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Hydroponic Production of Edible Crops: System and Crop Comparisons

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Introduction

Choosing the type of crop grown hydroponically and understanding the performance of various crop types in different hydroponic systems is important to crop and system selection. Plant performance can vary depending on the type of hydroponic system used. For example, it can be challenging to grow a tomato crop in a nutrient film technique (NFT) system because the plant root structure and the requirements to support a larger fruiting or vining crop (Bumgarner and Hochmuth 2019).

Figure 1. Tomato crop being grown in a bag system (left), and a lettuce plant with the root system exposed in a NFT system (right). (Chris Mullins, Virginia Cooperative Extension)

Many decisions need to be made to determine the best system to use in crop production. It is based on crop type, and facility space requirements or limitations. Some questions to consider are: What will the size of the crop be at full yield and how much space is needed around the plant for airflow requirements? Will the crop require vertical space? (Kear et. al 2005). These and other questions can help you define your system type. For example, float beds can easily support high density crops because variation in spacing is easy to configure, and while NFT systems are very good for supporting leafy greens (Bumgarner and Hochmuth 2019), these systems may have more limited crop arrangements. These considerations are important because growers need to efficiently produce the highest yield and quality of produce. Successfully growing under these circumstances can increase profitability.

In this factsheet, we will discuss the benefits of exploring growing techniques, choosing the right system for crop type, and share results from our research trials at Virginia Tech (VT) and Virginia State University (VSU) exploring crop performance in different hydroponic systems. We will also offer tips and resources that may help you in your journey in hydroponic production. While this factsheet should prove to be thought provoking, it is not intended to provide exact parameters for growing a specific crop using a particular production system. Instead, we encourage you to explore additional resources as outlined in Vallotton et al. (2023). As you read this factsheet, please refer to Table 6 for a glossary of terms used throughout this factsheet.

Exploring Your Space

Many growers explore production challenges with a ‘discovery space’. Whether that is somewhere in the home, greenhouse, or facility, this is a small, pilot size setup where you can explore and practice different growing techniques. In this space, you can experiment with different crop varieties and learn about different hydroponic systems, nutrients, grow media, or other ideas you may have so you can begin to understand some of the challenges before you scale up into a larger production setup (Figure 2).

Figure 2. Examples of ‘discovery spaces’ growing different varieties of crops using different setups. (Amber Vallotton, Virginia Cooperative Extension)

For example, if you decide to adapt your business model to an emerging market, you may need to consider growing a different crop in a new type of system. Depending on the system type you have, you can explore this by adjusting nutrient schedule, media type, or type of system. Doing these trials in a smaller setup can help you avoid assuming too much risk before you invest in your process. It can also improve your understanding of your farming practices and may even reveal a competitive edge. Of course, in order to do this, you may have to make some investment in this testing, which may or may not result in any profit from selling produce but in the long run is critical data for your decision-making. Of course, in addition to your own ‘discovery space’, it is vital to understand the dynamics of full-scale production and to do some concerted exploration as described in *Hydroponic Production of Edible Crops: Planning for the Market* (Vallotton et al. 2023).

Crop Trials

In the following sections, an overview and summary of results from small scale crop trials conducted at Virginia Tech and Virginia State University will be shared. The project, “Assessing and Addressing Educational Needs of Exploratory/Beginning Growers of Hydroponic Produce for Local Markets,” was targeted to the needs and questions of new or beginning hydroponic farmers in the state of Virginia. We compared spinach and parsley in nutrient film technique (NFT), vertical media stack (stack), flood and drain (F&D), and floating raft deep water culture (DWC) systems, as well as tomatoes and peppers grown in Dutch buckets, NFT, and media bags. Please note these trials were conducted during the COVID-19 pandemic and data collection was limited due to restrictions caused by differing university policies.

Spinach and Parsley Trials

At Virginia Tech, four hydroponic systems were used during these trials to compare yield amounts and performance of different cultivars of spinach and parsley. We conducted four separate trials. The plants were sown in rockwool starter plugs in trays in a controlled lab with artificial lighting in a warm environment (+68°F) (Figure 3).

