THESIS

EFFECTS OF CONTAINER SIZE AND GROWTH MEDIUM ON STOCK PLANT PRODUCTIVITY OF *HEUCHERA* 'SNOW ANGEL' AND *ZAUSCHNERIA GARRETTII* 'PWWG01S' ORANGE CARPET®

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ABSTRACT

EFFECTS OF CONTAINER SIZE AND GROWTH MEDIUM ON STOCK PLANT PRODUCTIVITY OF *HEUCHERA* 'SNOW ANGEL' AND *ZAUSCHNERIA GARRETTII* 'PWWG01S' ORANGE CARPET®

Herbaceous perennials represent a significant portion of plant sales across the country and are becoming more popular with the increased interest in sustainable landscapes. In order to address some of the propagation and production problems Plant Select® propagators were encountering with *Heuchera* L. 'Snow Angel' and *Epilobium canum* (Greene) P.H. Raven *ssp. garrettii* (A. Nelson) P.H. Raven *'PWWG01S' ORANGE CARPET®*, referred to throughout this paper as *Zauschneria garrettii* 'PWWG01S', a stock plant study was designed to investigate the effects of container size and growth media on cutting production. In conjunction with the stock plant study, a rooting experiment was also performed to determine the impact of the stock plant treatments on rooting rates, percentages and number of roots produced.

The objectives of the stock plant study were to identify the media and container size combination that resulted in the highest number and quality of cuttings for each taxon being grown and to develop a reproducible stock plant protocol for growers to follow in order to improve their success rates. The objective of the rooting study was to determine if the stock plant treatments had any effect on rooting percentages of the cuttings, or the number of visible roots produced.

Plant material was obtained as rooted plugs grown by Gulley Greenhouse in Fort Collins, Colorado and transplanted into square plastic 10.16cm (4 inch) pots for an initial establishment

period. During this period, plants were grown in 4 different media (Berger BM7, SunGro Metro Mix 360, SunGro Metro Mix 820, and Pindstrup peat substrate). After roots began circling the 10.16cm containers, plants were shifted into 3 different container sizes (#1 – 2.84L, #3 – 11.35L, and #5 – 14.55L) for the remainder of the study. Ten plant replicates were grown in each of the 12 different treatment combinations of media and container size and cuttings were harvested and weighed from each plant separately.

Once plants were established in the larger containers, cuttings were harvested 3 times total at four week intervals. After harvesting, the cuttings were weighed immediately prior to drying for at least two days before measuring dry weights. Other data collected included height and two widths of plants prior to taking cuttings along with photographs of the same stage.

The rooting study was performed after the stock plant study was completed by saving a subset of plants to use for stock. Cuttings were taken once every 4 weeks for a total of 3 harvests. Cuttings of *Heuchera* were dipped in Woods dip at 500PPM IBA for 5 seconds before sticking in Jiffy Performa cubes and being placed under mist with bottom heat set to maintain soil temperatures at 18.3 °C. Cuttings were observed every week for rooting status and roots that were visible on the outside of the Jiffy cube were counted. The *Zauschneria* cuttings were not treated with hormones, but stuck directly into the Jiffy cubes and placed on a heat mat set at 23.9 °C and misted intermittently. Data was collected in the same manner.

Stock plants of *Heuchera* ‘Snow Angel’ responded to media treatments differently depending on the batch of media being grown in. During the first experiment, Metro Mix 820 resulted in initially larger plants, more cuttings per plant and per square foot, as well as larger fresh and dry weights of cuttings. The increased success of stock plants grown in the first batch of Metro Mix 820 was mostly attributed to a lower pH (5.3-5.6) and temporary nutrition levels

provided by a pre-plant starter charge. During Experiment #2, the most successful stock plants were those grown in Metro Mix 360 and Pindstrup. These two substrates resulted in larger plants, more cuttings per plant and per square foot, as well as higher fresh and dry weights of the cuttings. The increased response was mostly attributed to more ideal pH levels (5.1-5.8) which were initially very different from the first batch of media used in Experiment #1.

Stock plant responses to container size were fairly similar between the two experiments with 11.35L and 14.55L containers resulting in slightly larger plants by the end of the study, though fewer cuttings per square foot, indicating that stock plants of *Heuchera* 'Snow Angel' would be more efficiently grown in 2.84L containers.

When cuttings from each stock plant treatment combination were rooted, the results showed that *Heuchera* 'Snow Angel' cuttings can be rooted with almost 100% success regardless of stock plant media or container size treatment. Rooting status was not statistically affected by treatment after 4 weeks on the mist bench and reached 100% for most treatments after 3 weeks. The number of visible roots produced by cuttings increased significantly with increasing container size, which was partially attributed to stock plant health during Experiment #1. During the second experiment, the opposite trend was observed, and increasing numbers of roots corresponded to a decrease in container size of the stock plant. Because the results of the two experiments did not agree, more research would need to be performed in order to investigate the primary cause of the response, but it may be related to changes in greenhouse temperature and time of year.

