Plant propagation for successful hydroponic production©

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INTRODUCTION

Hydroponics is a plant cultivation system in nutrient solutions with or without the use of a growth medium. Using hydroponics systems, crops can be grown in places considered hostile for crop production such as deserts, the Arctic and even in space. Hydroponics is a sustainable option to produce crops, as it offers many advantages such as higher crop yields in a smaller space. Increased productivity and sustainability is achieved through more efficient use of water, fertilizers, and pesticides, and faster production cycles, year around production, and production at the point of sale. Hydroponic production normally starts from seed propagation. Establishing vigorous, heathy disease-free uniform plant material is a key step for the success of hydroponic crop production. Several unique challenges need to be considered for successful establishment of plant material, which include choice of crops and cultivars, type of propagation media, hydroponic water quality and nutrient management, and environment control and management. The objectives of this paper are to provide some general information regarding propagation practices for hydroponics, and specific goals and unique strategies for each process to establish stronger and healthier seedlings. These guidelines will provide more sustainable options and help improve production efficiency of hydroponic crop production systems. The paper will be organized into sections on: (a) types of hydroponic growing systems, (b) choice of crops and cultivars, (c) growing media, (d) hydroponic propagation methods, (e) propagation environment management, and (f) transplanting.

TYPES OF HYDROPONIC GROWING SYSTEMS

Hydroponic systems are commonly designed as open (drain to waste) or closed (recirculating) systems (Raviv and Lieth, 2008) (Table 1). In open systems, nutrient solution is applied to the plant growth medium and then drained to waste. Fresh nutrient solution is applied to plants with each irrigation, and therefore, open systems require more water and chemical fertilizers than closed systems. Untreated wastewater from open hydroponics systems poses detrimental effects to the environment. In closed systems, nutrient solution is collected in a nutrient reservoir after each irrigation, and recirculated through the system. The nutrient solution is reused by adding more water and nutrients instead of replacing the entire solution (Jensen, 1999; Nederhoff and Stanghellini, 2010). Due to this practice, closed systems use 20-40% less water and fertilizer than open systems, but consistent monitoring and maintenance of electrical conductivity (EC) is required. Eventually the nutrient solution will be replaced, partly due to the imbalance of mineral elements in recirculating water as plants uptake nutrients at differential rates. To maintain a near perfect nutrient balance is a challenge in the recirculating system, and requires chemical analysis and constant addition of minerals that are in high demand. Deteriorating water quality is another reason for replacing the nutrient solution. Reuse of the nutrient solution increase the risk of disease build-up. Organisms such as *Fusarium* or *Pythium* can have a devastating effect if the water is not properly processed.

Disposal of hydroponic wastewater is an important issue. Even the closed systems generate wastewater that contains significant amounts of environmental pollutants such as nitrogen and phosphorus. Common practice is that wastewaters are collected, diluted and applied to either community gardens or open spaces. Despite the environmental concerns

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related to the open hydroponics systems, open systems are more common compared to the closed systems in the USA. Closed hydroponics has gained great interest from producers and scientists in the last two decades (Neocleous and Savvas, 2016). Globally, more than two-third of hydroponic growers are using open systems while less than one-third of hydroponic systems are closed (Carruthers, 2007). Improved cultural practices are needed to overcome point source pollution while maintaining high quality and yield in hydroponic crop production.

Table 1. Type of hydroponic production systems.

System type		
Substrate-based system	Drip irrigation	Open or closed
	Ebb-and-flow	Open or closed
Water-based system	Nutrient film technique (NFT)	Closed
	Deep water culture	Closed
	Substrate culture	Open or closed
	Aeroponics	Closed

There are four growing systems used for hydroponic production: nutrient film technique (NFT), deep water culture (floating hydroponics), aeroponics, and substrate (media-based) culture (Resh, 2013). The choice of growing system depends on the duration of crop production. Short-term crops such as leafy vegetables and herbs can be commonly grown in a deep water, NFT or aeroponics culture system. However, long-term crops requiring more than a month for production require strong support of the plants, and therefore, substrate culture is a better choice. In substrate culture, suitable substrates should be chosen to provide good support for plants, sufficient air space, and good water holding capacity, with proper chemical properties (see Growing Media for detailed information).