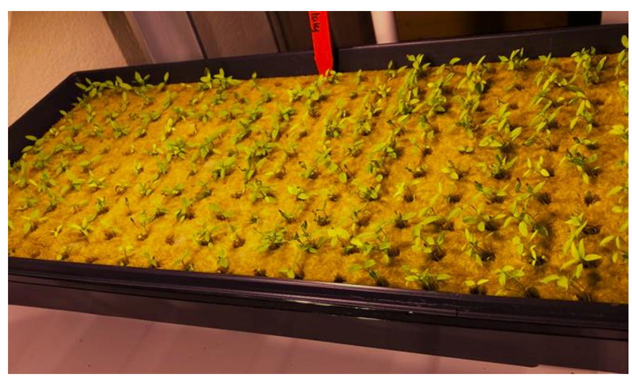

Figure 3. Spinach sprouting in a rockwool starter tray under artificial lighting. (Toni Sperry, Virginia Tech)

Once radicle emergence occurred, the trays of plants were then moved to a glass greenhouse with evaporative cooling pads and fan cooling as well as concrete floors (Latimer and Vallotton 2020). After the plants produced true leaves, they were grown in NFT, vertical media stack, flood and drain, and floating raft DWC systems (Figure 4). Please refer to our other factsheets in this series for a thorough description of system types (Mullins et al. 2023a-c).

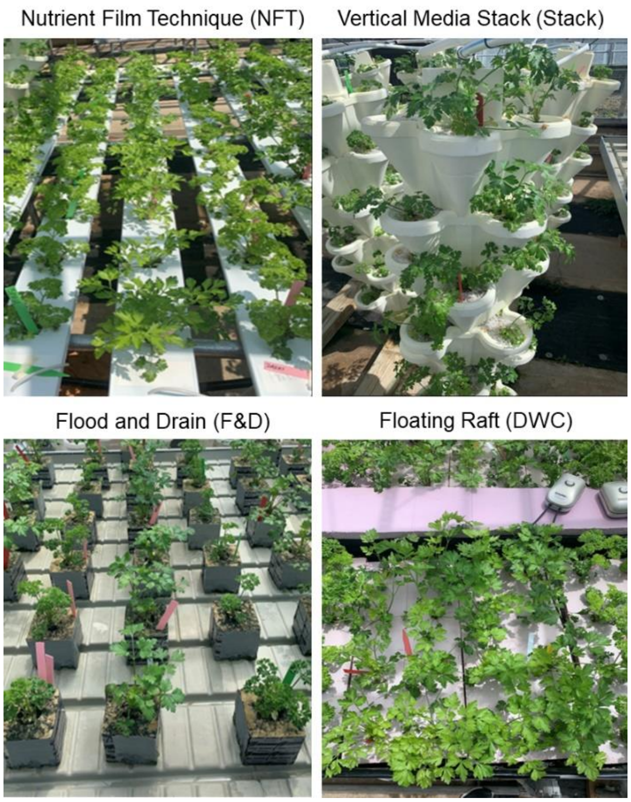

Figure 4. The four types of hydroponic systems used for growing the parsley (shown) and spinach crops. (Toni Sperry, Virginia Tech)

When the plants reached full maturity, they were harvested and fresh weight was measured. Some trials needed supplemental lighting during winter months, and photosynthetic active radiation (PAR) was recorded to calculate daily light integrals (DLI). This same method was used in a spacing trial for spinach in a float bed DWC system.

Tomato and Pepper Trials

Virginia State University evaluated three different systems for growing fruiting crops ('Eros' peppers and 'Conchita' tomatoes): Dutch bucket, NFT, and media bag systems. The peppers and tomatoes were germinated in net pots, then approximately 10 days after true leaf development, were placed in either: (a) perlite-filled Dutch bucket system with leachate collection; (b) NFT with 9-inch channels; or (c) 5-gallon plastic media bags with peat-based substrate placed in 9-inch channels (Figure 5). Irrigation was provided as continuous flow from separate 40-gallon reservoirs with submersible pumps for every system. As plants produced mature fruit, the fruit was harvested and weighed. However, a limited amount of fruit was harvested as a result of needing to terminate the crops in response to the COVID shut-down. Typically, tomatoes and peppers have a continual harvest, except for disease, insect pressures, or temperature extremes.