The response to media found in *Zauschneria garrettii* 'PWWG01S' stock plants was fairly consistent across both experiments with the best results observed in Pindstrup treatments, although differences were more dramatic during Experiment #1. Stock plants grown in

Pindstrup were larger, produced more cuttings per plant and per square foot with higher dry weights per cutting during the first experiment. While the second experiment showed no significant correlation between media treatment and plant size or number of cuttings produced, stock plants grown in Pindstrup resulted in cuttings with slightly higher fresh and dry weights. The increased response to Pindstrup was mostly attributed to a higher CEC, higher starting levels of phosphorus and a higher water holding capacity.

Zauschneria results from Experiment #2 showed a dramatic increase in number of cuttings and size of the cuttings regardless of treatment, and this response was mostly attributed to greenhouse temperature differences between the two experiments. It is also possible that differences between treatments were smaller during the second experiment because all plants were experiencing less temperature stress than Experiment #1 and plants spent about 6 weeks less in the treatments.

In contrast to the *Heuchera* stock plants, *Zauschneria* showed a more dramatic response to container size with the larger containers producing larger stock plants, more cuttings per plant. During Experiment #1, the larger containers also resulted in cuttings with larger fresh and dry weights and very similar numbers of cuttings per square foot when compared to 2.84L containers. During the second experiment, there was no significant effect of size on the fresh weights of cuttings, but dry weights increased with the larger container sizes by the end of the experiment. Stock plants grown in 2.84L containers during the second experiment produced significantly more cuttings per square foot, which is likely because they were not experiencing the same level of heat stress as the first experiment, allowing them to be more healthy and productive. Overall, the response to container size was mostly attributed to root restriction and higher root zone temperatures within the smaller containers.

In order to determine if media or container size treatments had any effect on the rooting of cuttings, a propagation experiment followed the stock plant experiment. Due to difficulties encountered in providing a conducive rooting environment for these cuttings and the resulting losses, very few trends were identifiable. During Experiment #1, *Zauschneria* cuttings exhibited higher rooting percentages and number of visible roots when stock plants were grown in 14.55L containers, though no advantage was seen from any media treatment. This response was mostly attributed to 14.55L containers producing larger cuttings that would have more water and carbohydrate reserves, making them more resistant to desiccation. During Experiment #2 Pindstrup resulted in slightly more visible roots after 3 weeks under mist. Since the difference was only found after the 3rd week and no other time point, more research will need to be conducted to determine the true effects of media treatment on rooting capability in this taxon. The second experiment also showed that larger containers tended to increase the rate of rooting slightly, although dramatic losses due to desiccation during week 3 convoluted the data. More research will need to be conducted to determine if container size has any effect on the rooting ability of *Zauschneria* cuttings.

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DEDICATION

For Jake

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CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Ornamental herbaceous perennials make up an important part of the green industry and have become more ubiquitous in recent years. According to the United States Department of Agriculture's (USDA) National Agricultural Statistics Service 2014 Census of Horticultural Specialties, sales of potted herbaceous perennial plants were $945 million, representing an increase of almost 12% since the 2009 census. This increase also corresponds to an 18% increase in sales within the horticulture industry as a whole (United States Department of Agriculture 2014).

As homeowners become more interested in water conservation, herbaceous perennials will likely become more popular in semi-arid climates like that of Colorado. With this increase in demand, producers will need to supply varieties that offer consumers hardy, drought tolerant options that thrive in the landscape. Plant Select®, an organization dedicated to identifying, trialing, and marketing varieties that are resilient and unique, has introduced two such perennials: *Heuchera sanguinea* 'Snow Angel', and *Zauschneria garrettii* 'PWWG01S' ORANGE CARPET®. Among other Plant Select® varieties, these two taxa thrive in the High Plains region of Colorado despite the unique environmental conditions they face, such as high light intensity, low precipitation and frequent weather fluctuations.

Unfortunately, these two taxa represent a specific challenge to the industry. Although very popular with consumers, they are difficult to propagate clonally in large enough numbers to meet the consumer demand. Low propagule numbers, low rooting percentages, and reproductive growth of stock plants all contribute to low production numbers. Vegetative or clonal

propagation relies on the plants' ability to form adventitious roots from a stem cutting. Because the foundation of this process is maintaining healthy and vigorous stock plants from which to take cuttings, a research project was designed to examine the effects of stock plant management practices on the number and quality of vegetative cuttings produced.

