Title: Growing Dahlias, *Dahlia coccinea* Cav., for Commercial Cut Flower Production in Aquaponics and AutoPots

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Abstract:

Commercial floriculture is years behind food agriculture in the adoption of organic and sustainable practices and enacts a heavy toll on the environment, resulting in excessive water usage, soil erosion, heavy pesticide use, and a massive carbon footprint. In this study, Dahlias (*D. Coccinea*) were grown in AutoPots fed by an established aquaponics system to explore the sustainability and environmental impacts of aquaponics on commercial floriculture. Dahlias were grown starting from both tubers and cuttings, for a six month period, in a greenhouse setting, assessing the bloom time, bloom quality, stem count, pesticide usage, water usage, and tuber formation. Dahlias bloomed in a typical time frame, compared to field grown plants, the quality of the blooms was equivalent to field grown, the stem counts were significantly lower than field grown, pesticide usage was slightly decreased, water usage was dramatically lower than field grown, and tuber formation was not impacted. To date, this is the first published evidence that Dahlias can be grown in aquaponics, that typical environmental benefits were observed when growing Dahlias via this method, and tuber formation was not hindered by the high moisture conditions produced by a coupled aquaculture system.

Keywords: Dahlias, Aquaponics, Sustainability, Cut Flowers

Introduction:

The US cut flower farming industry has shrunk at an unprecedented level for the last 20 years due to a little-known trade agreement with four Andean countries; Bolivia, Colombia, Ecuador, and Peru (USTR, 2008). The intention of this trade agreement was to encourage these countries to grow alternatives to coca, which was used primarily to produce cocaine, by eliminating tariffs on other exportable crops, ultimately to help fight the influx of drugs into the US. Cut flowers were one of the crops targeted, specifically roses. The impact that cheap roses had on the American rose farms was devastating. In a matter of a few short years a previously thriving rose farming industry was reduced to a tiny fraction of what it once was (Paletta, 2018). To this day, all major cut flower varieties have been affected by imports, from roses to Dahlias to tulips to peonies, and unfair trade practices have hindered the American flower farming sector's recovery and advancement. The carbon footprint of the floral industry is massive and it has been calculated that during Valentine's Day, the single biggest flower demand of the year, 9,000 metric tons of $CO_2$ are emitted to transport the millions of roses required to meet the surge of floral product (Kaplan, 2020) (Whelan, 2009). Regulations have not caught up with the flower importing industry when it comes to pesticide, herbicide, and preservative chemical use. A vast majority of flowers flow freely into the Miami port of entry every day, with little to no oversight about what has been sprayed on them (Morse, Baker, & Landrigan, 1979); (Toumi, Vleminckx, Loco, & Schiffers, 2016); (Toumi, Joly, Vleminckx, & Schiffers, 2017). Because flowers are not ingested like our food crops are, there is little incentive to monitor and change this (Stewart, 2007). The quality of imported flowers can never be as good as a flower grown locally. On average an imported flower was cut four days before it ever reaches the hands of a consumer. Anybody who has ever purchased a bouquet of flowers at a grocery store knows the vase life is incredibly short, and the data backs this up (Larson, 1992).

It has been made abundantly clear, via the vast amount of published research and overwhelming consensus of scientists, that the global climate is changing, and this is due to manmade activities. Recent data is outlining a dire prediction that if we do not alter this path we are on, catastrophic impacts will be felt by all humans. The Intergovernmental Panel on Climate Change (IPCC) released their latest commissioned report in 2018, providing yet another grim snapshot of the crisis. One striking feature was that of land degradation, defined as "a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity, or value to humans" (Allen, 2018). One of the core drivers of land degradation, according to the IPCC, is large- and small-scale agriculture. Monoculture farming, tilling, and pesticide and herbicide use are among a few of the practices that are leading to an erosion of our topsoil. If we continue the current methods our topsoil will continue to degrade over the next 100 years until there is little left. A move towards soil-less agriculture, like hydroponics and aquaponics, has been steadily growing over the last 20 years or so. With its water saving and soil use eliminating capacity, hydroponics and aquaponics are attractive solutions to the immense challenge presented by climate change and agricultural land degradation.

