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Vegetable Transplants in Aquaponic Systems

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Transplants are all too often an afterthought for the beginning aquaponic grower, but the quality of a transplant can make the difference between success and failure. Having the capacity to produce transplants is useful for aquaponic growers, as it allows flexibility in timing, quantities, quality, and sizes transplants. It is difficult to secure a contract transplant producer to grow the quantities and the diversity of crops needed, especially for the hobby aquaponics grower. Store bought transplants from local garden centers are usually of acceptable quality but are not normally varieties suitable for growing in greenhouse conditions. Growing transplants allows aquaponic growers to experiment with different varieties and to be in control of availability.

For most crops, time and space are too valuable for direct seeding within an aquaponics system. Space requirement for vegetable transplants is a fraction of that required for the final growout of the crop. For example, 24 heads of lettuce can be grown in a square meter, where over 2,000 lettuce transplants can be grown in that same space. Also, a lettuce crop would take 30 to 40 percent more time to grow if a grower were to direct seed at the final crop spacing in an aquaponic system.

Another benefit of growing transplants is to reduce losses due to poor germination. For example, if a grower were to direct seed pepper plants into a system and 15 percent of seedlings were stunted, a reduction in yield would be felt over the entire life of that crop.

This fact sheet will provide a baseline of information on starting and producing vegetable transplants. In it, we will discuss propagation, containers, media, nutrition, and specific recommendations for various crops.

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Propagation

The first step in transplant production is propagation. For vegetables, this is almost always accomplished through seeds. The age of a seed and how it is stored are important for seed viability and vigor. The more nutrient reserves a seed has, the more robust it will be during germination and early development. Most seeds that have been purchased from a reputable source have been dried to an appropriate moisture level (usually 10 percent) and can be stored in the home refrigerator. If available, it is best to use seeds that are less than 6 months old and have been stored in a cool, dark, low moisture environment to protect from heat and humidity. Most commercially available seed companies will publish expected germination results and seed age on the package.

The majority of commercial crops are hybrids. Hybrids are produced when plant breeders control pollination between inbred lines. This process is done to select desirable traits such as pest resistance, temperature tolerances, and increased yield. If an aquaponics grower chooses to save and propagate seeds, it is important to understand open-pollinated seeds from hybrid plants may or may not possess the same attributes as the parent plant material. There is no way to predict qualities or crop performance from open-pollinated seeds. For indoor aquaponic systems, it is recommended to use hybrid seeds bred for greenhouse conditions. Greenhouse varieties are bred for lower light and resistance to diseases associated with greenhouse production.

To reduce loss to disease or insect damage, commercially available seeds may be treated with pesticides and are called "treated seeds." Treated seeds are usually designated as so in seed catalogs and packaging, and descriptions of chemicals used in their treatment are often included. Seeds may also be listed as pelletized. Small and difficult-to-handle seeds are often pelletized through a process that

Figure 1. Non-pelletized lettuce seeds (left) compared to pelletized seeds (right).

encapsulates seeds into a clay pellet, making the seeds larger and more uniform in size. Pelletized seeds are easier to sow by hand or with mechanical seeders (Fig. 1).

Commercially available germination media is available and should be used in propagation. This type of media consists of fine particles that enable its use in small plug trays (Fig. 2). Plug trays can be used to germinate seedlings. Seedlings or "plugs" will eventually be transplanted into larger cells. Commercial transplant producers use plug trays to maximize seedling production in a small area. Shifting plants up from small containers to larger containers can provide an extra step in controlling plant development. Most of the vegetables used in aquaponic systems can be sown directly into the container intended to grow out the transplant. In general, a small cell dimension of 1.0 inch square (2.54 cm^2) and 2.5 inch (6.4 cm) depth is acceptable for most leafy greens and 1.5 inch (3.8 cm^2) squared cell with 2.5 inch (6.4 cm) depth for fruiting vegetable crops.