Although it is well known that different taxa of plants thrive under different environmental conditions and in different types of soils, it is common within the green industry to follow the same protocol for all perennial stock plants, regardless of taxa. Water loving and drought tolerant varieties are often grown in the same media and same container sizes despite the fact that the plants have different requirements. In order to determine if growth substrate or container size influence the success of stock plants of *Heuchera sanguinea* 'Snow Angel', or *Zauschneria garrettii* 'PWWG01S' ORANGE CARPET®, three container sizes and four growth substrates were used to grow stock plants and harvest cuttings.

1.2 Background Information on *Heuchera* 'Snow Angel'

Heuchera sanguinea is an herbaceous perennial in the family *Saxifragaceae* that thrives in well-drained soil and part shade with bright pink flowers in late spring to early summer. There are between fifty and seventy species of *Heuchera* that are native to North America with *H. sanguinea* being one of the most popular in American gardens due to its flowers, which are showier than many other *Heuchera* species (Armitage 1989). This species is native to Southern New Mexico and Arizona and grows in USDA zones 3-8 (USDA NRCS Plant Database, *Heuchera*). The cultivar 'Snow Angel' originated from Bluebird Nursery in Clarkson, NE and is thought to be a hybrid of *H. sanguinea*. This cultivar has attractive white and green variegated foliage that make it an excellent plant for a shady border even when not in bloom (Plant Select, *Heuchera*).

Although there has been little research specifically looking at *Heuchera sanguinea,* Albrecht and Crockett (1994) found that it is a day-neutral plant that must have a period of vernalization with subsequent long days in order to flower and that the critical day length for vegetative growth is around 12 hours and between 12 and 15 hours for reproductive growth. This daylength requirement makes it easy to keep in the vegetative or juvenile state in the greenhouse as long as temperatures stay above 4-5 °C (39.2-41.0 °F).

In a separate study by Yuan et al. (1997), results indicated that the juvenile phase of *Heuchera sanguinea* lasts until the plant has approximately 19 nodes. Plants with less than 19 nodes showed little flower development after vernalization at 5 °C for 10 or 15 weeks. However, according to the results, even with more than 19 nodes, plants that have not experienced a vernalization period should not produce any reproductive tissue.

While examining the effects of Daily Light Integral (DLI) on *Heuchera americana*, Garland et al. discovered that the plants became light saturated around 11 mol x m^{-2} x day^{-1}, with no significant gain in shoot dry mass above 11. Leaf count increased until DLI reached almost 15 mol x m^{-2} x day^{-1}, and then began to decrease at higher light levels. When exposed to higher DLI (Around 20.8 mol x m^{-2} x day^{-1}), there was a decrease in crown size, which was in part due to shorter petioles and smaller leaf area (Garland, et al. 2012).

A Virginia Polytechnic Institute study done by Holly Scoggins identified the best nitrogen rate, electrical conductivity (EC) and pH level for ten herbaceous perennials, including *Heuchera x* 'Mt St. Helens'. Based on quality ratings and shoot dry weight, the most successful plants were given 150 mg x L^{-1} Nitrogen, with soil pH and EC measured to be 5.9 and 2.0 respectively (Scoggins 2005). Although there can be differences between species and cultivars

within the genus *Heuchera,* these findings can be used to guide the development of a strong stock plant protocol for *Heuchera sanguinea.*

Cultivars of *Heuchera* are often propagated by tissue culture to maintain the desired characteristics of the mother plant, but for those growers who do not have the laboratory and equipment for that process, basal stem cuttings work fairly well. One limiting factor in propagating *Heuchera* from stem cuttings is that each stock plant only produces a few suitable cuttings at a time. The average number of cuttings per stock plant during the first experiment conducted at Colorado State University was only 6-8 per month. This requires growers to maintain larger numbers of *Heuchera* stock plants than most other varieties from which to procure cuttings, taking up valuable greenhouse space.

1.3 Background Information on *Zauschneria garrettii* ORANGE CARPET®

The genus *Zauschneria*, which was added as a section of *Epilobium canum* by P.H. Raven in 1976, is naturally found in western North America (Bowman 1980). *Zauschneria garrettii*, also known as *Epilobium canum subsp. garrettii* is a low growing subshrub or partially woody perennial in the *Onagraceae* family, which is native to Northwestern Arizona, Utah, Western Wyoming and Southeastern Idaho (USDA NRCS Plant Database, *Epilobium*). The subspecies *garrettii* is found only north and east of the Great Basin, whereas its close relatives *Epilobium canum subsp. canum* and *subsp. latifolium* grow in Southwestern Oregon and the Sierra Nevada of California. Although hybridization can occur between many of the subspecies, the Great Basin prevents the crossing of *Epilobium canum subsp. garrettii* (a diploid) with its Californian relatives (some triploid) (Bowman 1980). *Zauschneria garrettii* grows only about 4-6 inches (10.16-15.24cm) tall in a spreading habit up to 24 inches (60.96cm) wide. It prefers aerated, well-drained soil and full sun, but will tolerate light shade. It flowers in mid to late