Aquaponics is a primitive farming method, practiced by the Aztecs and Chinese, that emulates a natural process where plants grow in or near water that is heavily fertilized by fish and aquatic animals. It has been adapted into a modern-day technology amplifying and expanding its advantages. The fundamental process of any aquaponics system involves aquaculture (the growing of fish) coupled with hydroponics (the growing of plants in water) (Rakocy & Bailey, 2011). There are three biological participants, which must be balanced, that are required to maintain the closed loop system: plants, fish, and bacteria. The fish excrete ammonia through their waste, a sufficient quorum of nitrifying bacteria (Nitrosomonas and Nitrospira) convert the ammonia to nitrite and then to nitrate, which is finally absorbed by the plants for their rapid growth. The previously waste filled water is then cycled back to the fish cleaned of the toxic ammonia and the cycle repeats indefinitely (Bernstein, 2011). The bacteria are the linchpin to the entire process working and working well. These bacteria are omnipresent in the system; they inhabit the surfaces of the fish tanks, the grow bed, the media, and the entirety of the water column. The only input for an aquaponics system is fish food, hence it is a closed system, that has few maintenance requirements and is highly sustainable. There are three main styles of aquaponics systems in consistent use; Deep Water Culture (DWC), Nutrient Film Technique (NFT), and "Flood and Drain". DWC and NFT are utilized most in leafy greens production systems.

Because aquaponics mimics a natural process, and has few inputs, it is the quickest path to organic certification of all growing methods (Wildrick, 2018). The most notable benefit of aquaponics relates to its environmentally friendly mechanism. It has been shown that aquaponics systems used to grow vegetables require 95% less water than field grown veggies (USDA, 2020). In addition, because plants are not grown in soil, erosion is a non-factor. Aquaponic farms are typically implemented indoors in controlled environments, reducing pests thus minimizing pesticide use, abolishing herbicide use, and eradicating weeding. A typical complaint of environmentally minded agriculture practices is that they are not financially viable, even though it is clearly beneficial to the local ecosystem. Aquaponics addresses this issue as well. Research has revealed that vegetables grown in these systems can yield two times the growth rate of their field grown counterparts leading to a subsequent two-fold increase in crop yields (Rinehart, 2019). An even more appealing fact is that plants can be grown at waist height meaning a farmer does not have to bend over repeatedly to harvest their crop. Lastly, with the advent of supplemental lighting during parts of the year, crops can be produced year-round in climate controlled indoor spaces. All of this adds up to remarkable environmental and economical improvements in the production of vegetables. However, to date, flowers have not been fully studied to determine if they too can realize all these benefits.

Dozens of studies have demonstrated the validity of growing cut flower varieties in hydroponics systems (Buzby, West, Waterland, & Lin, 2016). Nasturtiums, Gerbera Daisies, Calendula, Chrysanthemums, and Gypsophila (Wahome & Masarirambi, 2011) (Yep, Gale, & Zheng, 2020), to name a few, have all been shown to respond with healthy growth and flowering in a hydroponics environment. In contrast, there is little evidence that flowers can develop in aquaponics, and only a handful of research publications have examined the possibility of growing flowers in these systems, however none showing cut flowers can be grown. Scant reports of anecdotal evidence exist amongst aquaponic farmers and growers, that flowers like roses, marigolds, and sunflowers will grow well in media bed-based aquaponic systems. What is truly lacking in the research data and observations previously made, is can aquaponics be a commercially viable approach to cut flower farming and can aquaponics improve the flowering of high dollar value cut flowers, like Dahlias.

## Materials and Methods:

### Aquaponics System and AutoPots

The Aquaponics System is a standard IBC tote "Chop and Flip" approach and was established in 2020 using pet store goldfish (*Carassius auratus*). The method was flood and drain using an automated bell siphon mechanism. The fish tank had a 1000-liter capacity but was never filled more than 750 liters with well water. The AutoPot system is a pot-based system that utilizes a low-tech float pump switch to maintain a small pool of nutrient rich aquaponics water at the base of the pot that allows plants to access it when needed, and once drained will automatically fill up to a preset level (Auto Pot USA, Santa Fe Springs, CA). The media in the pots was composed of expanded clay pellets, or Hydroton (Mother Earth, Harrisonburg, VA). A 3000 LPH submersible pump was used to move water from the fish tank to sump tank, that feeds the AutoPots via gravity (Active Aqua, Petaluma, CA). Goldfish (*C. auratus*) were fed once daily, 64g of Tetra Pond Koi Vibrance pellets (Spectrum Brands Pet, Blacksburg, VA). Goldfish started in the tank as 2.5 cm fingerlings and grew to 10-15 cm in length and 340-450 g in weight. Water temperature was regulated using ½ HP Active Aqua Water Chiller (Active Aqua, Petaluma, CA). Air temperature within the greenhouse was controlled via ventilation, box fans, and a 30% shade cloth and measured via thermometer (Johnny's Selected Seeds, Winslow, ME).