Substrate-based system (aggregate system; media-based system)

A medium of choice can be an inert medium for conventional hydroponics or a medium containing organic components for organic hydroponics. There are numerous types of media used in substrate-based hydroponic systems (see Growing Media for detailed information). In this system, the nutrient solution is directly delivered to the plant roots using a drip irrigation system or ebb-and-flow system, which can be designed to be either open or closed. Trickle or drip irrigation is the most widely used type of hydroponic system in the USA.

Deep water culture system

In deep water culture systems, plants are inserted into small holes of a Styrofoam board placed on a rectangular tray or tank of reasonable depth filled with nutrient solution. The roots are constantly submerged in a nutrient solution. Plants are held by soilless cubes or a net pot filled with soilless substrate (e.g., aggregated clay, rockwool cubes). This system is commonly used for large-scale commercial production of leafy vegetables. This system is designed to be closed, and the nutrient solution is monitored, and adjusted. The depth of water can vary. A deep water system is common for greenhouse production, while a low-deep water system is a popular choice for indoor vertical faming.

Nutrient film technique (NFT)

In a NFT system, the plant's roots are exposed to ample oxygen and a thin film of nutrient solution. The PVC channel is angled at a 1% gradient, and is closed to exclude light and prevent evaporation. However, holes in the channel allow for plants to be planted. Nutrient solution is pumped to the higher side of each channel and flows by gravity through plant roots to catchment pipes and return back to a sump. The nutrient solution in the sump is monitored and replenished of salts and water before recycled. Some capillary materials are used in the channel to help young plants to absorb water and nutrients, and promote root grow.

Aeroponics

In aeroponics, plants are inserted into the holes of Styrofoam board or other material, and their roots are suspended into a closed chamber or box kept in darkness, where high-pressure mist of nutrient solution is sprayed over roots periodically to provide a fully saturated humidity. The excess solution drains and recirculates through the system. The system is normally turned on for only a few seconds every few minutes, which keeps the roots moist while allowing them to be aerated. Some aeroponics uses the A-frame chamber system constructed using two Styrofoam or PVC boards.

CHOICE OF CROPS AND CULTIVARS

Plant varieties have been specifically developed for hydroponic production in controlled environments. The most popular crops grown in hydroponics are tomatoes (*Solanum lycopersicum*), cucumbers, lettuce, herbs, peppers and strawberries. All the varieties of tomatoes, cucumbers, and peppers are characterized by indeterminate growth, which means that the main stem continues to elongate indefinitely without being limited by a terminal flower structure. This "high wire or vine" growth habit help create unique form of plants to maximize crop production in a limited space.

GROWING MEDIA

There are many types of media and substrates for hydroponic propagation and production (Table 2). Media determines moisture retention, irrigation, cultural practices, production cost, and sustainability, and therefore, the choice of the growing media is critical. Soil is normally not used in conventional hydroponics, but it can be used in organic hydroponics. Media preferred for hydroponic plant propagation serve several purposes, including providing support, moisture, aeration and nutrition. The components of the medium, their particle size, and the degree of compaction are all characteristics that affect how well the medium provides for these functions. The ideal media for hydroponic propagation must also have a high moisture holding capacity, yet allow excess water to drain freely so that the seeds are not drowned in water. Roots may rot if the medium is poorly drained.

Table 2. Substrate and medium choice for hydroponic propagation.

	Substrates		Synthetic media
	Organic components	Mineral components	
Conventional hydroponics	Peat moss Coconut coir Sand Sawdust Rice hulls	Perlite Vermiculite	polymer bound plugs (e.g. peat pellets, coir pellets, composted organic material plugs, Oasis Horticubes, urethane foam plugs), rockwool cubes & blocks, coco coir cubes and blocks

One should consider compatibility with the production system. Commercial growers often use the "rockwool system" which consists of germination cubes, and blocks, which are placed onto slabs or bags. Such system can keep the work flow smooth and easy to handle.

The medium also should not be saline or contain toxic substances; should be capable of being sterilized; and be disease and insect free.