summer with numerous orange trumpet shaped flowers. Sometimes called California fuchsia, *Z. garrettii* is deer resistant and drought tolerant, as well as a hummingbird attractant, which is how it gets its other common name, hummingbird trumpet (Plant Select, *Zauschneria*). Due to its growth habit, it is commonly used in rock gardens or along walls where it can cascade over the side with waves of bright orange flowers. The variety ORANGE CARPET® was introduced by David Salman of High Country Gardens, who made the selection from seed collected in Idaho by Panayoti Kelaidis.

Although *Zauschneria garrettii* is known to grow in dry locations with well-drained soil, many of its relatives are known for growing in moist conditions. *Epilobium hirsutum,* for example, is mostly found in moist or wet habitats such as fens, marshes and bogs, and has a tendency to produce aerenchyma tissue under low-oxygen conditions, making it well adapted to partially or completely saturated soils (Shamsi and Whitehead 1974). In a study conducted by Lee et al (2017), the investigators determined *E. hirsutum* would produce the most vegetative growth and reproductive runners under high moisture content (75-100% of field capacity) and number of leaves was the highest in substrate with 7% organic matter. Another member of the genus, *Epilobium montanum*, is found in habitats that range from dry walls to damp forests and tolerates a wide variety of soil pH. Also tolerating a wide range of soil pH and dry to moist sites is *Epilobium adenocaulon,* which was introduced to Europe from North America. *Epilobium angustifolium* is also known to populate a wide range of soils from damp, muddy sites to dry, sandy soils and can tolerate alkaline to acidic conditions (Myerscough and Whitehead 1966). Based on research their research, Van Andel, Bos and Ernst (1978) claimed that *E. angustifolium* is actually adapted to both high and low pH conditions. According to Mosquin and Small (1971), *Epilobium latifolium,* a species closely related to *E. angustifolium,* is only found in sites

with continuously moist soils. P.H. Raven, who has written extensively about *Epilobium* and other species in the *Onagraceae* family noted that besides the previously mentioned species, *E. brevifolium ssp trichoneurum, E. platystigmatosum, E hirtigerum, E keysseri, E. detzerianum, E. hooglandii, and E. prostratum* are all found in wet sites near streams, bogs or peaty grasslands (Raven 1974). By examining the close genetic relatives of *Zauschneria garrettii*, it seems that while this plant grows well in dry locations, it may be a facultative xerophyte that actually prefers more moisture, but that has excelled in dryer areas because it is able to acclimate to these conditions better than other plants.

The critical photoperiod for *Zauschneria garrettii* has not been researched, although it may be a short-day plant, being that it flowers after the summer solstice. According to Myerscough and Whitehead (1966), *Epilobium angustifolium* seedlings produce vegetative tissues for about 5-6 weeks and this period is independent of day length and does not appear to be under direct control of photoperiod. However, growth and development of this species was influenced by temperature, nutrient levels, pH, and light intensity. Critical photoperiod for flowering is not known at this time, but represents an important void in research as the plant becomes more popular. Difficulties in maintaining vegetative stock plants leads to lower rooting rates of the cuttings harvested from these plants and should be considered a high priority for future studies.

In an article by Richard Anderson and Larry Rupp of Utah State University (2013), they stated that stock plants of *Z. garrettii* were improved by holding greenhouse temperatures between 39 and 50 °F (4-10 °C). Internodes were shorter and plants had thicker stems under

cooler greenhouse conditions, which also provided a longer window for taking cuttings. Propagules from these stock plants rooted at percentages near 100% and roots developed within 2 weeks.

1.4 Herbaceous Perennial Stock Plant Management Studies

Maintaining healthy and vigorous stock plants is an important part of propagation. Although the level of productivity as stock plants will depend on the species being grown, cultural practices can have a strong impact as well. It is important to start with healthy and disease-free plants to avoid transfer of pathogens to the progeny of a stock plant as well as to maintain a sanitary propagation area. Most growers starting new stock plants from plugs will allow the plants to grow for 6 to 12 weeks before taking cuttings, but that interval will vary with species (Gibson and Cerveny 2005). For example, Adam (2005) reported that *Heuchera* 'Snow Angel' only takes 4 to 6 weeks for cutting development while some other species can take twice as long before growers are able to harvest cuttings.