Figure 5. Pepper (top) and tomato (bottom) plants being grown in (a) Dutch bucket, (b) NFT, and (c) media bag systems. (Chris Mullins, Virginia Cooperative Extension)

The Full Crop Production Cycle

Starting The Crop

There are a variety of methods to germinate and sprout crops for hydroponic production. Rates of germination vary depending on crop type, choice of media, system type, and the available facility space. Sprouting plants in a media substrate, like rockwool, can be challenging. Rockwool is an inert material, so the pH will not change and nutrient buildup should not occur, but it is absorbent. Therefore, keeping the right amount of saturation and drainage during early sprouting is important while root systems are young and developing. One method is to use double trays supporting the rockwool sheets as a wicking system. The nutrient solution or water can be poured into the bottom tray and the tray with slots or holes in them can be placed on top, allowing the water to wick up to the roots and saturate the rockwool. This is also similar to how the plants will receive nutrients and water after they are moved into the systems. After a few minutes of wicking, the bottom tray can be drained. This same method can be used with netted cups placed in a nutrient solution.

In the trials for parsley and spinach, we used sheets of rockwool that were soaked with water or nutrient solution, and then placed the sheets into a double tray (i.e., one that drained into the other to prevent oversaturation and permitted the ability of the sheets to wick up from the bottom). Even though the sprouting media was the same for both crops, the crops themselves required different germination methods. Spinach had higher germination rates if there was a 48-hour blackout period and was covered with vermiculite, whereas parsley performed better when placed under light during the entire germination process. Artificial lighting was used to germinate these crops with a 10-hour on cycle. In the tomato and pepper trials, plants were started in 2-inch net pots using a sphagnum peat moss-based media typically used for germination under natural lighting.

All four crops had different germination timelines regardless of whether artificial lighting was used (Figure 6). Tomatoes and peppers had similar germination timelines, but spinach and parsley do not.

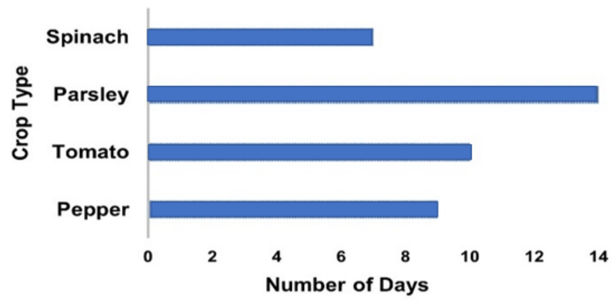

Figure 6. Chart displaying germination time (days) of the four different crops.

Transferring Plants into Systems

Crop plants, germinated in artificial lighting or a separate space, can be moved to the greenhouse after germination begins or before true leaves emerge. If plants are moved from an artificial light setting to a greenhouse setting, it is a good idea to acclimate plants before moving them into the systems. With the emergence of true leaves and good root development, crops can then be transferred into the various hydroponic systems (Figure 7).

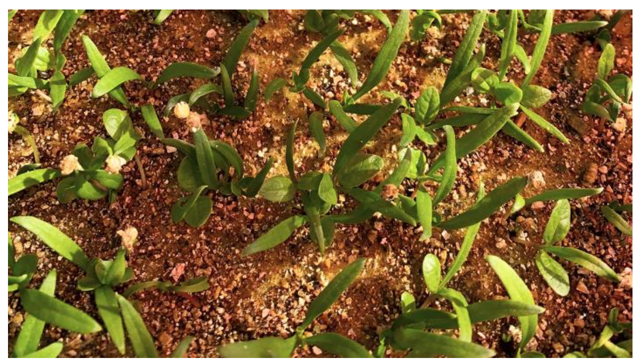

Figure 7. Emergence of true leaves of the spinach crop while in starter trays. (Toni Sperry, Virginia Tech)

Depending on how plants are sown will determine how the plants are transferred to the systems. Rockwool starter plugs need to be separated and placed into the systems. If plants are moved into media systems, each plant may need to be started individually in net cups. The crop should be transplanted into systems that can support the size of the crop and the root system.

