasons to help prevent rapid temperature gains that can damage seeds or seedlings. It may be best to germinate seeds indoors or in a shaded area during warm periods, but remove them from shaded areas as soon as germination begins.

Germination will generally begin within 24 to 48 hours. Raw seeds may germinate slightly faster than pelleted seeds, which need to take up water to crack or dissolve the coating. When seed leaves (cotyledons) appear, a dilute nutrient solution should be added. Often seedlings are started on a half-strength solution (0.5-1.0 mS/cm) for the first few days, and gradually the strength of the nutrient solution is increased to match the main system by the time transplanting occurs.

Transplanting and Growing Out

Transplanting

The time between seeding and transplanting varies by crop, environment and cube size. Often transplanting occurs 12 to 18 days after seeding. Seedlings are considered mature enough for transplant into a hydroponic system after development of both three to five true leaves (not counting the cotyledons) and roots visible on the bottom of the cube (Figure 7). Whether in a recirculating or floating system, these roots can be an asset to the young plant in transitioning after being transplanted. It is best not to wait until crowding occurs because seedlings will start stretching and these elongated stems are easier to break during transplanting.

Transplanting involves separating each individual cube and then placing in the production system. In general, using larger growing cubes will enable the plant to be older at transplanting. Use care to not damage the young stem or roots, but ensure that the cube itself will be in contact with the nutrient solution.

Environmental conditions for leafy crop growth

Figure 8. *Tipburn and early signs of flowering as a lettuce plant begins bolting. Bumgarner image, use courtesy of CropKing Inc.*

Lettuce and other cool-season leafy crops prefer daytime temperatures between 65 F and 75 F. They will still grow at lower temperatures, but more slowly. Conversely, growth will also be reduced when temperatures reach the mid-80s. High temperatures also create the potential for quality issues, such as tipburn (a physiological disorder related to poor calcium uptake in rapidly expanding leaves) or bolting (stem elongation and the beginning of seed production; Figure 8).

Optimum light conditions for lettuce and many cool-season leafy greens occur in spring and fall in many parts of the United States. Winter light levels in the Mid-South, and even in Florida in some years, are often not sufficient for optimum growth and quality, whereas summer light and heat may be too high throughout the Southeast. Shading can be beneficial during summer (and sometimes late spring and early fall). Supplemental lighting may be an asset in winter, but it can be costly. Keep in mind that additional steps taken to control the nutrient solution or environmental conditions (such as lighting) can often increase growth and productivity as well as quality.

Harvest and Storage

Harvest procedures

Harvest timing depends on growing conditions, personal preferences and the crop. Bibb lettuce is usually mature enough to be harvested when it reaches a weight of 5 to 8 ounces, but this is a general guideline. Oakleaf lettuce is often similar in growth rate and timing (Figure 9).

Romaine may be a little slower, and mixed leaf crops are generally harvested at a younger stage. Growth rates of kale, mustard and the other greens vary depending on cultivar and preferences. Kale, basil, Swiss chard and some other leafy greens may be harvested multiple times by harvesting leaves instead of the whole plant as is done with lettuce.

Whole plant or leaf harvests should be carried out during cooler times of day to reduce stress and water loss on plants after harvest. Early morning is often best because the plants will still be turgid (have a high water content in cells) from the preceding night. Plants are pulled from the channels, boards or other growing systems. Plants can be cut at the base and the entire cube and roots removed or the cube can be left attached. Roots may be trimmed at the bottom of the cube or wrapped around the cube. Any yellow, damaged or diseased leaves should be removed to increase storage life.

Storage and quality

The storage longevity and quality of crops grown in a soilless system varies based on the health and quality of the crop at harvest as well as handling and storage conditions. If healthy plants are harvested in good condition, cooled quickly, and stored promptly, they can be maintained in good quality for several days — and even up to weeks for some crops. Plastic containers called “crispers” or “clam shells” are a good way to protect and store lettuce, but they can be expensive in small quantities. Plastic bags can also work well, but injury is more frequent in bags when stacked. Bags may also allow crops to dry out more quickly or trap water in contact with the stems and leaves. Optimum lettuce storage temperatures range from 35 F to 38 F with a high humidity (above 85 percent) to prevent water loss. Many other leafy crops will have similar optimum storage temperatures. However, the exception is basil, which is sensitive to chilling and will deteriorate quickly unless stored above 50 F.

Figure 9*. Mature heads of oakleaf lettuce ready to be removed from growing system at harvest. Bumgarner image, use courtesy of CropKing Inc.*

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