The style of harvest will depend on the production needs of a grower, but there are two general strategies. The first type of harvest, called selective harvesting, refers to a process in which the grower will take only the highest quality cuttings. Hedging is a much more aggressive approach in which the grower removes all suitable cuttings if they meet certain minimum criteria (Gibson and Cerveny 2005). Obviously, the method of harvest will depend on the production demand and the number of stock plants available. The type of harvest can also dramatically change the recovery period needed by the stock plant before cuttings can be taken again.

Most of the time, cuttings taken from stock plants in the vegetative or juvenile state are more desirable. Reproductive tissue on cuttings should be avoided, as it can inhibit rooting and leaf development (Gibson and Cerveny 2005). In order to maintain vegetative stock plants,

growers utilize different lighting and temperature regimes because flower induction is mostly controlled by cold and photoperiod. The length of photoperiod necessary to maintain juvenility depends entirely on the species being grown and must be established for each plant taxa before recommendations can be made. Temperature plays a role in flowering for some plants that require vernalization, such as some cultivars of *Aquilegia* as well as *Heuchera sanguinea* (Heins et al 1997). Because popularity of herbaceous perennials is still on the rise, there is limited research on specific taxa and their flowering requirements at this time.

Temperature also plays an important role in growth rates of stock plants and the quality of cuttings they produce. In general, warmer temperatures will increase growth rates, but not without limit. Gibson and Cerveny (2005) recommended keeping stock plants in shade during the hottest months, while maintaining greenhouse temperatures between 70 and 75F during the day, and between 65 and 68F at night to encourage maximum growth.

Plant nutrition is very important in managing the productivity and longevity of perennial stock plants. According to Adam (2005), the nutritional needs of herbaceous perennials vary with species and even cultivar, and they should be grown at optimum levels in order to maximize their productivity. In his research on perennial stock plants, Adam noted that appropriate fertilizer applications can reduce ground water contamination as well as extend the life of stock plants. While Gibson and Cerveny (2005) reported a typical range of fertilizer concentrations used for stock plants is 150-250 ppm nitrogen, Adam (2005) asserted that many species could be grown using 60-150 ppm N. Through his research, Adam discovered that there were no beneficial effects of fertilizing with more than 136ppm N for the five varieties grown in this experiment.

Despite the many ways growers can influence the growth and vitality of their stock plants through environmental control, proper nutrition, and watering practices, the plant's productivity will level off with age. Initially, container grown stock plants produce more cuttings as the plants mature until they reach a plateau often due to limited root space or shoot crowding (Adam 2005). Adam suggested that the length of the plateau can be influenced by culture and management practices, but that eventually the quality and number of cuttings will decline when plants become too pot bound.

1.5 Studied Effects of Growth Media

Substrates used for container production of herbaceous perennials tend to be soilless mixes often made from varying amounts of peat, bark and perlite or vermiculite. Soilless mixes are designed to support the plant and supply proper amounts of water, fertilizers and oxygen, while being lightweight enough to keep shipping costs down. Although growers often use the same media for most or all of their stock plants, the appropriateness of the media characteristics will vary with the plant species being grown (Ingram et al 1993). Gabriel et al (2009) stated that the perfect mix will depend on the species and that plants will perform the best when grown in a substrate that mimics the species' natural habitat. Numerous studies have been done over the last 5 decades that have attempted to identify what makes a successful container substrate based on physical and chemical properties. The results of this research topic show that the ideal growth media will differ between species, container geometry, environmental conditions, irrigation practices, and substrate characteristics. Research done in an attempt to characterize media and draw connections between plant performance and substrate qualities can be separated into two broad categories: Physical characteristics (including bulk density, particle size distribution, pore

size and distribution, hydraulic properties, aeration, and gas exchange capabilities) and chemical properties (including nutrient holding and ion exchange capacities, pH, carbon: nitrogen ratios, and nitrification rates.)

1.5.1 Substrate Physical Characteristics

The physical characteristics of soilless media are very different from field soils, partially due to high levels of organic matter that contribute to their behavior as growth substrates. While most of the physical properties of substrates are inherently intertwined, it is possible to separate them into three main categories: **1. Descriptive measurements –** Relative amounts of substrate components, bulk density, particle size distribution, porosity, and pore distribution make up the group of measurements often taken to describe a substrate. **2. Gas relations -** Aeration and gas diffusivity are used to explain the way gases interact with the media, and depend greatly on porosity, pore size distribution and tortuosity of pores. **3. Water relations -** In order to describe the interaction of water with, as well as movement within a substrate, water content, water holding capacity, and water potential are examined often by creating a water release curve.