In addition to seed quality, environmental factors such as moisture, temperature, gas exchange, and light can influence germination. Seeds are typically kept at a low moisture level until planting. Low moisture levels ensure that seed metabolism remains low and prevents cell division. Regulating the moisture level of the media is important to provide adequate moisture to hydrate the seed but also to regulate gas exchange. Saturating the media will prevent oxygen from entering and carbon dioxide from exiting the media. Most vegetable seeds do not respond well to waterlogged conditions. When a media or soil is kept constantly saturated, it reduces the availability of oxygen needed for respiration. Fine particles also contribute to high moisture content. A media that is too wet may cause poor air circulation around roots and fungal diseases. During germination, moisture levels can be maintained by saturating the media and allowing it to slightly dry before the next irrigation event. It may also be accomplished by maintaining a moisture level by a frequent light mist. Mist can be applied by automated misting sprinklers or by hand using a misting water breaker attached to a water hose.

Figure 2. Tomato seedlings grown in a plug tray.

Air and root-zone temperature requirements for proper germination vary greatly with species. Air temperature is commonly increased with forced-air heaters while heating mats or cables can be used to maintain or increase root-zone temperatures. Growers are often forced to use their production greenhouses for germination. The energy required to maintain an entire greenhouse at the recommended temperature for germination can be cost prohibitive. Bottom heat may allow germination to occur at suboptimum air temperatures. For safety reasons, it is important to only use bottom heating equipment that is specifically designed for horticultural applications. When using bottom heat, media temperature and moisture must be carefully monitored as media can dry out quickly. Above optimal temperatures can suppress germination and even kill seeds. Most vegetables used in aquaponics can successfully germinate with a minimum night temperature of 64°F (17.8°C) and daytime temperature of 75°F (23.9°C).

Producing transplants

A good rule of thumb for growing transplants is that slow growth is good growth. A quality transplant is compact and well rooted (Fig. 3). Very fast growth often leads to plants that are fragile and disease-prone. Most vegetable seedlings will overindulge moisture and nutrients, resulting in a "spindly" plant with long internodes and thin stems. Low light conditions can also contribute to long internodes and weak plants.

Figure 3. An example of a compact and well-rooted tomato transplant.

When media is kept overly wet, the roots have no reason to grow in search of new resources. Instead the plant allocates growth to shoots resulting in an unbalance of shoot to root biomass. Transplants should be well rooted so that when the plant is removed from the container the roots do not tear from the plant. On the other hand, plants can become root bound if their roots have overgrown their container and are under proportioned for the shoots they support.

Containers, potting mix, and watering: A complex relationship

Slowing plant growth and limiting plant height is a major challenge when growing transplants. Water availability is a tool that can be used to control growth. Water can make up over 95 percent of a plant's mass and delivers the essential nutrients necessary for growth. Limiting moisture will force roots to allocate resources to root growth in order to increase the water available to the plant. Keeping transplants on the "dry side" will produce a better root system; however, the media should never be allowed to dry out completely. Maintaining proper moisture level can be achieved by allowing the media to slightly dry between irrigation events. The rate at which moisture needs to be replaced depends on the amount of moisture lost through plant uptake and on how the media holds moisture.

The most important physical property of soilless media is porosity. Porosity is all the space in a media that is not solid. This pore space may hold moisture and allow gas exchange. Container-grown transplants are grown with soilless media; that is, there is no mineral soil or "dirt" in the media. Harvesting and using mineral soil invites soilborne pathogens, weed seeds, or other pests. Common materials used for soilless media include perlite, coconut coir, pumice, vermiculite, peat moss, pine bark, and various composts (Fig. 4). These materials can be blended together at different ratios to create desired physical properties. Particle size plays an important role for drainage, gas exchange, and water holding capacity. Finer particles and aggregates enable a greater capacity for water retention but will also decrease air space (space filled with air after a media has drained). The water that remains in the media after draining is referred to as the water holding capacity. Because water requirement for vegetable transplants is high, peat moss is the major component of most mixes. Peat moss has a high water holding capacity but low air space, so it is often blended with smaller percentages of aggregate media like pine bark, perlite, and/or vermiculite to increase porosity. Figure 5 demonstrates the profound effect physical properties can have on plant growth. Transplants are grown in potting mixes similar to those used in the floriculture industry. Many growers choose to buy commercial blends of potting mixes sold in bags or compressed bails. Commercial potting mixes used by the greenhouse industry are usually uniform and have been blended to deliver the appropriate physical properties needed to produce quality transplants.