### Dahlia Plant Characteristics

Six different Dahlia cultivars were used for this experiment: Cornel Bronze, Big Brother, Doris Duke, Totally Tangerine, Castle Drive, and Thomas Edison. These cultivars were chosen due to their reliable growth habits, overall healthiness as popular cultivars, and their ability to flower prolifically. Of each cultivar, two different tissue origins were used: tuber and rooted cutting. 12 plant subjects in total were observed and measured over the six month study period.

### Nutrient and Health Monitoring

System health was monitored daily for pH, temperature, ammonia, nitrites, and nitrates. Monitoring was performed using the Hanna Instruments Groline Monitor (HI981420; Hanna Instruments, Smithfield, RI) and the API Freshwater Master Test Kit (API, Chalfont, PA). To adjust pH, when necessary, AquaUp pH Raising Kit was used which was either Calcium Carbonate or Potassium Carbonate (The Aquaponics Source, Wheat Ridge, CO). Data was downloaded via USB and analyzed using Microsoft Excel.

### Water Usage Measurement

Water use for the duration of the study was performed using the Flume Smart Water Monitor (Flume Inc., San Luis Obispo, CA). Water usage in liters was exported from the cloud based online service for Flume and then analyzed with Microsoft Excel. Field grown crop water usage was calculated as follows. The approximate square meters required to grow the same amount of Dahlia plants was calculated as 2.2 sq meters. The entire field growing space was approximately 230 sq meters, so the required space for 12 Dahlia plants took up about 1/100th of the space. Drip tape emitters, used exclusively on the farm, have a 0.95 Liters Per Hour per emitter rating. Each emitter was spaced every 20 cm, producing about 36 emitters per the 2.2 sq meters (two lines of drip tape in each row). Each emitter was rated as 0.95 LPH as designated by the irrigation manufacturer (Dripworks, Willits, CA). Irrigation was applied for 1 hour per day and on average 20 days out of the month irrigation was used in the field (turned off on rain days). The calculation provided a Liters per day usage and a Liters per month usage measurement. This measurement was then compared to the AutoPot/Aquaponics usage measurement to produce a water percent savings measurement.

### Documenting Plant Growth, Flowering, and Tuber Formation

Daily observations, pictures, and measurements were conducted, including time to flower, plant heights, general plant health, flower bud formation, flower quality, tubers formed, and number of stems. Observations and measurements were logged with pen and paper on a clipboard, and then transcribed into Microsoft Excel.

### Pesticide Usage Measurement

Pesticide use was measured simply by recording the number of days that standard OMRI listed pesticides were used on the Dahlia plants. Results were logged in Microsoft Excel. Neem oil was used exclusively in this study (Plantonix, Ashland, OR).

## Results:

### Aquaponic System Health

The aquaponic system maintained a consistent ammonia, nitrite, and nitrate level throughout the study period. Table 1 shows the average monthly concentration (ppm) of ammonia, nitrite, and nitrate levels recorded throughout the 6-month study duration. Ammonia levels are consistently higher in this system due to the use of goldfish (*C. auratus*), which are known to excrete higher levels as opposed to other fish species. Aquaponic system health was also monitored through measurement of pH, temperature, and electrical conductivity (EC) via the Groline Water Monitor. Table 2 shows the monthly average in pH, temperature, and EC over the duration of the study period. Temperature held mostly steady between 20-22 °C, however spiked on severely hot days during July and August. The pH of the system was consistently lower throughout the study (4-4.5 on average) and was adjusted weekly to keep it up around six using AquaUp, a favorable pH for both plants and fish. However, the constant high level of ammonia ($NH_3$) and production of hydrogen ions ($H^+$) due to natural fish metabolism and bacterial metabolism, kept the pH down at or below 4 throughout the study, complicating nutrient availability (see Figure 1). Air temperature was measured in the greenhouse environment, which was consistently about 15-20 degrees higher than the water temperatures (data not shown). Greenhouse air temperature control was managed only through fans, vents, and shade cloths.