The above listed substrates can be used alone or in mixture with other substrates. In some regions of the world, media such as coconut coir, sand, sawdust, and volcanic rock are also common due to local availability. Synthetic medium is a popular choice for hydroponics. Particularly for growing row crops such as tomato, cucumber, and pepper, the most popular growing media is rockwool followed by perlite as they are light-weighted, and easily handled and sterilized than many other types of aggregate materials. However, due to the disposal issue and increased environmental pressures on greenhouse operation, rockwool is being replaced by coconut coir in large hydroponic greenhouse operations as it being more sustainable choice of substrate.

HYDROPONIC PROPAGATION METHODS

Seed propagation

Most vegetable transplants are produced from seeds, and the choice of seed is one of the most important decisions a grower can make (Hartmann et al., 2011). Hybrid seeds are the common type of plant material to start with in commercial greenhouse hydroponic production. This is because plants derived from hybrid seeds will have the same characteristics and produce the same quality and yield. The seeds in the fruit from the hybrid plants will not produce the same plant as the hybrid seeds do. It is important to acquire seeds from the reliable commercial source to ensure the same plants of disease-free. The number of days to germination is crop specific. e.g., tomatoes about 5 to 6 days, lettuces about 7 to 10 days, and cucumbers about 14 days.

Vegetative cuttings are not desirable to establish transplants because virus disease from the mother plants can be transmitted to the cuttings. Purchasing hybrid seeds could be quite costly but the investment can be recovered from the economic return.

Seed germination trays

Seeds may be sown into molded plastic or Styrofoam plug trays or peat strips. The trays can be filled with germination mix, or other suitable substrates or media as listed in Table 2. Seedling plugs are the most popular choice for hydroponics. Seeds can be placed directly into the plugs, such as peat or coir pellets, rockwool cubes, or foam that are sized to fit the trays, and divided into small cubes. There are various sizes of plug trays and cubes on the market. The propagation medium should be thoroughly moistened before seeding. Some blocks are designed to nest small size plugs or cubes, and further placed onto a larger slab. Such system is effective in minimizing transplant shock. When sowing seeds, one seed per each cell or cube should be sown. Many commercial products such as rock wool and foam cubes, have a small hole in the top of each cube where a seed can be placed. The percentage germination should be considered and sown enough to meet the required number of seedlings. Depending on the types of seeds, seeds should be shown at proper depth, which can be found on the seed packet. General rule of thumb is to sow two to three times thicker than the seed diameter. Seeds of herbs and many leafy vegetables may be placed at the surface. Sprinkle a thin layer of vermiculite over the seeds to keep moisture for germination.

Vegetable grafting

Vegetable grafting is common method of growing most cultivars of tomatoes, peppers, and eggplants (Figure 1). This requires skills and specialized techniques (Caula and Trigiano, 2014). Fruiting scion varieties are often grafted onto a rootstock for disease resistance and more vigorous growth, providing greater yield potential and crop performance. The choice of rootstocks can be determined depending on the traits to introduce.

Splice grafting (also known as top grafting, tube grafting and slant-cut grafting) is the most widely used grafting technique for tomatoes (Figure 1A). Splice grafting is quicker and less complicated to do than cleft grafting because it only requires a single straight cut on both the root and shoot portions of a graft with a high success rate (95%). Splice grafting should be carried out when two to four true leaves are present on seedlings and the stems are 1.5 to 2 mm in diameter. For proper healing to take place, the vascular tissue in the rootstock and scion must align so that their tissues can easily grow together, forming a strong union for water and nutrient uptake. An essential component for grafting success is to use rootstock and scion plants that have similar stem diameters.

Grafting should take place when there is little water stress upon the plants. Early in the morning or just after dark are excellent times to graft as transpiration has typically slowed to reduced levels. The grafting process should be carried out indoors or under some sort of shading device. Sanitation is extremely important during grafting. Wash with anti-microbial soap, use latex gloves, and use latex gloves and sterile tools to reduce the exposure of the plant to pathogenic bacteria, fungi and viruses.

Figure 1. A: Slice graft; B: a small-scale grafting system (tray, plastic dome, and grafted tomatoes in plugs); C: grafted tomato for hydroponics where a dome was removed for photo clarity.

