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Hydroponic and Soilless Culture Systems and Transplant Practices Influence Production of Basil (Omicum basilicum L.)

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Hydroponic and Soilless Culture Systems and Transplant Practices Influence Production of Basil (*Omicum basilicum* L.)

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Abstract

Two controlled-environment greenhouse experiments evaluated (1) plant growth and morphology of basil (Omicum basilicum L.) grown in three different hydroponic and soilless substrate systems and (2) seedling tray cell-count and transplant date into hydroponic culture effects on basil growth and yield at harvest. For the first experiment, four basil cultivars ('Genovese', 'Mrs. Burns Lemon', 'Sweet Thai', and 'Cinnamon') were grown in deep flow technique (DFT) hydroponics, nutrient film technique (NFT) hydroponics, and a novel shallow aggregate ebb-and-flood (SAEF) soilless substrate system and were harvested after 21 d. Plant yield and morphological characteristics measured at harvest included shoot fresh mass, shoot dry mass, leaf SPAD chlorophyll content, total leaf area per plant, plant height, node number, and internode length. For the second experiment, seedlings of 'Genovese' basil were germinated in a soilless peat-based substrate and grown in trays with cell-counts of 32, 50, 72, 105, and 162 and corresponding root volumes of (in cm3) of 98.1, 50.2, 38.5, 19.6, and 16.3, respectively. Basil seedlings for each tray type were transplanted in NFT hydroponic systems at 14 d, 21 d, and 28 d after sowing seed. Plants were harvested from NFT systems 35 d after sowing seed, and collected data at harvest included shoot fresh mass, shoot dry mass, plant height, and substrate pH and electrical conductivity (EC). Plant growth and morphology of basil cultivars differed between hydroponic and soilless culture systems, and harvested yields were overall greater for basil produced in DFT hydroponics compared to NFT hydroponics and SAEF soilless substrate systems. Basil seedlings grown in low cell-count trays and transplanted at earlier dates into NFT systems had greater yields compared to basil grown in high cell-count trays and transplanted at later dates. The combination of growing seedlings in trays with low cell-counts and early transplant into hydroponics likely increased yield by reducing potential for root restriction,

increasing nutrient and water availability per plant, and increasing individual plant spacing for greater accumulation of photosynthetic light.

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Dedication

This thesis is dedicated to my parents, Dan and Penny, who taught me to work and always drove me to finish tasks, and to my best friend Hannah who has continually supported me on the meandering path that has allowed me to explore my passions.

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CHAPTER 1. LITERATURE REVIEW

Controlled environment production of produce is an increasingly important part of the agriculture industry and had an annual value of $3 billion dollars that is expected to reach $4 billion by 2020 (Rabobank, 2013). The greenhouse industry in the United States is growing, and the number of farmers producing greenhouse tomatoes increased from 2,919 in 2007 to 7,949 in 2017 (National Agricultural Statistics Service, 2017). The value of greenhouse-grown tomatoes increased from $393 million in 2007 to $418 million in 2017. The number of U.S. farms growing greenhouse vegetables (excluding tomatoes) and herbs increased from 4,056 to 7,169 from 2007 to 2017. The value of greenhouse vegetables (excluding tomatoes) increased from $234 million to $329 million during the same time period.

Although large and medium-sized controlled environment food operations have become commonplace, a large proportion of the growth in this sector has been from relatively small farmers (4,000 square feet or less) producing primarily for local markets (National Agricultural Statistics Service, 2017). A significant factor driving this demand is the uniform quality and reliability of greenhouse-grown produce (Rabobank, 2013). Greenhouse produce is typically considered to be more uniform due to lower levels of pest damage and due to the higher degree of control over light levels, nutrients, carbon dioxide, and the availability of water.

There are other factors driving the growth of the greenhouse-grown produce industry. Food service buyers are willing to pay more for food grown locally (Starr et al. 2003). In 2015, over 163,000 farmers were reported to be marketing foods locally (Economic Research Service, 2015). The demand for local food offers significant revenue potential for farmers. One challenge facing traditional farm operations is that locally grown fresh produce is only seasonally available. During winter months, many traditional field-based farmers have little to no product to offer. This can make it difficult for farmers to fully capitalize on local food markets. For example, restaurants and grocery stores need year-round product on set schedules. Many municipalities have begun to operate winter farmers' markets (USDA, 2010), and farm to school programs (Izumi et al., 2010) are becoming more popular across the country. These programs offer another potential winter market for growers. If a grower cannot provide a consistent year-round predictable product, they may not be able to meet the customers' needs and thus unable to obtain and fulfill a contract. Due to the unpredictability of weather, prices for fresh produce can be high during winter months and those higher prices offer a significant opportunity for farmers who grow greenhouse food crops.

Traditional field agriculture requires significant expenditures for land and equipment to begin operation and this can be a major impediment in being able to begin a farming business (Freedgood and Dempsey, 2014). However, because of the high production per square foot for greenhouse food crops, greenhouse food crop operations can begin with minimal land and startup costs even with a small greenhouse (Mills, 2011; Cantliffe et al., 2008). Thus, smaller specialty crop farms, including those with greenhouse operations, provide an entry point (fewer economic barriers) into farming and the farm business can be grown as markets are established (Freedgood and Dempsey, 2014). Entrepreneurs are drawn to urban agriculture for a variety of reasons. Some seek to overcome the high energy costs of transporting food, or to improve inner-city access to fresh food (Kaufman and Bailkey, 2000). In 2018, 52% of greenhouse growers sold directly to consumers through an on-farm market or garden center (Regelbrugge, 2018). Others are drawn to urban agriculture in order to be more involved in their communities (Mincyte and Dobernig, 2016).

Greenhouses are also an important part of the local food movement because they allow production in urban environments (Sanyé□Mengua et al. 2013) and on non-arable land (Zhang et al., 2019). These urban greenhouses can then lower production costs through decreasing fuel use and transportation costs (Pahlavan, et al., 2012). Due to the controlled environment of greenhouse production, pesticide use is significantly less than in field grown crops, and the integration of biological controls into greenhouses may eliminate or significantly limit the use of pesticides in controlled environments (van Lenteren, 2000). This is important because food industry buyers are typically willing to pay more for food grown without the use of pesticides (Star, et al. 2003). Growing produce in a greenhouse allows for more control over environmental conditions than traditional agriculture. Controlling watering schedules and water usage (Giacomelli, 1998) is more efficient in a greenhouse, and the use of hydroponic or soilless systems can provide further control over growing conditions. Typically, soilless cultivation systems utilize a recirculating fertilizer solution that allows for the careful application of nutrients. Hydroponic systems commonly used in greenhouses allow for more accurate control over the electrical conductivity (EC) and pH levels of a fertilizer solution (Savvas ,2013), and generally lower water usage compared to field crops.