Figure 4. Common materials used in soilless media. (Top left is a blended potting mix, top right is vermiculite, middle is peatmoss, bottom left is pine bark and bottom right is perlite)

Figure 5. Effects of substrate physical properties on plant growth. Airspace and particle size decrease left to right.

The container or cell size used to grow transplants also influences physical properties of the media. There are many different sizes and styles of containers and cell trays (Figs. 6 and 7). Many growers prefer to use cell trays. Cell size

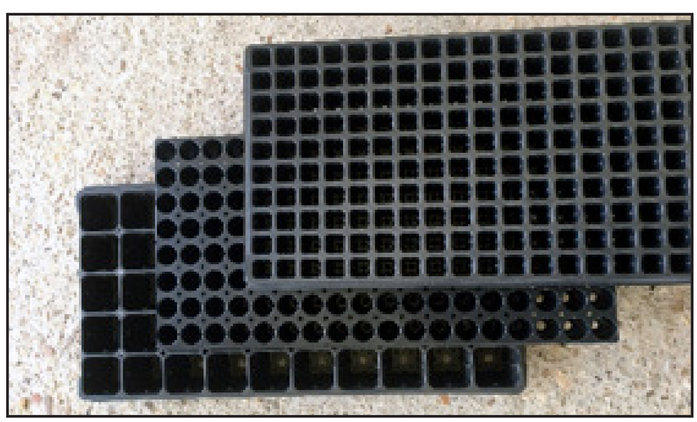

Figure 6. There are many different size cell trays and are designated by the number of individual cells per tray.

is chosen based on the crop. Deep containers drain more quickly than shallow containers due to gravity. The bottom of a container is always going to have the highest moisture content. The depth of this layer is dictated by the depth of the container. For example, two pots with the same media and volume, but different overall height will have dissimilar water holding capacities. The layer is deeper in shallow containers because there is less force pushing the water out of the pot (Fig. 8).

Figure 7. Transplants can be grown in individual containers. There are commercially available containers and some hobby growers choose to use homemade containers.

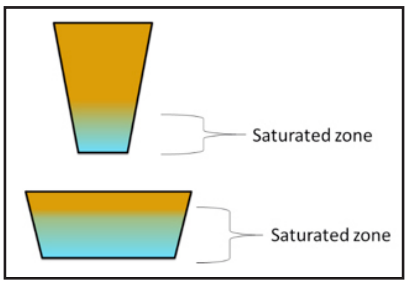

Figure 8. Container dimension influences water holding capacity of media within the container.

Many commercial greenhouse vegetable growers are now using cubed media. Cubed media can be made of porous rigid materials and functions as both media and container (see SRAC Publication No. 5009, *Greenhouse Crops and Cropping Systems for Commercial Aquaponics,* for more information on systems that use cubed media). These materials can be made from a foam/cellulosic material or Rockwool™ (Fig. 9). They are available in 10 in. × 20 in. (25.4 cm × 30.8 cm) sheets and fit in a standard greenhouse "10–20" flat. The sheets are perforated so the cubes can be easily broken off when ready to transplants. Each cube has a small hole for seed placement. Cubed media reduces the labor involved in transplanting. Seedlings grown in cubed media can be directly planted into any hydroponic growing system because the media will maintain its shape and structure. Transplants grown in media mixes need to be transferred into a net pot for raft based systems.

Figure 9. Cubed media and net pots

Nutrients

In nature, soil serves multiple functions including as a reservoir for plant nutrients. Plants are only able to take up nutrients that are dissolved into the soil solution. Most mineral soils, with the exception of sand, have a strong propensity to hold nutrients as the soil particles are negatively charged and most plant nutrients are positively charged. The ability of a soil to hold positively charged nutrients is referred to as the cation exchange capacity (CEC). Soilless media used in transplant production has a much lower CEC than mineral soil. The high porosity of potting media also requires considerably more irrigation than mineral soil. Frequent irrigation coupled with low CEC, requires plants grown in soilless media to have significantly more nutrients available than plants grown in mineral soil.