PROPAGATION ENVIRONMENT MANAGEMENT

Depending on the type of crop, germination may occur within a week or two weeks of seeding. Seeds may require light for germination. Light environment should be adjusted depending on the crop. If the seeds require light, LED lights can be used to avoid heat-overloading to the seedlings. Radiant heat emitted from the light source can dry up the surface of substrates and restrict water for seed germination, leading to poor germination rate or poor-quality seedlings. Alternatively, the tray can be covered with a clear plastic dome, which can control water environment better. However, it should be removed when seedling emergence occurs. Once seedlings emerge, the seedling trays should be moved to the greenhouse environment to allow them gradually to acclimatize to the production environment. If germination is done in the greenhouse, avoid the use of plastic dome as it may trap high heat when direct sunlight hits the dome.

Source water in these systems primarily comes from municipalities. Water should be tested to ensure it is equal to or better quality than drinking water.

Environment conditions during seed germination

Seeds are often germinated in a germination room or chamber where high relative humidity and temperature is maintained to facilitate seed germination. If a germination room is not available, a germination system consisting of a plastic dome, tray and bottom heat, will serve the purpose for small scale seed germination. During seed germination, water should be applied from the bottom to moisten the medium where water can be taken up by capillary action of the substrate. Avoid overhead watering during seed germination as it may knock down seedlings, and avoid overwatering as it can cause damping-off disease. Ebb and flow systems are quite effective for large scale seed germination. Once the blocks are evenly moist, the tray is drained, which allows aeration of the roots. This process will need to be repeated often throughout the day. Supplemental light with LEDs for ~16 hours daily will help grow healthy seedlings during winter months, particularly in Northern latitudes.

Environment conditions after seedling emergence

Once seedlings emerge, the seedling trays should be moved to the greenhouse environment to allow them gradually to acclimatize to the production environment with optimum growth temperature, and light level. Overhead irrigation using mist is the most common method for seedling establishment. Overwatering will not only increase the risk of damping-off disease, but also encourage succulent growth of seedlings making them more susceptible to disease and transplant stress. It should be also noted that encouraging root growth during seedling establishment is important because it helps minimize transplant shock and enhance crop performance in a hydroponic system. Establishing sturdy transplants with well-established roots is the major goal during this process.

Seedlings grown in a germination mix or substrates containing organic components may have sufficient nutrients available to support growth, and therefore, may not require any additional nutrients during seedling establishment except water. However, for seedlings grown in an inert medium need nutrient solution, diluted nutrient solution at an electrical conductivity (EC) of 0.5 mS cm^{-1} and a pH of 6 is recommended for seedling growth, as it supplements nutrient reserves depleted from the seeds. Once the early first-true-leaf emerges and the cotyledons expand, one should consider applying diluted nutrient solution with an EC ranging from 1.0 to 1.5 mS cm^{-1} (or mmho).

Established seedlings can be placed inside plastic containers called net pots or web pots, which are commonly used in deep-water or NFT hydroponic systems. The pots can be filled with either perlite, aggregated clay (clay pebbles), or rock wool.

Environment conditions for grafting-healing

Environment control is critical for grafting success (Figure 2). Newly grafted plants must be kept under high humidity (85 to 100%) and either low light (or heavy shade) or darkness to help ensure that the graft will take. High humidity decreases water loss from the grafted plants and increases success rate. A small-scale grafting-healing system (Figure 1B) can be set up using a plastic dome and a tray, or a transparent plastic box to maintain high humidity. Covered benches using a plastic covering with a misting system can be constructed in the greenhouse. After 3-4 days, a graft union is formed. Allow a couple of days to help a strong graft union is formed. During this time, humidity level is gradually decreased, and light level can be gradually increased to indoor environment or shaded condition. Once graft union is formed, grafted plants will resume taking up water through the roots. It is important to note that diluted nutrient solution should be added to the medium, particularly when an inert medium is used. The grafted plants should be protected from direct sunlight, low humidity or high temperature. They are gradually reacclimatized to a brighter and drier environment. After 7 days, plants can be moved into a normal production environment. Extra days of acclimation will allow the grafted plants to better perform during the transition period.