There are some disadvantages to greenhouse production, however. While occurrences of pests can be less frequent in greenhouses, infestations can spread quickly within enclosed spaces and damage or destroy entire crops (Van Lenteren and Woets, 1988). Although the value of greenhouse produce is often higher than field grown produce (Cantliffe et al., 2008) the input costs can be higher due to cost of maintaining the environmental conditions within the greenhouse (Pahlavan et al., 2012). Although a simple Quonset-style greenhouse can be built for around $25,000 (Mills, 2011) this cost can be prohibitive for some growers.

Greenhouse food production often uses hydroponic or soilless agriculture systems, and the two most common types are nutrient film technique (NFT) and deep flow technique (DFT). With an NFT system, a thin film of nutrient solution, 2 to 3 mm deep, runs in the bottom of a tube, trough or gutter made of HDPE and PVC and is recirculated continuously by pumping water from a nutrient solution reservoir. DFT systems use a large tank of nutrient solution. Plants are grown in net pots which are placed into a foam board that is floating on top of the nutrient solution. The entire solution is aerated by an air bubbler in order to provide adequate root oxygenation (Park and Kurata, 2008).

Some ornamental greenhouse crop growers could benefit from diversifying into food crops (Regelbrugge, 2018). Certain high value food crops could become an important part of their business models, particularly when marketed locally or during a time when those crops are not typically available. Ornamental growers that utilize hydroponic or soil-less culture predominately use ebb and flow or dutch tray systems that are not typically used for growing these more profitable crops like lettuce and herbs. Purchasing all new equipment for growing these crops would be cost prohibitive, and not make financial sense for most growers. Utilization of greenhouse space that has already been constructed and the use of existing equipment are both strategies to avoid further investment.

To address this issue, researchers at the University of Arkansas evaluated the use common ornamental greenhouse equipment for hydroponic lettuce production. Chidiac (2017) demonstrated that using a shallow layer of aggregate inside commonly used ebb and flow systems can result in an effective system for growing lettuce. In this study, was determined that an aggregate depth of 38 mm, irrigated every two hours, can produce yields of lettuce comparable to DFT and NFT hydroponic systems. This shallow aggregate ebb and flow (SAEF) system uses a pump to flood the aggregate-filled dutch trays to a predetermined depth of 38 mm, and then the reservoir drains back into the holding tank immediately after the pump is shut off. The use of dutch trays or other existing equipment for food crop production would allow ornamental producers to utilize existing systems to enter this segment of the market without the expenses associated with purchasing new equipment or adjust current labor practices.

With the SAEF system, there can be considerable energy and water savings because the pumps are not running continually and only about 2 cm of water is pumped into the tank, which is immediately drained from the system. This method has been shown to also help to prevent tipburn in lettuce (Chidiac, 2017). The aggregate in the system provides support for plant roots and will allow for stability with larger individual plants.

Basil is a valuable and popular culinary herb, with strong year-round demand for culinary use (Wolf, 2005), and an herbaceous annual and a member of the mint family (Lamiaceae). It has been cultivated as both food and medicine for centuries by humans (Pushpangadan, 2012). This has resulted in basil becoming economically valuable as a culinary crop and for its nutraceutical qualities. It is one of the most popular fresh or dried herbs (Simon, et al, 1999) and has significant demand during all times of the year for commercial and at-home culinary use. Even in the mild climate of the southeastern United States, basil can be damaged during a cold winter leaving the product unsuitable for harvest (Csizinszky, 1992). Within the continental United States, the cultivation of basil in a controlled environment is favorable for year-round production due to the environmental controls that can prevent low-temperature damage to basil crops. No research has been conducted comparing basil cultivar performance within a SAEF system.

Another factor of interest to growers is the size of media plugs used in basil production, as is the amount of time that the crop is left in propagation stage before transfer to the hydroponic system. Both transplant size and date can influence final crop yield by restricting root volume and stunting plant growth (Fisher et al., 2006; Latimer et al., 1991; van Iersel, 1997; Weston, 1988), although there is limited published work studying these factors in hydroponic systems. Initial root volume can influence plant growth, with larger liner sizes resulting in reducing production time in *Calibrachoa sp.* by nearly two weeks (Fisher, 2006). Further research related to transplant size and date could aid hydroponic growers in creating efficient production schedules to maximize their yields, as well as lowering fuel and labor costs through the improved timing of crops.

Objectives of this project were to compare three hydroponic systems for basil production in a controlled environment, and to study the influence of transplant size and date on final crop yield within an NFT hydroponic system.

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CHAPTER 2. COMPARING BASIL CULTIVAR PERFORMANCE WITHIN HYDROPONIC SYSTEMS

Abstract

Four basil cultivars (‘Genovese’, ‘Mrs. Burns Lemon’, ‘Sweet Thai’, and ‘Cinnamon’) were grown in deep flow technique (DFT) hydroponics, nutrient film technique (NFT) hydroponics, and a novel shallow aggregate ebb-and-flood (SAEF) soilless substrate system and were harvested after 21 d. Plant yield and morphological characteristics measured at harvest included shoot fresh mass, shoot dry mass, leaf SPAD chlorophyll content, total leaf area per plant, plant height, node number, and internode length. Plant growth and morphology of basil cultivars differed within and between hydroponic and soilless culture systems. Overall, harvested fresh and dry mass yields tended to be greater for basil produced in DFT hydroponics compared to NFT hydroponics and SAEF soilless substrate systems

Introduction

Basil (*Omicum basillicum.* L.) is a culinary herb increasingly produced using hydroponic and soilless substrate culture to meet the growing market demand in North America (Resh, 2001; Walters and Currey, 2015; Wolf, 2005). Potential yields with hydroponics and soilless culture can be greater compared to conventional soil-based production, partially because production often takes place in controlled environments, where plants are more protected from biotic and abiotic stresses. However, hydroponic and soilless culture systems can differ in their effects on plant growth, crop management requirements, and operating costs (Blok et al., 2017; Walters and Currey, 2015), and therefore selection of a hydroponic or soilless substrate system is a critical grower decision.