## Plant Growth and Flowering

Both tubers and rooted cuttings of the six distinct Dahlia cultivars grew at a pace similar to field grown Dahlias (12-14 weeks to maturity) and bloomed at a normal time as well (14-16 weeks) (data not shown). Severely high temperatures during July and August slowed growth and blooming, typical of most Dahlia cultivars. Figure 2 shows the normal progression of the only three cultivars, over 150 days, that produced blooms by the end of the study period: Cornel Bronze, Doris Duke, and Totally Tangerine. The cultivars of Big Brother, Castle Drive, and Thomas Edison never produced blooms, although plants did reach maturity (data not shown). Stem counts were significantly less than what could be harvested from an equivalent number of plants in the field. Only eight total blooms were harvested from the three cultivars that produced blooms: three from Cornel Bronze, two from Doris Duke, and three from Totally Tangerine. One typical field grown Dahlia can produce as much as 10-20 blooms per season, depending on conditions (data not shown).

## Water Usage

Water usage by the AutoPot system was monitored using a relatively new technology created by Flume; a smart water monitor that can detect small water changes (down to a tenth of a liter) in a system. Using Flume, water usage was assessed daily in the AutoPot system and then averaged over the month. Water usage was then compared to field grown crops of an equivalent number of plants (12) and sq meters required (2.2 sq m). Table 3 and Figure 3 shows the monthly averages for both scenarios and the percent water savings of AutoPots and aquaponics versus field grown crops. There was a 95.6% savings in water from the AutoPot experimental setup compared to field grown. For the calculation used to estimate field grown water usage, see Materials and Methods.

## Pesticide Usage

Typical field grown application of Neem Oil on Dahlia plants, and other OMRI listed agents, was twice a week at doses recommended for the size of the plot being sprayed. Dahlias grown in the AutoPot system were sprayed on average once a week but had several weeks where spot spraying was necessary twice a week (data not shown). Neem Oil was sufficient to suppress most pest pressure on the Dahlias, which consisted primarily of spider mites and aphids.

## Tuber Formation

Of the six cultivars and twelve total plants, all but one formed tubers at the end of the study period. Dahlia tubers are notoriously sensitive to high moisture environments when it comes to tuber rot. Figure 4 shows a representative sample of the tuber formation and root production that occurred in the AutoPot system. These results are nearly identical to what is observed in field grown Dahlias.

Discussion:

Maintaining a healthy aquaponics system is incredibly difficult in a greenhouse environment. It’s a downside to the technology that requires a high level of technical knowledge to maintain. The pH and temperature data indicates the absolute requirement for tighter control over these environmental variables. The three most important parameters in growing healthy Dahlias that bloom prolifically are pH, temperature, and photoperiod (day length) (Dole & Wilkins, 2005). Figure 1 illustrates the direct relationship between pH and macro and micronutrient availability (RGJ Aquaponics, 2021). This issue likely played a role in the drastic reduction in blooms in this study, as a pH around four suppresses the availability of critical growth and development nutrients like Phosphorous, Potassium, Sulfur, Calcium, and Magnesium. Future studies of Dahlias in these systems will require precise control over these variables to ensure the optimal results of aquaponics can be observed and documented. Water temperature was controlled using a powerful aquarium chiller helping to keep the water at an ideal temperature, even on hot days. However, the air temperature was much more difficult to control in this environment, which can have and likely did have a deleterious effect on Dahlia growth and blooming. Additionally, a 30% shade cloth was used to aid in keeping temperatures down in the greenhouse, but this has the unfortunate side effect of limiting the photosynthetically active light that can reach the plants, slowing their growth as well.

To date, there have been no published reports of Dahlias being grown either hydroponically or aquaponically. Anecdotal evidence can be found on the internet of Dahlias growing and blooming in hydroponics; however, no such evidence exists for aquaponics. This is the first published data showing that Dahlias can mature and flower normally in an aquaponics system, paving the way for future studies to optimize the conditions and environment to produce cut Dahlia flowers year-round, organically, and sustainably for commercial resale. Results here show that flowers were produced in three of the six cultivars grown, but that stem counts were dramatically lower than what can be grown in the field. Future research should focus on the three aforementioned parameters that will yield the best growth rates and stem counts for Dahlias: temperature, pH, and photoperiod.