Major Event	Scion seed sowing Rootstock seed sowing		Grafting	Acclimation to indoor environment	Acclimation to production environment
	Germination chamber/greenhouse		Healing chamber		Greenhouse
Environment control	2-5 days	≈10-14 days	3-4 days	3-4 days or longer	≈ 7 days
Humidity	Seed propagation environment		85-100%	Gradually decrease (≈ 60%)	Gradually decrease (40-60%)
Light intensity			Low light or heavy shade	Gradually increase	Gradually increase
Air temperature			25-30°C	Gradually decrease	–

Figure 2. Timeline and environmental control for grafting and healing.

TRANSPLANTING

Transplanting for leafy vegetables occurs in 2-3 weeks. Too early transplanting to hydroponic environment may delay initial growth of seedlings, while too late transplanting can also slow down plant growth due to root bound. Transplanting of fruit vegetables should be done once true leaves are unfolded. This could vary by vegetable crops, e.g. tomato in 2 to 3 weeks after sowing. Seedlings should be transferred into larger growing blocks or pots from the original seedling cubes, and then evenly spaced out to avoid mutual shading and promote better light interception to each plant. Slight water and nutrient stress may help establish stronger seedlings. The final growing media should be properly leached and moistened, and the production environment should be kept at a proper temperature before plants are moved to the production area. Plants should be irrigated with a half to full strength nutrient solution immediately after transplanting.

One of the advantages of hydroponics is higher planting density compared to conventional production systems. Planting density varies depending on the crop: fruiting vegetables, e.g. tomato and cucumber, 4-8 plants m^{-2} and leafy vegetables 20-25 plants m^{-2} (FAO, 2014). To increase planting density, two seedlings can be nestled in a slab or a pot. Alternatively, a growing point of a seedling can be removed and a double-headed plant can be induced. Removing a growing point may slightly delay plant growth; however, seed cost can be reduced compared to planting two seedlings in a given area. Greenhouse crops with indeterminate growth must be trained using support strings to help grow upright. Mature plants with normal fruit loads can weigh anywhere between 10 and 20 kg (22 and 44 pounds) for tomato. Therefore, the strings should be hung from the crop support of the greenhouse, with or without additional support using horizontal wires that run through the greenhouse.

Literature cited

Carruthers, S. (2007). Challenges faced by the hydroponics industry worldwide. Acta Hortic. *742*, 23–27 https://doi.org/10.17660/ActaHortic.2007.742.2.

Caula, B., and Trigiano, R. (2014). Plant Propagation Concepts and Laboratory Exercises, 2nd edn (Boca Raton, Florida USA: CRC Press Taylor & Francis Group).

FAO. (2014). Small-scale aquaponic food production-Integrated fish and plant farming. Food and Agriculture Organization of the United State and aquaculture technical paper: 15, 22. Available online: http://www.fao.org/3/a-i4021e.pdf (accessed October 10, 2017).

Hartmann, H.T., Kester, D.E., Davies, F.T., and Geneve, R.L. (2011). Hartmann and Kester's Plant Propagation: Principles and Practices, 8th edn (Upper Saddle River, New Jersey, USA: Prentice Hall).

Jensen, M.H. (1999). Hydroponics Worldwide. Acta Hortic. *481*, 719–729 https://doi.org/10.17660/ActaHortic.1999.481.87.

Nederhoff, E., and Stanghellini, C. (2010). Water use efficiency of tomatoes in greenhouses and hydroponics. Pract. Hydroponics and Greenhouses. *115*, 52–59.

Neocleous, D., and Savvas, D. (2016). NaCl accumulation and macronutrient uptake by a melon crop in a closed hydroponic system in relation to water uptake. Agric. Water Manage. *165*, 22–32 https://doi.org/10.1016/j.agwat.2015.11.013.

Raviv, M., and Lieth, J.H. (2008). Soilless Culture: Theory and Practice (Oxford UK: Elsevier B.V).

Resh, H.M. (2013). Hydroponic Food Production: a Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower, 7th edn (Santa Barbara, California, USA: Woodbridge).