Nutrient film technique (NFT) and deep flow technique (DFT) are common hydroponic systems used for commercial production of basil and other culinary herbs (Fenneman et al., 2013; Hochmuth and Cantliffe, 2014; Jensen, 2002; Morgan, 2005). Nutrient film technique systems contain plants within narrow gutters or troughs, where developing root systems are exposed to a continually flowing thin film of nutrient solution. Alternatively, DFT systems expose plant roots to a relatively large volume of nutrient solution, typically ranging from six to eight inches in depth, where roots are completely submerged in nutrient solution. Soilless substrates are also used for the production of culinary herbs, where typical substrate components include clay or gravel aggregates, peatmoss, coconut coir fiber, vermiculite, sand, perlite, synthetic foams and rockwool (Maher et al., 2008; Resh, 2003). Commercial growers using NFT and DFT hydroponic and soilless substrate systems maintain strict control over nutrient and water supply for optimal plant growth, managing critical factors such as solution pH, electrical conductivity (EC), and individual nutrient concentrations using a combination of automation and hands-on approaches.

The objective of this study was to evaluate the growth and morphology of four common commercial basil cultivars in two common hydroponic culture systems (NFT and DFT) and one novel shallow aggregate ebb-and-flood (SAEF) soilless substrate system.

Materials and Methods

In 2017, a greenhouse experiment was conducted to evaluate four cultivars of basil grown using three different hydroponic system types to determine effects on shoot growth, leaf SPAD chlorophyll content, plant height, and leaf area. Hydroponic systems consisted of nutrient film technique (NFT), deep flow technique (DFT), and a shallow aggregate ebb-and-flood system (SAEF). The basil cultivars were: 'Genovese', 'Mrs. Burns Lemon',' Cinnamon', and 'Sweet Thai', and represented cultivars common to commercial hydroponic production (Walters and Currey, 2015). The experiment was conducted in a controlled-environment glasshouse at the University of Arkansas in Fayetteville, AR (36.0764° N, 94.1608° W). Greenhouse heating and cooling set points were set at 23°C and 27°C, respectively, and all plants in the experiment were grown under ambient light conditions and photoperiod.

Plant culture. Raw untreated seed for each cultivar (Johnny's Selected Seeds, Waterville, ME) were sown into 162-cell rockwool sheets (A/O sheets, Grodan, The Netherlands) at three seeds per cell and germinated on a greenhouse bench. During germination and early plant growth, rockwool sheets were sub-irrigated for two minutes every hour using a hydroponic nutrient solution complete with all plant essential nutrients, where the applied solution pH and electrical conductivity (EC) was 5.9 and 1.0 $mS \cdot cm^{-1}$, respectively. Basil seedlings were transplanted into hydroponic systems 14 d after sowing, when all plants had at least two true leaves.

Hydroponic systems. Three systems were used in this study:

The NFT system consisted of 12 separate 150×10×5 cm polypropylene hollow gutters (AM Hydro, Arcata, CA) positioned on a 2.5% slope across the top of the greenhouse bench. Basil were transferred into 5 cm diameter holes drilled into the top of each gutter, so that the rockwool cube and root system were located within the gutter interior. Hydroponic nutrient solution was continually pumped from a reservoir tank below the bench and into each gutter at 126 $mL \cdot min^{-1}$, where nutrient solution flowed over plant roots before draining back into the reservoir. Each gutter held eight basil plants, and individual plant spacing both between and within gutters was maintained at 20 cm. Three gutters were used for each cultivar for a total of 24 basil plants per cultivar (3 gutters × 8 plants/gutter = 24 total plants per cultivar), and gutters containing the same cultivar were adjacent.

The DFT system consisted of two separate polypropylene tanks measuring 90×175×15 cm (Botanicare, Chandler, AZ) positioned on top of two adjacent greenhouses benches and filled with hydroponic nutrient solution. Each tank held a 90×175×5 cm polystyrene foam board (Dow, Midland, MI), which floated on the surface of the nutrient solution contained within each tank. Basil transplants were transferred into 5 cm diameter net baskets (one transplant per basket), which fit into holes drilled into the polystyrene foam board. Roots were submerged and allowed to grow into the nutrient solution, which was continually aerated using an electric air pump. The DFT system held 80 plants total (40 plants per tank), and plants were oriented in 16 rows with five plants per row. Each cultivar occupied four adjacent rows (4 rows × 5 plants/row = 20 total plants per cultivar), and plant spacing was the same as used for the NFT system.

The SAEF systems consisted of two separate polypropylene tanks measuring 125×250×15 cm (Botanicare, Chandler, AZ) positioned on top of two adjacent greenhouses benches and partially filled with expanded round clay aggregate (Hydroton, Germany) to a depth of 38.5cm $\pm$ 0.5 cm. Hydroponic nutrient solution was pumped from a reservoir tank below the benches and into both tanks simultaneously at 126 $mL \cdot min^{-1}$ for 2 minutes, every 2 hours, allowing the nutrient solution to cover the roots before draining back into the reservoir. The SAEF system held 80 plants total (40 plants per tank), and plants were oriented in 16 rows with five plants per row. Each cultivar occupied four adjacent rows (4 rows × 5 plants/row = 20 total plants per cultivar), and plant spacing was the same as used for the NFT system.

The hydroponic nutrient solution was the same across all three systems, and consisted of (in $mg \cdot L^{-1}$) 195.1 nitrogen (N), 34.1 phosphorus (P), 267.2 potassium (K), 171.0 calcium (Ca), 60.6 magnesium (Mg), 75.8 sulfur (S), 4.5 iron (Fe), 1.0 manganese (Mn), 0.5 boron (B), 0.1 copper (Cu), and 0.1 zinc (Zn) formulated using commercial-grade calcium nitrate, potassium nitrate, potassium sulfate, monopotassium phosphate, magnesium sulfate heptahydrate, iron-DTPA (11%), manganese sulfate monohydrate, zinc sulfate heptahydrate, boric acid, copper sulfate pentahydrate, and ammonium molybdate tetrahydrate mixed in tap water. Solution electrical conductivity (EC) and pH were monitored daily and maintained at 1.4±0.05 $mS \cdot cm^{-1}$ and 5.9±0.2, respectively, by daily adjustments to the fertilizer concentration in the replenishment solution and additions of 0.1 *N* sulfuric acid (H_2SO_4).

Experimental design. The experiment was a split-plot factorial with culture system (NFT, DFT, and SAEF systems) as the whole plot factor and basil cultivar ('Genovese', 'Mrs. Burns Lemon', 'Cinnamon', and 'Sweet Thai') as the split-plot factor, with three replicates per culture system-cultivar treatment combination. Replication was achieved by conducting three separate experimental runs, where each experimental run contained all three hydroponic systems and cultivars and served as one replication. Placement of cultivar groups was randomized within each system for each replication. Statistical variances were determined not different between experimental runs using an F test. Each experimental run started with the transfer of basil seedlings into the different culture systems, which occurred on 19 May 2017, 14 Aug 2017, and 1 Jan 2018.