Previous research on leafy greens grown in aquaponics documents a decrease in the use of pesticides in commercial production (reference) (Joyce, Goddek, Kotzen, & Wuertz, 2019). The rationale for this benefit is the added protection that a controlled environment and more healthy plant can confer to pest resistance. In this study only a slight decrease in the use of Neem Oil was observed in the AutoPot grown Dahlias. Future work may solidify a starker reduction in usage when conditions are optimized, and tighter integrated pest management (IPM) measures are employed.

The substantial reduction in water usage is a hallmark feature of plants grown in aquaponics. Previous research noted water savings of 95% over field grown crops (reference) (Dalsgaard, et al., 2013). Results here aligned almost perfectly with what has been observed in other growing contexts. Given that the water conserving nature of aquaponics is what makes it an attractive growing alternative, it is encouraging that the savings was replicated in the growth of Dahlias. Dahlias are extremely thirsty plants, requiring more water than most other cut flower varieties. A method that can minimize water use and still produce a high volume of stems is an appealing alternative.

The formation of storage tubers is a critical aspect of a healthy Dahlia plant. In the field, this has been the predominant propagation method of most growers, both hobbyists and commercial operations (however cutting propagation is becoming more common). The sale of tubers is lucrative and whole farm businesses are centered around the production of this one item. The results of this study show definitively that tubers can form in the AutoPot system if they are not kept constantly wet. The design of the AutoPot setup is to allow plants to access the nutrient rich water via root expansion, but not to keep the moisture level too high that other parts of the plant are constantly moist. This feature aided the production of healthy tuber clumps in almost all cases in the study, for both origination tissue types: tuber and rooted cutting. In the future it may be advantageous to only use rooted cuttings as the source for new Dahlia successions because they are easier to produce, require no storage, and take up much less grow space.

## Tables and Figures

| | **Monthly Average** | |
|---|---|---|
| **Month** | **pH** | **Temp (Celsius)** |
| June | 4.1 | 21.2 |
| July | 4.3 | 24.1 |
| August | 4.2 | 24.8 |
| September | 3.9 | 22.3 |
| October | 4 | 20.7 |
| November | 3.9 | 16.7 |

Table 1. Monthly average of pH and temperature readings via the Groline monitor (6-month duration). The pH was consistently low, even though regular additions of calcium carbonate and potassium carbonate (AquaUp) were added to raise the pH and keep it closer to 6. Temperature was regulated via an Active Aqua Chiller and was kept within an ideal range of 20-22 degrees, except for the hottest two months of the summer, July and August.

| | **Monthly Average** | | |
|---|---|---|---|
| **Month** | **Ammonia (ppm)** | **Nitrites (ppm)** | **Nitrates (ppm)** |
| June | 4 | 0.5 | 160 |
| July | 8 | 1 | 160 |
| August | 4 | 1 | 160 |
| September | 8 | 2 | 80 |
| October | 8 | 1 | 160 |
| November | 8 | 1 | 80 |

Table 2. Aquaponic system health was monitored for ammonia, nitrite, and nitrate concentration using the API Freshwater Master Test Kit. The test kit is limited in its measurement range maxing out at 8 ppm for ammonia, 5 ppm for nitrite, and 160 ppm for nitrate. It is possible these concentrations were significantly higher than what was detected.

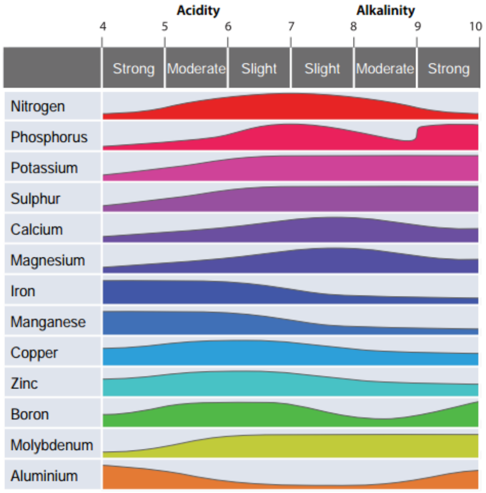

Figure 1. Nutrient availability in soil and water is dictated by pH. The chart shows that, depending on the pH, certain macronutrients and micronutrients could be more or less available for plants to absorb. It is evident that the low pH observed in this study could have had an impact on the growth rate and flowering of Dahlias. (RGJ Aquaponics, 2021)