1.5.1.1 Substrate Measurements

The most common component in soilless media mixes is peat, which is formed as mosses and sedges decompose slowly. Among the various kinds of peat, sphagnum is probably the most well-known, although there are numerous types that vary by the plant matter that makes them up as well as their state of decomposition. In general, peat is physically quite stable, maintains good aeration and high water holding capacity, has low bulk density and high porosity, which together make it very useful in soilless substrates. Specific peats will vary in their proportion of air-filled pore space and "easily available water" based on the particle size distribution, so it is important

to match the peat texture to the plant species being grown to provide the correct amount of water (Maher et al 2008).

Bark has become widely used as a component of soilless substrates, although not usually on its own except for some orchids and bromeliads. Used more commonly since the 1970s, bark can be a good addition to a medium and provide a high level of air-filled porosity even though it may slightly decrease the total porosity. As the amount of bark added increases, air-filled porosity tends to increase, but "easily available water" decreases, so finding the right ratio is important. The addition of bark also significantly increases the bulk density, and can result in higher shipping costs.

Bulk density is a physical parameter often used to describe soils and soilless substrates. Although it is relatively uninformative to growers and researchers without additional information about particle size and distribution, it is important for trade and handling (Blok et al 2008). In order to calculate bulk density (BD), substrates are often compressed with a known pressure into a cylinder of known volume and dried. The dry mass is measured, divided by the volume and usually presented in kg m^{-3} or g cm^{-3}. Although the BD of various components will contribute to the overall BD of a soilless mix, it is important to note that the mix's BD will not be a sum of the components that make it up. For example, media mixes with a wide variation of particle sizes will have a higher BD than the individual components because the smaller particles settle into the spaces between larger particles (Wallach 2008).

According to Rony Wallach (2008), particle size distribution (PSD) is "the most fundamental physical property of a porous medium" and is responsible for its texture. The distribution is often determined by passing substrate particles through a series of sieves of different sizes which only provides discrete ranges of particle sizes, or by using a hydrometer.

Soil scientists use PSD to estimate hydraulic properties of soil and to predict the shape of water release curves although these models have not been adapted for soilless substrates (Wallach 2008).

Total porosity (TP) refers to the percent by volume of the substrate that is not taken up by solids. It includes both air and water filled pores and is defined by the arrangement of particles as well as the shape and size of them. Because particle size and distribution is closely related to total porosity, most of the time TP is inversely related to BD (Wallach 2008). In other words, when particles fit more closely together creating a higher BD, that substrate will also have lower TP. Probably more useful than total porosity is determining the air-filled and water filled porosity which relate to the distribution of pore sizes and partially determine water and oxygen availability to plant roots.

Until recently, soil scientists generally separated pore sizes into two categories: macropores and micropores (Drzal et al 1999) although they do not always agree on the size ranges for those categories (Fonteno 1993). When considering the large variation in particle sizes, it makes sense that there are an infinite number of pore sizes and that separating them into only two categories is not only arbitrary, but may not give an accurate representation of the substrate properties and suitability as a container medium. In order to address this issue, Drzal et al (1999) separated pore sizes into four categories: **1.** Macropores were considered to be larger than 416 mu and correspond to pores that cannot hold water under normal gravitational tensions. **2.** Mesopores are between 10 and 416 mu and correspond to pores that provide available water to plants and are constantly being drained and refilled through the course of repeated irrigation. **3.** Micropores are between 0.2 and 10 mu and correspond to pores that hold water between 33kPa (generally considered Field Capacity) and 1.5MPa (generally considered Permanent Wilting

Point). The water held in micropores under this definition will act as a drought stress "buffer" and will not normally be used by plants unless tensions exceed 31MPa. **4.** Ultramicropores are considered smaller than 0.2 mu and hold water at tensions above 31MPa which is not available for plant uptake. Using these definitions, it is possible to describe a substrate's pore fraction by examining the moisture release curve.

Through extensive research at the Horticultural Substrates Lab at North Carolina State University, Fonteno (1993) presented many problems surrounding the characterization of soilless media physical properties. Although it could help determine the aeration and hydraulic properties of a container substrate, one of the most elusive physical properties of soilless media is particle density. Particle density can be measured more easily in field soils, but the high organic matter content in soilless substrates makes it very difficult to calculate accurately. Because most soilless substrates include components such as peat and bark which break down over time, the density of particles can change throughout the life of a plant. Chavez et al (2008) noticed this phenomenon when growing petunias and impatiens in various soilless media. In their study, total porosity was initially highest in substrates with the highest peat content but decreased over the course of the growing period. Ingram et al (1993) also warned that components of soilless media become smaller as they decompose, fitting closer together and decreasing pore space along with total volume. The substrate volume can decrease and physical properties can change over time because of other factors such as shrinkage, compaction, erosion, and root penetration. One of the components used in soilless mixes due to its high water holding capacity and Cation Exchange Capacity (CEC) is vermiculite, but it is also prone to compaction and has poor physical stability especially after being wetted or in large containers. Taller containers will result in more compaction toward the bottom where the weight of the soil column