Data collection and statistical analysis. Basil plants were harvested for data collection 21 d after seedlings were transferred into the different culture systems for each experimental run. Data collection included measuring shoot fresh mass, shoot dry mass, leaf SPAD chlorophyll content, plant height, number of nodes, internode length, and total leaf area per plant. Culture systems differed in total number of basil plants per cultivar; however, the experimental units used for data collection were identical across systems. Each experimental unit consisted of six basil plants harvested per cultivar and culture system treatment, where harvested plants were taken from the center of each group of cultivars within each system. The extra plants surrounding those harvested for data collection served as buffer plants and were otherwise not used. Data were collected on each of the six harvested plants, and averaged to obtain one value per experimental unit or replicate.

Leaf SPAD chlorophyll content was measured non-destructively using a portable Minolta SPAD meter (Minolta Corp.; Tokyo, Japan), where each measurement was the average SPAD taken across three randomly selected and fully expanded leaves per plant. Plant height and number of nodes were measured, and average internode length was calculated by dividing the height by the number of nodes per plant.

Shoot fresh and dry mass were measured by destructively harvesting shoot tissue. Shoots were cut at the base of the stem and just above the rockwool surface and immediately weighed for fresh mass determination. Fresh shoot tissue was oven-dried at 70°C for two d for dry mass determination. Total leaf area was measured before shoot tissue was oven-dried using a LI-COR 3050C leaf area meter (LI-COR; Lincoln, NE).

Analysis of variance from PROC GLIMMIX (SAS Institute, Cary, NC) was used to evaluate culture system and cultivar effects on shoot fresh mass, shoot dry mass, leaf SPAD chlorophyll content, leaf area, plant height, node number, and internode length. Mean separation used Tukey's honestly significant difference (hsd) at α=0.05.

Results

Shoot fresh and dry mass per plant at harvest differed between cultivars and culture systems (P<0.05; Table 2). Shoot fresh mass was greatest for 'Genovese' (104.6 g) and 'Cinnamon' (97.1 g) and lowest for 'Sweet Thai' (71.0 g). Dry mass was greatest for 'Genovese' (8.7 g) and lowest for 'Mrs. Burns Lemon' (7.3 g). Shoot fresh and dry mass across cultivars was consistently greatest for DFT at 102.6 g and 9.1 g, lowest for NFT at 75.6 g and 6.6 g, and intermediate for SAEF at 90.4 g and 8.3 g, respectively. 'Sweet Thai' basil was the only cultivar where fresh and dry mass were similar between SAEF and NFT systems (data not shown), which resulted in the interaction effect between cultivar and system as reported in Table 2.

Total plant height and leaf area at harvest were also influenced by cultivar and culture system ($P<0.05$; Table 2). Cultivars 'Cinnamon' (13.8 in) and 'Mrs. Burns Lemon' (14.2 in) were taller than 'Genovese' (12.3 in) and 'Sweet Thai' (11.8 in). Overall plant height also decreased for cultivars grown in in NFT (12.3 in) versus DFT (13.7 in) and SAEF (12.1 in) systems. Leaf area was also decreased for NFT (1417.8 cm^2) compared to DFT (1798.5 cm^2) and SAEF (1801.3 cm^2), and was lowest for 'Sweet Thai' (1455.8 cm^2) compared to other cultivars. Similar to shoot fresh and dry mass, plant height and leaf area were similar between NFT and SAEF for 'Sweet Thai' (data not shown), resulting in the interaction effect between cultivar and system (Table 2).

Leaf SPAD chlorophyll content differed between cultivars at harvest ($P<0.0001$), but was not influenced by culture system (Table 2). In this experiment, leaf SPAD chlorophyll content values greater than 30 indicated visibly green foliage. The lower leaf SPAD chlorophyll content for 'Mrs. Burns Lemon' (leaf SPAD of 27.6) is characteristic of this cultivar, where genetic foliage color tends to be pale green and yellow.

Node number per plant and average internode length at harvest differed between cultivars at harvest ($P<0.05$), but were not affected by culture system (Table 2). Although statistically significant, the number of nodes per plant were only slightly different between cultivars, ranging from 5.2 nodes for 'Genovese' to 7.2 nodes for 'Cinnamon'. Similarly, internode length as slightly greater for ‘Genovese’ (2.4 in) compared to ‘Cinnamon’ (2.1 in), ‘Mrs. Burns Lemon’ (2.0 in), and ‘Sweet Thai’ (2.1 in) as shown in Table 2.

Discussion

Results indicated basil cultivars differed in growth rate and morphology, which was also influenced by hydroponic and soilless substrate system. Overall, ‘Genovese’ and ‘Cinnamon’ tended to produce greater shoot fresh and dry mass at harvest compared to ‘Mrs. Burns Lemon’ and ‘Sweet Thai’. Similar trends were reported for these cultivars grown in NFT and DFT hydroponics by Walters and Currey (2015). Cultivars ‘Genovese’, ‘Cinnamon’, and ‘Sweet Thai’ had greater leaf SPAD chlorophyll contents compared to ‘Mrs. Burns Lemon’. However, the cultivar ‘Lemon’ is generally characterized as having a more yellow leaf color, and there was no evidence suggesting nutrient deficiency or unhealthy plants.

Hydroponic and soilless substrate systems influenced shoot yields at harvest, which overall greatest for DFT, lowest for NFT, and intermediate for SAEF. Walters and Currey (2015) also found across 35 different basil cultivars that shoot dry mass was on average 2.6 g greater for plants grown in DFT compared to NFT systems. Blok et al. (2017) also reported greater growth rates of chrysanthemum (*Chrysanthemum sp.* L.) in DFT compared to NFT, and suggested the thin film of solution with NFT supplied water and nutrients (including oxygen) at rates below the maximum root uptake potential, therefore limiting plant growth. Localized depletion of nutrients and oxygen in the rhizosphere is also known to occur with NFT (Blok et al., 2017; Sonneveld and Voogt, 2008), particularly with long-term crops and high temperature conditions. In contrast, DFT systems allow roots to develop in a relatively large solution volume, minimizing potential for root restriction and maximizing uptake of nutrients and water. Nutrient and water availability and root uptake in soilless substrate culture is more complex and influenced by several interacting factors including nutrient concentrations, applied irrigation volumes and frequency, leaching fraction, and substrate chemical and physical properties (Bunt, 1988).