Fertilizing transplants will become necessary once true leaves unfold. Many AP growers wish to use their aquaculture effluent in place of fertilizer. If utilizing effluent in this manner, then approach with caution as high nutrient concentrations can burn young plants. Some aquaponic systems operate on low nutrient concentrations (< 30 mg/l (ppm) N. Low concentrations in the system are acceptable because plants are constantly exposed to nutrients in the aquaponic water. Plants grown in soilless media may require higher concentrations of nutrients because exposure to roots is primarily dictated by irrigation frequency.

Most commercial growers will use a soluble synthetic fertilizer for transplant production. A solution of 50 to 100 mg/l (ppm) N from a complete, soluble fertilizer can be used 2 to 3 times per week. Some common soluble fertilizers have Nitrogen:Phosphorus:Potassium (NPK) ratios of 20-10-20 or 15-5-15. Table 1 lists various fertilizer needs at given concentrations. The age of the transplant and the frequency of application will determine the needed concentration. Fertilizer should be withheld until the first true leaves have developed because seedlings do not need fertilizer when only the cotyledons are present. Concentrations of 50 mg/l (ppm) N can be used on young transplants with irrigation frequency increasing over time. The more

Table 1. Fertilizer needed to achieve given concentrations in 5 gal. stock tank

	Concentration (ppm Nitrogen)				
20-10-20	50	75	100	125	150
5 gal. stock tank (g)	5	7	10	12	14
1:16 venturi (oz)	2.7	4	5.3	6.7	8
1:100 injector (oz)	16.6	25	33.3	41	50
	Concentration (ppm Nitrogen)				
15-5-15	50	75	100	125	150
5 gal. stock tank (g)	6	10	13	16	19
1:16 venturi (oz)	3.5	5.3	7.1	8.8	10.6
1:100 injector (oz)	22.2	33.3	44.4	55.5	66.6

frequently a fertilizer is applied, the lower the concentration is required. The inverse is also true where high concentrations will require fewer applications.

Soluble or liquid fertilizer can be applied using watering cans for small groups of plants but larger groups may warrant a Venturi or fertilizer injector. Venturi-type injectors such as Hozon™ or Syphonjet™ operate at injection rates of 1:16 at a given pressure (Fig. 10). Injectors and venturi pull from a concentrated stock solution and inject directly into the watering system injection rates are given in ratios. A 1:16 injection ration can be interpreted as the concentration being diluted by a factor of 16. For every 16 gallons of water that enters the injector, one gallon of concentrate will be injected. For large-scale production, there are several piston-type injectors available that allow for high flow rates and high stock tank concentrations (Fig. 11). Injectors usually have an adjustable injection ratio and can use much more concentrated stock solutions. Table 1 lists the amount of fertilizer needed to reach a specific concentration of nitrogen using injection type equipment.

Figure 10. Venturi-type injector

Figure 11. Piston-type fertilizer injectors.

When using a low concentration (50 mg/l (ppm)) at every watering, it may be necessary to apply clear water once or twice weekly to flush accumulated fertilizer salts from the media. The amount of fertilizer salt in a media can be estimated by measuring electrical conductivity. Electrical conductivity (EC) is an indicator of nutrient concentration in the solution, but doesn't measure specific element concentrations. Fertilizers are salts, and salts increase a solutions ability to conduct electricity. Conductivity meters (EC meters) can be used to measure electrical conductivity (Fig. 12). Researchers have developed tools for the floriculture growers to monitor both EC and pH in a media. For most aquaponic growers, monitoring EC and pH is not worth the trouble in the short seedling phase, but becomes much more important in the growout phase. The ability to measure EC is also useful for checking fertilizer concentrations in stock tanks. Most commercial greenhouse fertilizers will list, on the bag, given acceptable EC ranges for specific nitrogen concentrations.

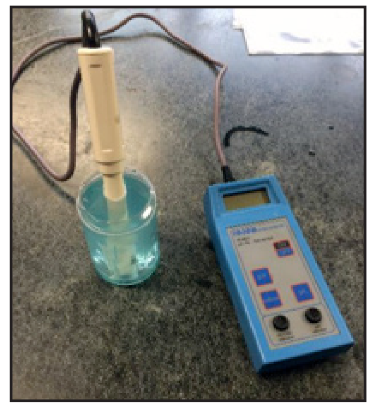

Figure 12. An electrical conductivity (EC) meter is used to monitor and check fertilizer concentrations.