creates higher pressure. As Fonteno (1993), Bailey et al (2002) and Drzal et al (1999) asserted, it is not just the components of the substrate that determine the hydraulic properties, but how the media is handled, the irrigation practices and the container geometry. Bailey et al (2002) even claimed that the method with which plants are watered is more important in determining root zone water content than the media itself. While it remains important to characterize substrates before planting in them, it is important to acknowledge the changes that occur by simply growing in a medium. Also, one should try to account for these changes with responsible handling and irrigation practices. It may also be of value to test soils after they have been grown in to determine the effect of these practices.

1.5.1.2 Gas Relations

Pore size and distribution, along with arrangement of pores and pore tortuosity (the connection of pores within a substrate) greatly affect the water holding and aeration capacity as well as the gas exchange properties of a growth medium. In most soilless media, solids only account for 10-20% of the total volume, leaving 80-90% as pore space which is difficult to characterize (Drzal et al 1999). Nkongolo and Caron (2006) examined the impacts of pore organization on two woody species and found that an increase in bark particle size resulted in a 25% decrease in growth parameters. The investigators suggested that gas exchange processes were limited under these circumstances because of an increase in pore tortuosity and a decrease in gas diffusivity through the substrate. Nkongolo and Caron therefore recommended that researchers examine gas exchange properties in conjunction with other physical properties of a substrate to determine the potential value as a container medium.

When choosing or developing the ideal media for container grown plants, it is vital to provide a balance of aeration for oxygen uptake and enough smaller pore space to house

available water (Ingram et al 1993). As stated by Wallach (2008), after media has drained and saturation conditions no longer exist, gases will occupy the larger pores that have drained due to gravity, while water is retained in the smaller pores. Providing enough large pore space within a substrate to allow for gas exchange between the roots and the atmosphere is essential. Optimal levels will depend greatly on the species being grown as well as the container being used. In a study of substrate characteristics on poinsettia growth, Jackson et al (2008) claimed that 10-30% air space is recommended to provide adequate oxygen to roots. Ingram et al (1993) were more conservative in their estimate, stating that 10-15% drainable pore space was adequate for most greenhouse crops.

Because particle size distribution is so closely linked to pore size, it is appropriate to mention that a study of bark as a growth substrate revealed that particle sizes can vary dramatically depending on the processing. Gartner et al (1973) found that if the majority of particles are between 0.8mm and 6.4mm, hardwood bark will have high water holding capacity and good drainage. If particles were larger than 6.4mm, the investigators saw a decrease in water content and rapid drying of the medium. If bark particles were less than 0.8mm, plants suffered from poor aeration in the root zone. Good results were obtained using mixes that included 20-40% of particles below 0.8mm which likely provided the smaller water-retaining pores and only 10-20% of particles were above 6.4mm which probably helped provide larger pores for better aeration and gas diffusion.

In their investigation of pore fraction analysis, Drzal et al (1999) noted that, of total pore space, peat mixes that were tested contained around 47% mesopores which accounts for their ability to store large quantities of water and their ability to provide available water to roots. Peat

mixes also contained about 9% micropores which correspond to their drought "buffer" capacity, while bark mixes that were tested had less than 1% micropores, causing plants to wilt more quickly. Although characterizing porosity of a media is important for overall understanding of the media's effect on plant growth, Fonteno (1993) warned that porosity measurements will only be accurate if moisture content and bulk density are controlled.

1.5.1.3 Water Relations

The physical composition of any soil or soilless substrate greatly affects the water holding capacity and more importantly, the water potential of the medium. Poorter et al (2012a) asserted that it is more important to characterize the water potential of a medium than the water content because the water potential is what determines the availability of water to the plant. A common way of measuring water potential of a medium is to create a water release curve which relates water content to water potential (Poorter et al 2012a) and can indirectly inform researchers about the pore size distribution based on water movement though the substrate (Drzal et al 1999). Although it is difficult and tedious to determine total pore space because particle density must first be established, one can make some broad statements about the pore size fraction based on a water release curve (Fonteno, 1993).