Conclusions

Plant growth and morphology differs between basil cultivars and can be influenced by hydroponic and soilless culture system. In this study, harvested yields were overall greater for basil produced in DFT hydroponics compared to NFT hydroponics and SAEF soilless substrate systems. Differences in plant growth between systems may have resulted from differences in the distribution and availability of nutrients and water for plant uptake.

Table 2-1. Cultivar effects on total shoot fresh mass, total shoot dry mass, leaf SPAD chlorophyll index, total leaf area, average plant height, average node number, and average internode length after 21 d (after transplant??) and at harvest in deep flow technique (DFT), nutrient film technique (NFT), and shallow aggregate ebb-and-flood (SAEF) hydroponic systems.

Hydroponic system	Cultivar	Total shoot fresh mass (g) [y]	Total shoot dry mass (g)	Leaf SPAD chlorophyll index	Total leaf area (cm^2)	Average shoot height (in)[x]	Average node number	Average internode length (in)
DFT	Cinnamon	110.8 ab	9.4 a	35.4 a	1805 a	14.1 a	6.8 ab	2.0 bc
	Genovese	126.1 a	10.3 a	32.0 b	2014 a	13.7 a	5.6 b	2.5 a
	Lemon	81.4 b	7.1 b	27.8 c	1540 b	13.6 a	7.4 a	1.8 c
	Thai	92.0 b	9.4 a	37.5 a	1835 a	13.2 a	6.0 ab	2.2 ab
		**	**	***	**	NS	*	**
NFT	Cinnamon	76.9 a	6.2 a	33.2 b	1376 a	12.7 a	6.1 ab	2.1 a
	Genovese	89.6 a	7.4 a	33.1 b	1541 a	11.4 a	5.0 b	2.3 a
	Lemon	70.4 a	5.9 a	25.7 c	1416 a	14.0 a	7.1 a	2.0 a
	Thai	66.1 a	6.8 a	38.1 a	1338 a	11.2 a	5.7 b	2.0 a
		NS	NS	***	NS	NS	*	NS
SAEF	Cinnamon	103.6 a	9.0 a	35.9 b	1920 a	14.5 ab	6.6 a	2.2 a
	Genovese	98.2 a	8.4 a	32.9 c	1825 a	11.8 bc	4.9 b	2.4 a
	Lemon	105.0 a	8.9 a	29.4 d	2266 a	15.0 a	7.2 a	2.1 a
	Thai	54.9 b	6.9 a	40.9 a	1194 b	11.0 c	5.5 b	2.0 a
		*	NS	***	**	*	***	NS

Cultivar effects were analyzed separately for each system, and data represent least-square means of three replicates per cultivar. Mean separation used Tukey's honestly significant difference (hsd) with α=0.05.

[x]Values indicate average plant height, node number, and internode length of three shoots per replicate.

[y]NS, *, **, and *** correspond to not significant, $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.0001$, respectively.

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CHAPTER 3. THE EFFECTS OF TRANSPLANT ROOT VOLUME AND TRANSPLANT DATE ON BASIL PERFORMANCE WITHIN A HYDROPONIC SYSTEM

Abstract

Seedlings of 'Genovese' basil were germinated in a soilless peat-based substrate and grown in trays with cell-counts of 32, 50, 72, 105, and 162 and corresponding root volumes of (in cm^3) of 98.1, 50.2, 38.5, 19.6, and 16.3, respectively. Basil seedlings for each tray type were transplanted in NFT hydroponic systems at 14 d, 21 d, and 28 d after sowing seed. Plants were harvested from NFT systems 35 d after sowing seed, and collected data at harvest included shoot fresh mass, shoot dry mass, plant height, and substrate pH and electrical conductivity (EC). Basil seedlings grown in low cell-count trays with larger root volumes per plant and transplanted at earlier dates into NFT systems had greater yields compared to basil in high cell-count trays and transplanted at later dates. The combination of growing seedlings in trays with low cell-counts and early transplant into hydroponics likely increased yield by reducing potential for root restriction, increasing nutrient and water availability per plant, and increasing individual plant spacing for greater accumulation of photosynthetic light.

Introduction

Grower decisions regarding seedling tray type and transplanting date of basil (*Ocimum basillicum* L.) into hydroponic and soilless systems may influence plant growth and final harvested yield. Standard seedling trays often have similar length and width dimensions and are characterized by the number of plants per tray, or tray cell-count. A greater cell-count indicates a greater number of plants per tray, higher seedling density, and a lower root volume per plant. Past research with floriculture crop species has shown that transplant production in trays with higher cell-counts and lower root volumes have greater potential to restrict roots and stunt plant growth following transplant to larger containers or the landscape (van Iersel, 1997; Latimer, 1991). Fisher (2006) showed with calibrachoa that high cell-count trays combined with later transplant dates, or a longer transplant production period, increased the total amount of time needed to produce a marketable container crop.

Tray type and transplant date may also impact crop scheduling and the production efficiencies. For example, trays with high cell-counts (i.e. low root volume per plant) would allow for greater planting densities and efficient use of growing space for transplant production but would also require earlier transplant into hydroponic/soilless systems to avoid potential root restriction. Trays with lower cell-counts (i.e. greater root volume per plant) may require additional growing space and time during transplant production, but because seedlings would be larger at transplanting, the amount of time plants are in hydroponic/soilless systems before harvest could be reduced. Typical guidelines for commercial growers recommend transplanting seedlings of culinary herbs into hydroponic and soilless systems anywhere from four to eight weeks after sowing (Resh, 2003). However, these guidelines often do not take into consideration tray type and transplant date, as well as other factors likely influencing transplant production such as environmental conditions, irrigation/fertilization practices, plant species and cultivar.

The objective of this study was to evaluate the effects of transplant tray type and transplant date on plant growth and yield at harvest for basil grown in nutrient film technique (NFT) hydroponics We hypothesized that basil seedlings grown in low cell-count trays with larger root volumes and transplanted into hydroponic culture at earlier dates would result in the greatest yield at harvest.

Materials and Methods

In spring 2019, a greenhouse experiment evaluated five seedling tray types (Table 3-1) and three transplant dates into NFT hydroponic systems for effects on shoot fresh mass, shoot dry mass, and shoot height at harvest. Seeds of ‘Genovese’ basil (Johnny's Selected Seeds, Waterville, ME) were sown into seedling trays containing cells of a cylindrical paper-wrapped and peat-based soilless substrate (Elleguard, Denmark) at one seed per cell. Greenhouse heating and ventilation set points were 19°C and 23°C, respectively. Plants received ambient light and approximately 200 $\mu mol \cdot m^{-2} \cdot d^{-1}$ of photosynthetically active radiation (PAR) from 1000 watt high-pressure sodium lamps from 0700 HR to 1900 HR.