Harvesting

Common production practices, such as trellising, pruning, clipping, and leaf pruning, were employed on all systems and plant types.

Spinach leaves were grown until they were the size of a typical wholesale packaged products, and cut at the base above the rockwool and fresh weight was measured. Parsley was harvested by cutting the older leaves weekly over a course of six weeks. Fruit from all systems growing tomatoes and peppers were harvested at a mature stage and weighed.

The days to germination, true leaves, and harvest varies by crop type (Table 1), and is important to consider for planning crop rotations and bench time.

Table 1. Time (days) to yield by crop type.

Crop Type	Germination	True Leaves	Harvest
Spinach	7 d	21 d	42 d
Parsley	14 d	28 d	49-84 d
Tomato	10 d	14 d	77 d
Pepper	9 d	15 d	80 d

Note: Timeline can be dependent on environmental factors and type of crop.

System Requirements

Setup

A layout should be created to plan where and how the systems will be configured. During this time, you should coordinate where your water supply will be to replenish the systems, how the systems and production areas will be cleaned, where you will store chemicals, and where and how the produce will be transported to packing and cooling/storage areas. Also, consider where the systems can safely be drained if needed for cleaning or in between crop rotations.

Irrigation

Irrigation techniques are different for each hydroponic setup. For the parsley and spinach trials, the NFT, vertical media stack, flood and drain, and floating raft DWC, each stored a different amount of water, while also distributed water to the systems at different times. The NFT system provided continuous water flow using small tubing that fed from a single ½ inch tube into the channels (Figure 8).

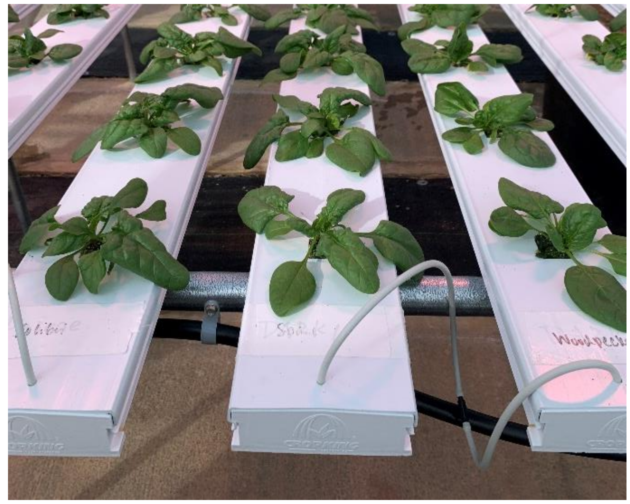

Figure 8. Irrigation tubing connecting into NFT channels from a single line of tubing carrying nutrient solution. (Gordon Brockington Gibson, Virginia Tech)

The vertical media stack systems had tubing that ran along the top of a row of stacks, in which the nutrient solution was distributed to the systems three times per day — for six minutes at a time — through small drip irrigation lines (Figure 9).

Figure 9. A single tube running across the top of the media stack system distributes nutrient solutions through drip irrigation lines. (Gordon Brockington Gibson, Virginia Tech)

Flood and drain systems are a type of system that will flood a table with nutrient solution that the media will soak up. After a certain amount of time, the nutrient solution will drain away. The flood and drain tables were initially programmed to flood the beds twelve minutes once per day. The nutrient solution was absorbed by rockwool cubes and the roots of the plants grew into them. The challenge with this system, is that the rockwool can be under-or over-saturated. Throughout the trials, the amount of time was adjusted based on the amount of saturation required (Figure 10).