Timing and managing temperature

Temperature requirements for growing transplants vary by crop and can be used to control growth. Cooler temperatures can slow down growth and lead to more compact plants. However, temperatures below 50° F (10° C) may stunt or cause other physiological problems in warm-season plants. As previously mentioned, where greenhouse environmental controls are limited, bottom heating using heating mats (approved for plant production) are an inexpensive method to provide supplemental heat. For more information on controlling greenhouse temperatures, see SRAC Fact Sheet 5008.

Crop specific information

Solanaceae crops: Tomato, pepper and egg plant

Solanaceae crops are warm-season crops. Transplants can be grown in 4 to 6 weeks. Seeds for these crops are similar in size and shape, and can be sown at ¼-inch to ½-inch (0.6 to 1.3 cm) depth. Growout temperatures for these crops range from 60° F to 80° F (15.5° C to 26.6° C) with a night time minimum heater set point of 60° F (15.5° C). Avoid temperatures over 95° F (35° C).

Tomatoes germinate in about 5 days and can be transplanted from seed in 4 to 7 weeks, depending on cell size. Controlling height and internode length can be difficult for tomatoes because they respond rapidly to heat, water, and nutrients. Height can easily be controlled by reducing temperature and moisture. Height can also be controlled by gently running a broom stick or piece of pipe gently over transplants, to bend them over 45 to 90 degrees several times per day. Bending the plants at these angles causes micro fractures in the plant and strengthens the stem. The disadvantage of this technique is the potential of disease infection. Tomato seedlings grown in plug trays should be transplanted to larger pots when the first true leaves first appear. To grow a thicker-stemmed plant, some growers prefer to plant the seedling deep, almost to the cotyledon leaves. Planting deeply is only suited for tomatoes and should not be done to the vast majority of other vegetable crops.

Vegetative propagation of tomatoes using cuttings can be a quick method to propagate transplants for the hobby AP grower; however, care must be taken to use only healthy plants. Suckers (lateral shoots) can be rooted but the cuttings need to be near the same size for uniform crop establishment. Rooting cuttings can decrease transplant production time but is not a common practice among commercial growers. The use of clonal propagation warrants more research but is acceptable for the hobby aquaponics grower.

Peppers require slightly warmer temperatures and take longer to finish than tomatoes. Peppers can require as much as 9 weeks to produce quality transplants from seed. Depending on temperature, peppers will germinate in 7 to 14 days. Peppers tend to stay more compact than tomatoes and grow at a much slower rate. Eggplants can be grown in a similar manner to both tomato and pepper but may require more room to grow. This is especially true when growing larger transplants (3 to 4 inch (7.6 to 10 cm) pots) for the reason that eggplant leaves can become quite large compared to peppers and tomatoes.

Cucurbits

With vegetable crops, in general, "the bigger the seed, the faster the plant". This is especially true for cucurbit species (squash, zucchini, and cucumber). The large seeds allow for fast establishment. Grow out temperature for transplants is 70° F to 80° F (21.1° C to 26.7° C) during the day and 60°F to 70° F (15.5° C to 21.1° C) at night. Cucurbit transplants can be produced in as little as 2 weeks but may take up to 4 weeks depending on temperature. Some aquaponic hobbyists may choose to directly sow the seeds into the system to save time. Most commercial growers prefer to use transplants to insure a uniform crop establishment. Curcubits, members of the gourd family, have large cotyledon and true leaves quickly outgrow the allocated space in most trays. Cucurbit stems and roots are very fragile. To reduce the risk of breaking a stem, it is better to transplant cucurbits when they are small. They can be transplanted when the first true leaf is about the size of a silver dollar. At this stage, plants may not be well rooted and removing plants without damaging the root system can be difficult.