Trays were placed on a greenhouse bench for seed germination and transplant growth, and trays were sub-irrigated as needed using a complete hydroponic nutrient solution (16-4-18 Jack’s Oasis Hydro FeED, JR Peters, Allentown PA) mixed at 200 $mg \cdot L^{-1}$ N in tap water. Applied nutrient solution EC and pH was 1.3 $mS \cdot cm^{-1}$ and 5.9, respectively. Starting at 14 d after sowing, basil seedlings were transplanted into hydroponic NFT systems for the remainder of the experiment.

Similar NFT systems to those used in Expt. 1 were set up on greenhouse benches, and the same nutrient solution previously mentioned for seedling transplant production was continually pumped from a reservoir tank below the bench and into each gutter at a rate of 126 $mL \cdot min^{-1}$. Solution pH was maintained between 5.5 and 6.5 and solution EC between 1.5 $mS \cdot cm^{-1}$ and 2.0 $mS \cdot cm^{-1}$ by daily adjustments to the fertilizer concentration in the replenishment solution and additions of 0.1 *N* sulfuric acid (H_2SO_4).

Each NFT system contained 12 separate 150×40×4 cm polypropylene gutters (AM Hydro, Arcata, CA) positioned on a 2.5% slope across the top of the greenhouse bench. The top of each gutter was removed and replaced with 6 mm white-black horticultural plastic film with the white side facing upwards. Substrate for each transplant was pushed through perpendicularly-cut slits in the plastic film, allowing direct contact between the substrate and flowing nutrient solution, with individual plants spaced between and within gutters at 20 cm.

The experiment started on 3 May 2019 with sowing of seed and consisted of a 5 tray type × 3 transplant date factorial using a randomized complete block design. Seedling trays differed in tray cell-count and root volume per plant, with cell-counts of 32, 50, 72, 105, and 162 per tray and corresponding root volumes of (in cm^3) of 98.1, 50.2, 38.5, 19.6, and 16.3, respectively, as shown in Table 3-1.

Seed were sown into three separate individual trays per tray type, where each individual tray served as one replicate for a total of three replicates per tray type. Two transplants were taken from the center of each tray type replicate and transferred to NFT systems at 14 d, 21 d, and 28 d after sowing. Three NFT systems were located on the same greenhouse bench, and transplants taken from the first, second, and third replicates per tray type were transferred to the first, second, and third NFT system, respectively. At each transplant date, the newly transferred plants within each tray type were randomized within two gutters per NFT system, resulting in a total of six plants per tray type and transplant date treatment combination. In addition, all gutters per NFT system were re-randomized at the second and third transplant dates (21 d and 28 d respectively). Extra plants not used for experimentation were placed at the front and back of each gutter as well as in additional gutters surrounding replicate plants as a buffer. Plants were grown in the NFT systems until harvest and final data collection.

Data collection and analysis. Basil were harvested from NFT systems on 8 June 2019 (35 d after sowing seed) and final data were collected on each plant per tray type and transplant date treatment combination. Within each NFT system, the two plants per treatment served as sub-replicates, and sub-replicate data were averaged for one replicate value and data analysis. Total shoot height per plant was measured just prior to harvest. Shoot tissue was cut at the base of the stem above the substrate surface and immediately weighed for shoot fresh mass determination. Shoot tissue was then oven-dried at 70°C for two d for shoot dry mass determination. At harvest, pH and EC was measured in solution squeezed from the substrate of each plant using the plug-squeeze method described by Scoggins et al. (2002). Analysis of variance from PROC GLM (SAS Institute, Cary, NC) was used to evaluate tray size and transplant date main and interaction effects on substrate pH and EC, shoot fresh mass, shoot dry mass, and plant height at harvest. Mean separation used Tukey's honestly significant difference (hsd) at $\alpha=0.05$.

Results

Tray type and transplant date had main effects, but no interaction, on final shoot fresh mass, shoot dry mass, and shoot height at harvest ($P<0.05$, Figures 3-1 and 3-2). Overall, harvested shoot fresh mass was greatest for plants transferred to NFT systems at the first transplant date (14 d after sowing, 139.4 g per shoot) and lowest at the third transplant date (28 d after sowing, 50.5 g per shoot), with the second transplant date being intermediate (21 d after sowing, 116.5 g per shoot) as shown in Fig. 3-1. Trends for shoot dry mass were similar to those observed for shoot fresh mass (Figure 3-1A). Shoot dry mass at harvest was greatest (10.9 g per shoot), intermediate (9.3 g per shoot), and lowest (4.2 g per shoot) for the first, second, and third transplant dates, respectively (Figure 3-1B). Shoot height was greatest for the first and second transplants dates (75.1 cm and 80.5 cm) and was lower (56.6 cm) for the third transplant date (Figure 3-1C).

Transplant tray type and cell-count had main effects on shoot fresh mass ($P \leq 0.0001$), shoot dry mass ($P \leq 0.0001$), and shoot height ($P \leq 0.0001$) at harvest (Figure 3-2). Overall, shoot fresh mass increased as tray cell-count decreased and root volume increased (Figure 3-2), where harvested fresh mass was greatest for plants grown in 32-cell trays (148.51 g) and lowest for 162-cell tray (72.82 g). The plants grown in intermediate tray sizes (50-cell, 72-cell and 105-cell) had fresh masses of 116.40 g, 94.48 g, and 78.11g, respectively. Trends for shoot dry mass were similar to those observed for shoot fresh mass, where shoot dry mass increased as tray cell-count decreased and root volume increased (Figure 3-2B), with dry mass being greatest for plants grown in 32-cell trays (12.17 g), and lowest for the 162-cell tray (5.50 g). The plants in intermediate tray sizes (50-cell, 72-cell and 105-cell) had dry masses of 9.46 g, 7.51 g, and 6.05 g, respectively. Shoot height at harvest was also greatest for plants grown in 32-cell trays (83.83 cm) and lowest for plants in 162-cell trays (58.94 cm), indicating that plant height also increased as tray cell-count decreased and root volume per plant increased (Figure 3-2C). The plants in intermediate tray sizes (50-cell, 72-cell and 105-cell) had shoot heights of 76.00 cm, 71.33 cm and 63.50 cm, respectively.