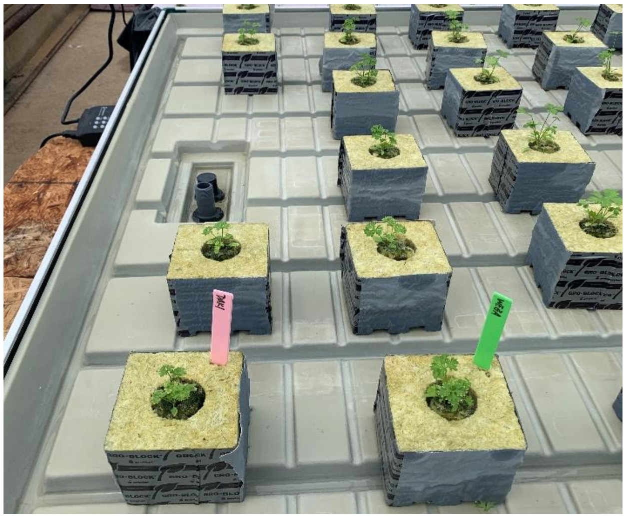

Figure 10. A flood and drain table with parsley growing in rockwool cubes. (Cory Reyes, Virginia Tech)

The float beds are a type of DWC system, in which the plant roots grow down into the nutrient solution. Holes were cut into foam boards to support 1-inch rockwool plugs. Once, the plants were inserted, the foam boards floated on top of the water like a raft. A recirculating pump was used to distribute nutrients and oxygen around the tanks, but the water was otherwise not displaced (Figure 11).

Figure 11. A foam raft with holes cut in it to allow root system to grow into nutrient solution. (Toni Sperry, Virginia Tech)

In the pepper and tomato trials, pressure compensating emitters and drip stakes were used. There were two drip stakes per Dutch bucket emitting nutrient solution at 0.5 gallons per hour (gph). In contrast, the NFT and media bag system had a water/ nutrient flow rate of 0.25 gallons per minute (gpm) and was distributed through ½ inch plastic tubing. The NFT system was used for comparison purposes only and not typically recommended for these types of crops (Figure 12).

Figure 12. Young plants in Dutch buckets (top left), NFT (top right), and media bags (bottom). (Chris Mullins, Virginia Cooperative Extension)

System Control Parameters

Nutrients

Growing crops in hydroponics and a greenhouse is considered a type of Controlled Environment

Agriculture (CEA) production. Therefore, in order to provide plants with nutrients, nutrient blends are added to the water supply creating a nutrient solution to support plant growth. Because there is no soil to buffer the root uptake of nutrients, they must be carefully blended and measured before administering to the system. One way to measure nutrient availability in the water is called electrical conductivity (EC). Optimal EC is crop specific and is important to maintain during crop production. It works synergistically with pH, therefore both EC and pH need to be constantly measured and adjusted.

Throughout all of our trials, EC was increased in gradual amounts until the plant reached a certain growth stage. Also, the nutrient blends for the crop types were different between the vegetative (parsley and spinach) and fruiting (tomatoes and peppers) crops.

Oasis Hydroponic Fertilizer 16-4-17 NPK (nitrogen, phosphorus, and potassium) was used as a nutrient blend for parsley and spinach. Nutrient can be added during germination between 0.8 and 1.0 mS/cm. Nutrients were increased in the parsley and spinach starter trays until they reached about 1.4 mS/cm before being moved into the systems, and then continued to increase between 1.6 and 1.8 mS/cm depending on system type. The nutrients and pH were checked two to three times per week, and added to the different water tanks that either distributed water through the systems (NFT, vertical media stack, and flood and drain), or held water (floating raft DWC).

A nutrient blend comprising of 5-11-26 (potassium nitrate, calcium nitrate, and magnesium sulfate) was applied to peppers and tomatoes based on conventional tank mixing methods. A quarter (25%) of the full-strength nutrient solution was applied during germination without potassium nitrate. An EC of 1.3 mS/cm of the nutrient solution was applied to seedlings and then increased to between 2.0 and 2.5 mS/cm and a pH of 6.5 for mature plants. Stock solution was used to adjust reservoir when needed. EC and pH from input and reservoir were monitored twice each week.