Lettuce and leafy greens

Crops considered leafy greens can all be handled in the same way. Most are cool-season crops and can germinate at low temperature; however, optimum germination temperature is 60° F to 70° F (15.5° C to 21.1° C). These crops can be sown just under the soil surface to ¼ inch (0.6 cm). Most commercial growers use cubed media where the sowing depth is predetermined by the depth of the hole in each cube. It is not necessary to cover the seeds with media when using cubed media. It is very important to use transplants in cubed media before they get too large. The ideal transplant in a 1 inch (3.5 cm) cube of Oasis® or rockwool has 3 to 4 true leaves. Roots from each seedling can grow into neighboring cells. When a seedling becomes too large and

Figure 13. Seedlings 1 to 3 are too large. Seedling 4 is ideal and seedling 5 is too small for transplanting.

Figure 14. Net pots are commonly used for deep water culture or nutrient film technique systems.

the cube is broken off from the sheet, many of its roots are also broken off. In this case, the seedling will become stressed and likely wilt for the first couple of days until the root system can re-establish and support the shoot biomass again. Figure 13 demonstrates the ideal seedling size for most leafy greens when grown in cubed media.

Most aquaponic systems will support the use of net pots or cubed media for growing lettuce. The most common net pot size used in NFT and Raft systems is 2 inches (5.0 cm) (Fig. 14). Net pots are filled with a soilless media and seeds are directly sown into the pot. Depending on the pot size 1 to 3 week old seedlings, are transplanted into the system. When using net pots in a raft aquaponic system, make sure the raft material is no thicker than 1.5 inches (3.8 cm). Material thicker than 1.5 inches will prevent transplant roots from contacting water which results in wilt and potential mortality. Space in an aquaponics system is high value real estate so reducing the time between transplanting and harvest is desirable. A larger transplant can be produced using net pots and there is potential to reduce the time needed to finish off the crop.

Basil, mint, and other herbs

Most herbs can be produced by using the same methods used with leafy greens. Because most plants used for herbs are stemmed plants, there are options to sow multiple seeds in the container to achieve a fuller plant faster than with a single seedling. Planted by itself, a single basil plant will often look lanky and too tall. Pinching or removing the terminal growth can increase lateral branching. Many of the stemmed plants used as herbs can easily be rooted. This is especially true of mint and basil. If pinching is the technique used to increase lateral branching, the removed terminal can be rooted to start the next crop. Stem cuttings of 1 inch. (2.54 cm) or longer are appropriate to root most basil and mint. The cutting can be rooted directly into a net pot or media cube. A cyclic misting system can improve rooting but isn't always necessary. Rooting cuttings can significantly reduce the time it takes to produce a transplant of mint, basil, oregano, and other herbs.

Hardening off

The final step in transplant production is called hardening off. In order to reduce transplanting shock, plants grown under greenhouse conditions are often "hardened" before being transplanted into the system. Hardened plants may be achieved by exposing plants to cooler temperatures, moisture stress, wind, and rain for a period of 10 or more days so that they are less tender at planting. For the small grower, placing plants on a wagon or cart will allow the gradual moving of plants back and forth from indoor to outdoor. This is especially helpful when acclimating plants to full sun. Warm-season plants should not be exposed to cool temperatures for hardening purpose; however, this can benefit cool-season transplants. Tender cool-season plants that are properly hardened to cool temperatures can handle a light frost depending on the species. During the hardening period, plants can be allowed to slightly wilt.

Hardening off is not as crucial for indoor aquaponics systems because plants are usually protected and are exposed to constant moisture. Hardening off may be more appropriate for media based aquaponic systems and may not be beneficial for transplants placed into raft aquaponic systems. At planting, water seedlings grown in commercial mixes heavily 2 hours prior to transplanting. This will help free the media plug from the cell tray and prevent damage to the root system. When extracting a transplant from a cell, do not pull excessively on the shoot. Try to remove the transplant by gently gripping the root ball. Some cell trays have a small hole at the bottom where a pencil can be inserted to help push the root ball up and out of the individual cell.

Summary

For the beginner grower, it is important to be observant and to develop a feel for how plants respond to water, temperature, and fertilizer. Notes on temperature, timing, and varieties can help fine tune your cultural practices for the next crop. Do not expect to produce a perfect transplant the first season, growing transplants is a skill that develops over time.

Suggested readings

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USDA United States Department of Agriculture National Institute of Food and Agriculture

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