Tray type and transplant date had main effects, but no interaction, on substrate pH and EC at harvest ($P \leq 0.05$, Table 3-2). The same substrate was used across tray types, and initial substrate pH and EC at the time of sowing averaged 5.6 and 0.9 $mS \cdot cm^{-1}$, respectively (data not shown). As shown in Table 3-2, substrate pH was greater for plants transplanted at 14 d (pH 6.17) and 21 d (pH 5.98) after sowing and remained lower for plants transplanted after 28 d (pH 5.52). Substrate pH also appeared to increase over time with increasing tray cell-count (decreasing root volume) and ranged from pH 6.21 with 162-cell count trays to pH 5.59 with 32-cell count trays (Table 3-2). Trends with substrate EC were similar to those observed with pH, where substrate EC at harvest was greatest for plants transplanted after 14 d (0.46 $mS \cdot cm^{-1}$) and lowest at 28 d (0.33 $mS \cdot cm^{-1}$), and ranged from 0.47 $mS \cdot cm^{-1}$ with 162-cell count trays to 0.32 $mS \cdot cm^{-1}$ with 32-cell count trays (Table 3-2).

Discussion

Increasing the amount of time before transplanting basil seedlings into hydroponic culture resulted in decreased yield at harvest (Figure 3-1), particularly for plants grown in high cell-count trays with low root volumes per plant. Past research with floriculture crops has shown that transplants grown with low root volumes combined with excessively long periods before transplant increases the potential for restricted root and shoot growth as well as negative carry-over effects after transplant (Fisher et al., 2006; Latimer et al., 1991; van Iersel, 1997). It is possible that trays with high cell-counts caused root restriction and negative carry-over effects in this study, especially since harvested yield tended to increase as transplant root volume increased as shown in Figure 1. However, basil grown in 32-cell count trays with the largest root volumes still had a reduced final yield when transplanted at later dates into hydroponic culture and did not exhibit the highly dense and matted root systems that are often characteristic of root restriction.

Another possible explanation for the yield differences between tray types and transplant dates may be that root zone nutrients and water were limiting to plant growth during transplant production. All tray types were sub-irrigated to container capacity at each irrigation event, and it is possible for root zone nutrients and water to become depleted between irrigations as plants absorbed solution. In addition, high cell-count trays held less substrate and nutrient solution per plant compared to low cell-count trays, and therefore would have been less buffered against fluctuations in nutrient and moisture levels. Compared to transplant production, plants in hydroponic systems received a constant supply of nutrients and water, and root systems also expanded into the NFT troughs for greater exposure to nutrient solution. Earlier transplant dates therefore resulted in plants being grown for a greater amount of time in hydroponic culture, where a more optimum and consistent supply of nutrients and water likely increased growth rates.

Planting density was influenced by both tray cell-count and transplant date and may have also impacted plant growth. For example, the density of basil seedlings per tray increased as tray cell-count increased, which would have created greater competition between individual plants for available light for photosynthesis. Basil were also provided the maximum spacing when transplanted into the NFT hydroponic systems, where transplanting increased the amount of available light per plant for the remainder of the experiment. Therefore, basil grown in lower cell-count trays and transplanted earlier into hydroponics would have had overall lower planting densities and greater potential to accumulate light for growth.

The greater substrate pH at harvest for basil grown in higher cell-count trays and transplanted earlier into hydroponic culture was likely related to nutrient uptake by roots. It has been well-documented that a greater net uptake of cation (positively charged) or anion (negatively charged) nutrients causes roots to produce acidity (decreases pH) or basicity (increases pH), respectively (Dickson and Fisher, 2019; Haynes, 1990; Marschner, 2012). In addition, nitrogen represents approximately 70% to 80% of total nutrient uptake and can be supplied in cationic (ammonium-N or NH_4^+-N) or anionic (nitrate-N or NO_3^--N) form, and therefore has a major impact on root zone pH (Dickson and Fisher, 2019; Lea-Cox et al., 1999; Marschner, 2012). Dickson and Fisher (2019) showed that roots of basil grown in substrate and hydroponics produced basicity and increased pH over time when supplied nitrate-based nutrient solutions, which likely occurred in this study considering the use of similar nutrient solution formulations. Lower root volumes per plant would have decreased the amount of substrate available to buffer against pH changes, which may explain why pH increased more rapidly for basil grown in higher cell-count trays whereas pH was less affected in lower cell-count trays with more substrate. As previously discussed, earlier transplant dates increased the amount of time basil were in hydroponic culture, therefore increasing nutrient uptake as well as the potential rise in root zone pH.

Conclusions

Basil seedling tray type and transplant date into hydroponic culture influenced plant growth and yield at harvest. Basil seedlings grown in lower cell-count trays with larger root volumes per plant and transplanted earlier into hydroponic culture had greater yield compared to basil grown in high cell-count trays (lower root volume per plant) and transplanted at later dates. The combination of growing seedlings in trays with low cell-counts and transplanting earlier into hydroponics may have increased yield by reducing the potential for restricted root growth, providing plants with a greater and more consistent supply of nutrients and water, and increasing individual plant spacing for greater accumulation of photosynthetic light.

Table 3-1. Tray count, cell diameter, cell height, and cell volume for cylindrical paper-wrapped substrates.

Tray count (number of cells/tray)[x]	Cell diameter (cm)	Cell height (cm)	Cell volume (cm^3)
162	2.2	4.5	16.3
105	2.5	4.0	19.6
72	3.5	4.0	38.5
50	4.0	4.0	50.2
32	5.0	5.0	98.1

[x]Tray count values indicate number of cells per 1.6ft^2 tray area

Table 3-2. Effects of basil seedling tray cell-count and transplant date into NFT hydroponics on substrate pH and electrical conductivity (EC) at harvest (35 d after sowing seed) for Expt. 2. Data represent least-square means of nine and 15 replicates for tray count and transplant date main effects, respectively. Mean separation used Tukey's honestly significant difference (hsd) with α=0.05.