Dissolved Oxygen

Dissolved oxygen (DO) should be maintained between 7 to 10 ppm in order to have optimal plant yields and reduce disease, and is especially important for DWC style systems where roots receive oxygen from the water supply. This can be achieved by directly adding pure oxygen into the water supply and recirculating it using a sump pump. A minimum DO of 4 ppm is required (Brechner and deVillers 2013). In our trials, air stones were used to provide oxygen to the roots of the plants in the float bed system, and an average of 5.23 ppm of DO was maintained (Figure 13).

Figure 13. Water nutrient solution from a DWC system being measured using a dissolved oxygen meter (Hanna Instruments, Inc.). (Toni Sperry, Virginia Tech)

Lighting

In a greenhouse setting, supplemental lighting can be used to improve plant yields. There are various methods and lighting types that can be applied for photosynthetic response. Lights can be utilized on cloudy or seasonally shorter days. If growing entirely indoors, artificial lighting will be required for crop production (Latimer et al. 2023, p3).

When the daily light integral (DLI) was at least 17 mol/day, it ideal conditions were present for higher crop yields in leafy green and herb production (Mattson 2016). A WatchDog data logger was used to continuously monitor photosynthetically active radiation (PAR) at 30-minute intervals (Figure 14).

Figure 14. Using a WatchDog (Spectrum Technologies, Inc.) data logger to measure PAR. (Toni Sperry, Virginia Tech)

Temperature and Humidity

Air and water temperature should be measured to monitor and maintain ideal conditions. It is important to consider seasons as well as temperature controls depending on your crop selection. Humidity impacts transpiration, plant disease, and water and nutrient uptake (Latimer et. al 2011). It is important to maintain ideal conditions for plant health during the crop growing cycle (Latimer et al. 2023; see Table 2).

Table 2. Parameters used to maintain spinach and parsley trials.

Variable	Measurement
Nutrients	Oasis Hydroponic Fertilizer: 16N-4P-17K
EC	1.6 – 1.8 mS/cm (Mature Plants)
Air Temp.	67° – 72°F
Rel. Humidity	36.9% – 72.7%
Water Temp.	66 – 79°F
pH	6.0 ± 0.2
DO	5.23 ppm (Average)

Maintenance and Cleaning the System

Occasionally, maintenance was needed to make sure the systems were working properly. Some of the methods used during the trials included patching leaks with silicone, replacing tubing, and cleaning and replacing filters. Vinyl pond liners were used in the DWC systems and were either cleaned or replaced in between crop rotations. Before each crop round, the systems were cleaned with gentle dish soap and scrubbed to remove any debris. The systems were then thoroughly rinsed and sanitized with a 3% hydrogen peroxide solution. A ZeroTol 2.0 cleaning mixture was then flushed through each system 24 to 48 hours before production. A weaker ZeroTol 2.0 dilution was also used for disease prevention and control during the crop cycles.

Data Analysis

In the spinach and parsley trials, results were measured with statistical software to determine differences between types of crops and hydroponic system production. Although we were not able to perform the same statistical analysis for tomatoes and peppers due to limitations of trials during COVID-19, crop yield for the two crop types were compared within the three different systems.

Crop Type and System Comparisons

Spinach and Parsley Trials

NFT and floating raft DWC produced the highest crop yields in both spinach and parsley trials (Table 3). Also, average crop yields increased as DLI increased which may suggest that supplemental lighting can improve yields, especially during winter months or cloudy days.

In the Spinach trials, fresh weight per plant was highest for the NFT system when compared to the plants that grew into media (flood and drain, and vertical media stack). However, the floating raft DWC and the flood and drain, in both trials, had significantly higher yield than the vertical media stack system indicating poor performance of spinach in a drip style media system. In the second spinach trial (2021), the fresh weight per plant was not significantly less for floating raft DWC than NFT like it was in first trial (2020). It is likely that decreasing the temperature of the greenhouse, taking more preventative measures to reduce the impact of *Pythium*, and adding supplemental lighting resulted in higher yield weight in the floating raft DWC system.