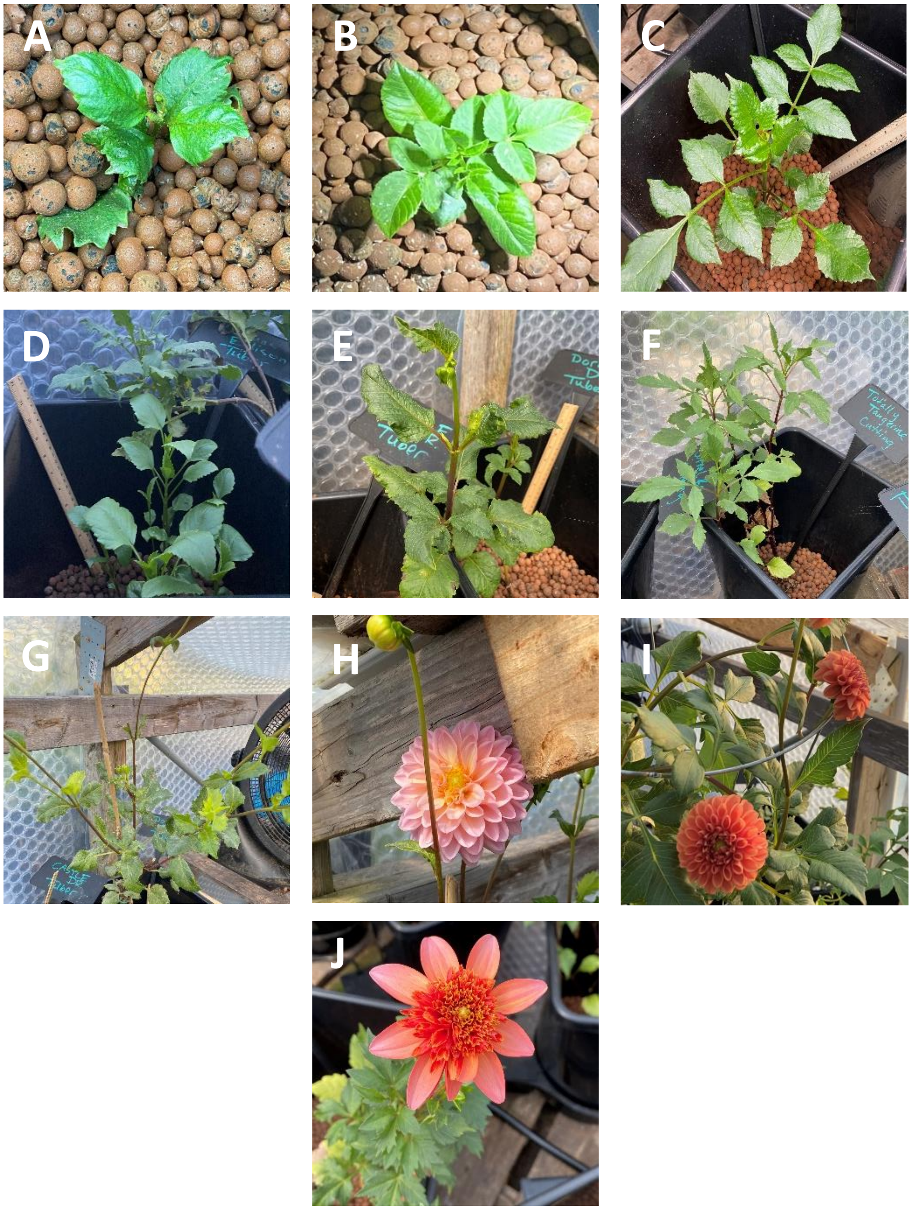

Figure 2. Dahlia growth and blooming progression throughout the 6 month study period. Dahlias grown in AutoPots and aquaponics matured and bloomed in a typical timeline as field grown Dahlias. Figure 2A shows the first few weeks of growth from a Cornel Bronze cutting; Figure 2B shows early stage growth of a Doris Duke cutting; Figure 2C shows a middle stage of a Totally Tangerine tuber; Figure 2D shows later stage growth of a Cornel Bronze tuber; Figure 2E shows a late stage of growth with buds of a Doris Duke cutting; Figure 2F shows later stages of growth and buds for a Totally Tangerine cutting; Figure 2G shows late stage growth and buds for a Doris Duke cutting; Figure 2H shows a full bloom Dahlia of a Doris Duke cutting; Figure 2I shows two full bloom Cornel Bronze Dahlias from a Cornel Bronze cutting; Figure 2J shows a full bloom Totally Tangerine Dahlia from a cutting.