		Substrate pH		Substrate EC (mS/cm)	
Transplant date	14 d after sowing	6.17	a	0.46	a
	21 d after sowing	5.98	a	0.42	b
	28 d after sowing	5.52	b	0.33	c
Tray count	162-cell	6.21	a	0.47	a
	105-cell	6.01	ab	0.46	a
	72-cell	5.83	ab	0.39	b
	50-cell	5.80	ab	0.36	bc
	32-cell	5.59	b	0.32	c
	Transplant date	**		***	
	Tray count	*		***	
	Transplant date*tray count interaction	NS		NS	

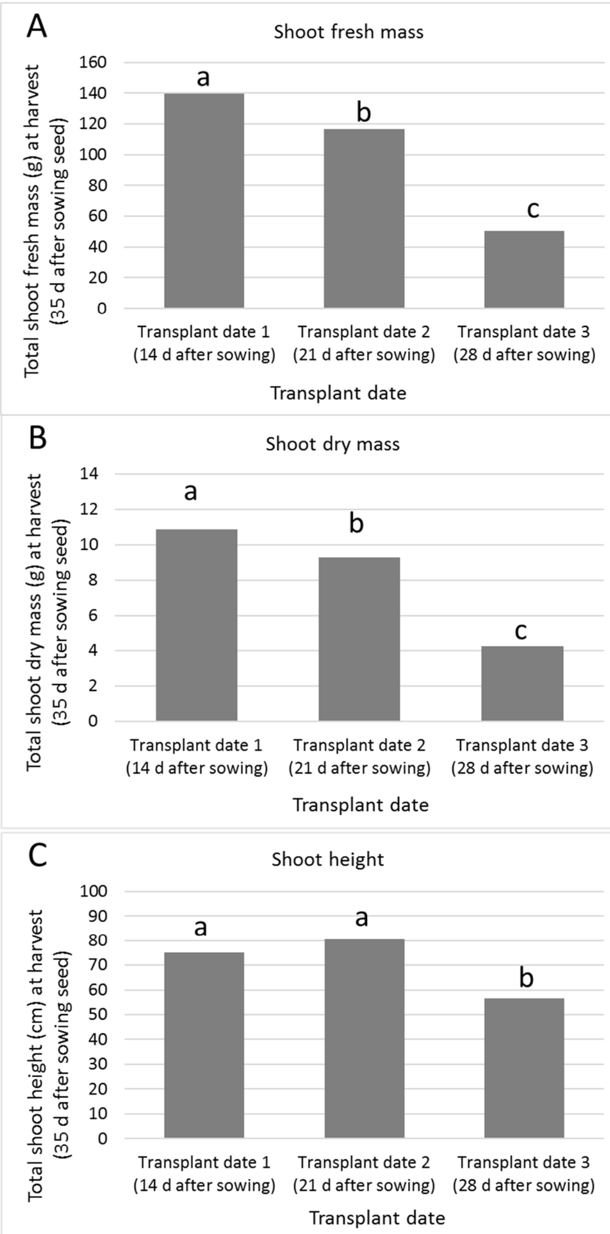

Figure 3-1. Effects of basil seedling transplant date main effects on shoot fresh mass (A), shoot dry mass (B), and height (C) per plant at harvest (35 d after sowing seed) for Expt. 2. Data represent least-square means of 15 replicates per treatment. Mean separation used Tukey's honestly significant difference (hsd) with α=0.05.

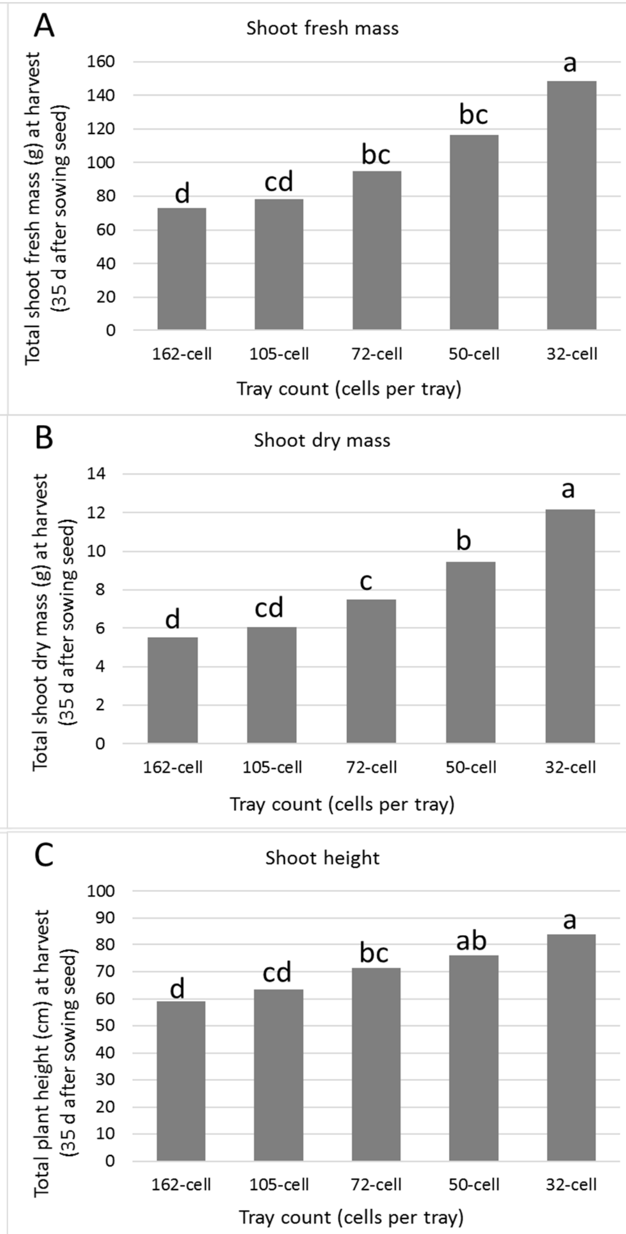

Figure 3-2. Effects of basil seedling tray cell-count main effects on shoot fresh mass (A), shoot dry mass (B), and height (C) per plant at harvest (35 d after sowing seed) for Expt. 2. Data represent least-square means of nine replicates per treatment. Mean separation used Tukey's honestly significant difference (hsd) with α=0.05.

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CHAPTER 4. CONCLUSIONS

The production of basil within hydroponic and soilless systems is an important part of the greenhouse agriculture industry and its popularity will likely continue to increase with demand for greenhouse produce, leafy greens and fresh herbs.

In the first study, harvested yields were overall greater for basil produced in deep flow technique (DFT) hydroponics compared to nutrient film technique (NFT) hydroponics and shallow aggregate ebb and flood (SAEF) soilless substrate systems. Differences in cultivar performance between systems may have resulted from differences in the distribution and availability of nutrients and water for plant uptake.

Basil seedling tray type and transplant date into hydroponic culture influenced plant growth and yield at harvest. The combination of growing seedlings in trays with low cell-counts and transplanting earlier into hydroponics likely providied plants with a greater and more consistent supply of nutrients and water, and increased individual plant spacing for greater accumulation of photosynthetic light.

Greenhouse producers should select basil cultivars based on yields and the demand of their local markets. Cultivar seems to have a more significant impact on yield than hydroponic system, so system can likely be selected based on cost, space and operating preference. Further comparison is needed to evaluate the specific effects of these three hydroponic systems on the four cultivars tested. For Genovese basil, starting seedlings in low cell-count trays and transferring them early appears to be the best practice for optimizing yield and crop time in NFT hydroponic systems.