In contrast, parsley produced the highest yield in a floating raft DWC system compared to media systems, like, flood and drain or stack systems where the root of the plant grew into a media and received intermittent nutrient solution rather than constant contact or root saturation. This would also explain why in the second trial, a significantly higher yield was seen in the nutrient film technique system than the stack system.

Table 3. Summary of crop yield average by system type for spinach and parsley.

System Type	Crop Type			
	Spinach		Parsley	
	No Lights[1]	Lights[2]	No Lights[3]	Lights[4]
NFT	9.61 oz	11.55 oz	3.57 oz	3.78 oz
Stack	2.56 oz	3.37 oz	2.05 oz	1.51 oz
F&D	4.99 oz	7.85 oz	1.29 oz	3.17 oz
DWC	6.10 oz	8.74 oz	3.02 oz	4.63 oz
Average	5.82 oz	7.88 oz	2.48 oz	3.27 oz
DLI	9.51 mol/day	16.6 mol/day	7.47 mol/day	23.6 mol/day

Note. Each column of data presents a different trial. The table is a summary of crop yield for those trials and not meant to be used for pairwise comparisons, since each trial was conducted at different periods of time.

[1]Trial harvested December 2020.

[2]Trial harvested March 2021.

[3]Trial harvested between November and December 2021.

[4]Trial harvested between June and July 2021.

Tomato and Pepper Trials

Both tomato and pepper plants had higher yields when grown in substrate-filled bags and buckets rather than NFT systems (Table 4). Fruit quality did not differ between systems or within crop types, but differences in yield weight were observed.

Table 4. Greenhouse crop yield average by system type for peppers and tomatoes.

System Type	Crop Type	
	Tomatoes	Peppers
Dutch Bucket	7.8 lbs	5.9 lbs
NFT	4.4 lbs	2.4 lbs
Media Bags	8.3 lbs	6.7 lbs

Overall Results

Spinach and parsley produced the highest yield in NFT and floating raft DWC systems, while tomatoes and peppers produced the highest yield in media bag systems (Table 5).

Table 5. Relative crop yield comparisons between system types.

Crop Type	System Type			
	NFT	Media Stack	DWC	Media Bag
Spinach	Highest	Lowest	-	-
Parsley	Highest[1]	Lowest	Highest[2]	-
Tomato	Lowest	-	-	Highest
Pepper	Lowest	-	-	Highest

[1]Trial with harvest during winter 2021.

[2]Trial with harvest during summer 2021.

A reasonable explanation as to why different crops performed differently in the system types can be directly related to the nutrient solution saturation and aeration techniques used in the different systems. Media systems — where the root of the plant grows into a media and receives intermittent nutrient solution, rather than constant contact or root saturation like in a NFT or DWC system — provide more drainage. Another explanation is how the system supports the plant roots, size, and weight. A fruiting crop typically will need more space for the root system, along with other supports for the vegetative and fruiting stages of the plants.

Take-Aways

Although spinach had the highest yield grown with NFT and DWC systems, we also had issues with *Pythium*. This pathogen is very prevalent with spinach and causes stem and root rot disease in greenhouse crops (Latimer et al. 2011), and needs to be controlled and mitigated in recirculating systems. Some disease can be managed by increasing the amount of oxygen there is in the water supply, especially when using DWC or float bed systems.

In the vertical media stack system, we saw nutrient deficiencies from top to bottom because the drip irrigation system flowed through media. The plants at the top of the vertical media stack system tended to be more vibrant than those at the bottom (Figure 15).