| | **AutoPots** | **Field Grown** | |
|---|---|---|---|
| **Month** | **Water use in Liters** | **Water use in Liters** | **# of days irrigated** |
| June | 26.46 | 646.38 | 19 |
| July | 37.8 | 884.52 | 26 |
| August | 37.8 | 918.54 | 27 |
| September | 18.9 | 578.34 | 17 |
| October | 22.68 | 612.36 | 18 |
| November | 30.24 | 340.2 | 10 |
| **Average** | **28.98** | **663.39** | **19.5** |
| **Percent Savings** | | **95.6** | |

Table 3. Dahlias grown in AutoPots used 95.6% less water than field grown Dahlias. Utilizing the Flume Smart Water Monitor, data was recorded throughout the 6-month study period, averaged over the month, and compared to field grown Dahlias. Calculations approximating field grown irrigation amounts are described in Materials and Methods.

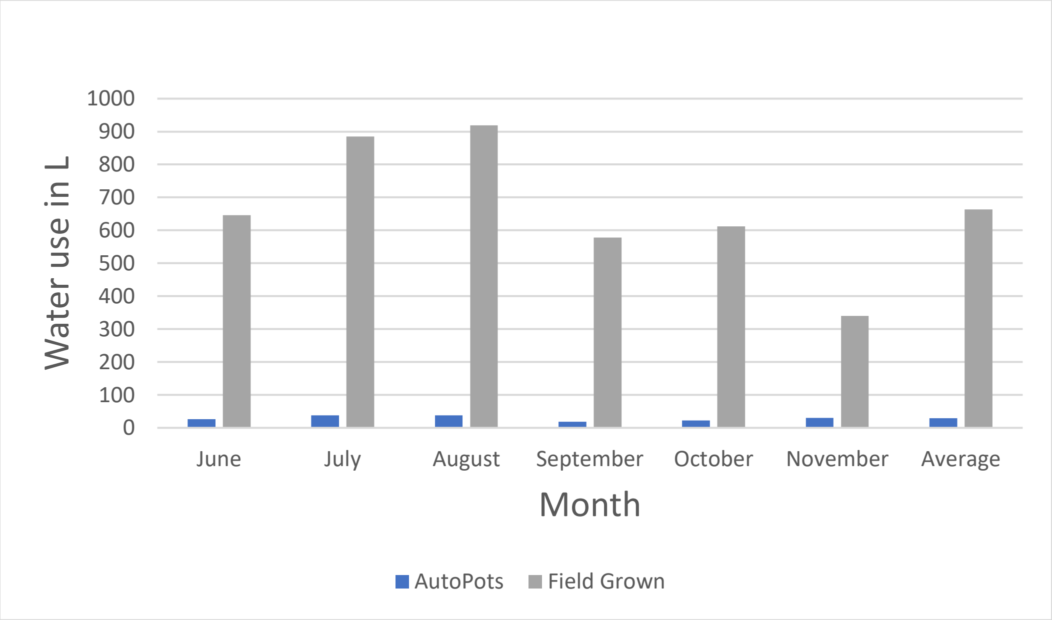

Figure 3. Graphical representation of water usage differential between AutoPot grown Dahlias and field grown Dahlias. AutoPots save a massive amount of water as compared to field grown Dahlias.