Figure 15. Vibrance gradient impacts to spinach (left) and parsley (right) plants, from the top to the bottom, in vertical stack media systems. (Toni Sperry, Virginia Tech)

Another issue with the vertical media stack systems was that not all sides received the same amount of lighting throughout the day, impacting plant growth. We had to turn the systems daily to ensure that all sides were getting equally distributed light, however the vertical systems cast shadows on others which impacted how the light was distributed among plants (Figure 16).

Figure 16. Varying light levels caused by vertical media system stacks casting shadows both within and between stacks. (Toni Sperry, Virginia Tech)

Crop type can also be impacted by the time of year the crop is grown and the type of system used to grow it. For example, spinach performs better in the cooler months. Growing the crop in the winter months helps to control *Pythium* growth in the water. Adding supplemental artificial lighting during the crop cycle can also improve crop yields when growing during winter months, when there is lower natural DLI. Parsley, on the other hand, does well during warmer months. Parsley can also be harvested several times on the same plant stalk, by removing older leaves weekly until yields begin to diminish.

Hydroponics is considered a type of controlled environment agriculture (CEA) growing technique, which can reduce the impacts of weather and help with water conservation or reduce nutrient runoff. Water irrigation and nutrient dosing to the plant roots can be directly controlled, but growing space and harvest techniques can be limited. In general, hydroponic crop production can have many benefits, but there are limitations. There are some field crops that would either result in poor performance, or be impossible to grow in current hydroponic technology. Not all hydroponic techniques are profitable for all crop types.

As you make decisions about your system and crop, it is important to understand the different farming techniques used growing different types of crops, and choose the best methods for your farm (see other factsheets in this series, *Hydroponic Production of Edible Crops*). Doing due diligence by thoroughly researching extension and industry resources can greatly assist with your own production setup and design (Vallotton et al. 2023).

Glossary of Terms

Table 6. Terms used in this factsheet.

Acronym	Definition	Description
CEA	controlled environment agriculture	Controlled agriculture that provides ideal growing environments for food production.
DLI	daily light integral	Amount of photosynthetic light

		received in one square meter during one day.[1]
DO	dissolved oxygen	Oxygen concentration in nutrient solution measured in parts per million.[2]
DWC	deep water culture	A type of hydroponic system where the roots of the plants grow into a pool of nutrient solution, usually aerated.
EC	electrical conductivity	An indirect measurement of the strength of a nutrient solution.[2]
F&D	flood and drain	A type of hydroponic system that uses a flood and drain technique to saturate a grow media housing plant root systems.
Float Raft		A type of DWC system that uses rafts that float on ponds of nutrient solution and house media to support seeds and plant growth.
gph	gallons per hour	Measurement of how many gallons a pump can move per hour.
gpm	gallons per minute	Measurement of how many gallons a pump can move per minute.
LED	light emitting diode	A type of artificial lighting source for indoor or supplemental plant production.
mS/cm	millisiemens per centimeter	Unit of conductivity measurements to express electrical conductivity (EC).
µmol/m²/s	micromoles per square meter per second	Unit of measure for the amount of photosyn-thetically active radiation (PAR) that plants are receiving at any one point in time.[3]
N-P-K	nitrogen-phosphorus-potassium	A nutrient blend mixture.
NFT	nutrient film technique	A hydroponic system where a film of nutrient solution runs along a channel across the roots of the plants.
PAR	photosynthe-tically active radiation	Wavelengths that correspond to the visible light spectrum (400 to 700 nm) used by plants for photosynthesis.[3]
ppm	parts per million	Unit of concentration for very small values, which describes the number of 'parts' of a given substance that are within the whole mixture (one million parts).
RH	relative humidity	The moisture content in the air expressed as percentage of the maximum amount of moisture possible at the same temperature.[4]
Stack	vertical stack media system	Styrofoam or plastic forms filled with inert substrate and vertically stacked.
USDA	United States Department of Agriculture	Agency that provides leadership on food, agriculture, natural resources, rural development, nutrition, and related issues.[5]

[1]Latimer et. al 2011.

[2]Brechner, M and D. de Villers 2013.

[3]Johnson, D. 2019.

[4]Cambridge Dictionary. 2023.

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