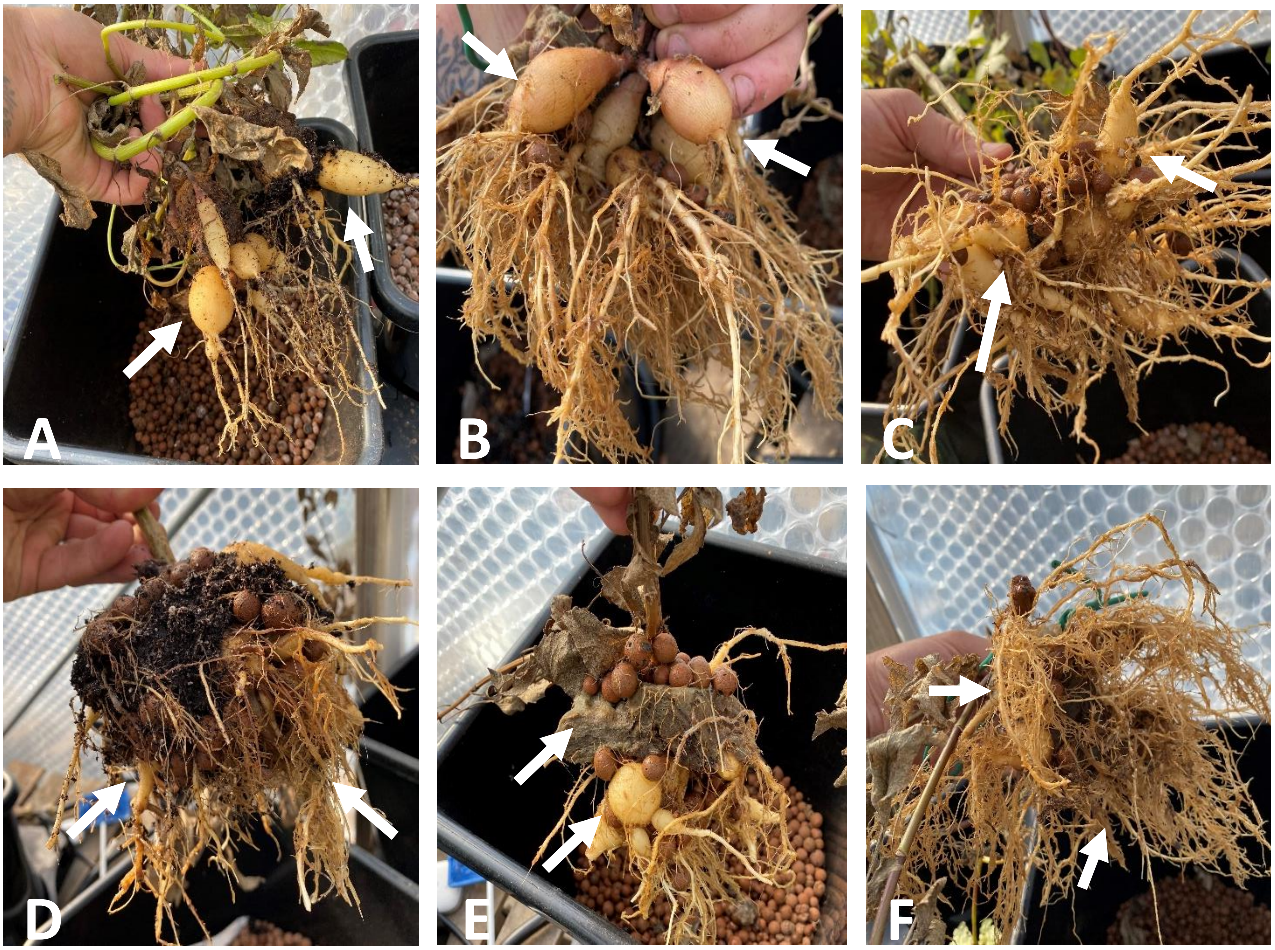

Figure 4. Dahlia tuber formation is not impacted by the AutoPot growing environment. Dahlia tubers were pulled from the AutoPots in November at the end of the study period to observe the impact of growing in AutoPots and aquaponics had on the formation of storage tubers. In both the tissue of origin conditions, tuber and rooted cutting, tuber formation was not impacted. Figure 4A shows robust, plump tubers formed, as indicated by the arrows, from a Doris Duke tuber origin. Figure 4B shows both healthy tuber formation, indicated by arrows, and extensive root network development from a Cornel Bronze tuber origin. Figure 4C shows healthy tuber clumps formed around a Thomas Edison tuber origin, as indicated by arrows. Figure 4D shows healthy root development and the beginnings of tubers forming from a Doris Duke rooted cutting origin. Figure 4E shows a significant tuber clump developing from a Castle Drive rooted cutting origin. You can see the dark brown agra-wool medium that was used to root the cutting before transplant. Figure 4F shows a highly branched root network with several thousand root hairs formed from a Totally Tangerine rooted cutting origin.

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