Fonteno (1993) wrote in detail about the hydraulic characteristics of soilless media, claiming that while there is a lack of agreement on which measurements to take as well as how measurements are taken, it is important to examine water movement and storage capabilities. Fonteno separated media hydraulic properties into two categories: **1.** Water retention characteristics that involve the substrate's ability to store water, and **2.** Hydraulic conductivity, which describes a substrate's ability to transmit water. Both of these properties are extremely important in determining soil-plant water relations. Fonteno believed that one of the most

common misconceptions about container media is that water is equally available within a range of water volumes present in the container. However, after saturation, and as water drains out of the medium, large pores empty and the tortuosity of the flow path increases, forcing water to move through smaller pores, which alters the availability to plant roots (Fonteno 1993).

Water retention within a substrate is determined largely by the pore sizes as mentioned previously and the height of the container. Wallach (2008) described the water release curve in relation to water content, stating that the water retained in a media at any given point on the water release curve represents the equilibrium water content at a certain suction and is a function of pore size and distribution as well as the adsorption of water molecules to the media particles. Because this is ultimately a function of water suction and a perched water table exists at the base of the soil column in container culture, the suction decreases lower in the container and water retention increases. This is a major difference between container and field grown plants with relation to water content and availability, which can vary greatly from the substrate surface to the bottom of a container.

Even though water movement through the substrate is important to the understanding of a soilless medium, it can only be measured indirectly. Direct measurements that can be taken are limited to structural components such as bulk density and particle size distribution (Drzal et al 1999), thus characterizing water movement must be done by inference from these measurable parameters. In general, water moves more slowly through media with a finer texture because the larger surface area of the small particles creates more drag on the water molecules. However, since fluid movement through substrates also relies on the properties of the fluid, pore structure and geometry, and saturation level of the soil, hydraulic conductivity is difficult to calculate accurately (Wallach 2008).

1.5.2 Plant Growth Responses Attributed to Substrate Physical Properties

Numerous studies have been performed on various plant species to determine some of the effects of media physical properties on plant growth. In a recent study by Baskaran et al (2016) using chrysanthemum, the investigators recorded the greatest shoot and root biomass, the highest number of roots, largest shoots in height and width, largest leaves, and the greatest number of leaves when plants were grown in a mix of coir compost and vermicompost. The authors suggested that this was because that media combination had the best physical properties of the combinations tested. Coir compost mixed with vermicompost (1:1) provided good water holding capacity, more pore space, and the coir compost breaks down more slowly than peat which discourages bacterial and fungal growth. Baskaran et al thought that the development of more leaves may be due, in part, to an earlier establishment of roots in a more favorable rooting medium. In 2016 study of bell pepper by Aghdak et al, the authors found that their most successful treatment of Perlite + Zeolite had the best combination of air filled porosity (25.9%) and water holding capacity (36.6%) which resulted in greater vegetative growth, root growth, and yield. Nkongolo and Caron (2006) noted in their study of two different woody ornamental species that the shoot and root dry weights and plant size increased with increasing water potential. However, if saturation conditions exist, roots can suffer from oxygen deprivation (Kafkafi 2008).

1.5.3 Substrate Chemical Properties

Because most soilless media components decompose fairly slowly and release such low levels of nutrients as to be practically negligible, (Silber 2008) this section will focus on the inherent chemical properties of soilless substrates rather than nutrient levels. In contrast to field

soils, low nutrient release rates allow for much more control over the nutrients available to the plant, making soilless substrates highly adaptable and allowing growers to tailor the nutrient solutions to the species being grown by altering the fertilizer contents.

Soilless substrates by themselves do not provide a complete array of necessary nutrients; it is therefore common for manufacturers to apply pre-plant nutrient starter charges. However, there is an initial decrease in these nutrients after planting that should be accounted for. Argo and Biernbaum (1996) noted that in peat-based media, the nutrient concentration in the root zone decreased quickly within the first 14 days after planting due to irrigation. Some of these nutrients migrated to the substrate surface and some were leached out with irrigation, but the authors suggested that to get an accurate sense of initial nutrition, soil samples should be taken 2-4 days after planting to allow for initial changes.

The purpose of container media is to provide adequate water availability, oxygen, and nutrients to plant roots. In order to supply nutrients to the roots, a soilless substrate must have an adequate Cation Exchange Capacity (CEC), Carbon: Nitrogen ratio (C:N), and pH. As is true with many physical properties of growth media, ideal levels will vary with the species being grown (Ingram et al 1993). Choosing a growth medium based on its appropriateness for the specific taxa being grown is important.

1.5.3.1 Cation Exchange Capacity

The cation exchange capacity (CEC) of a medium refers to the maximum number of cations the substance can hold tightly enough to resist leaching, while remaining exchangeable with the soil solution (Atland et al 2014). Components that make up soilless substrates carry electrical charges that determine their ability to hold and release nutrient ions for uptake by plant roots (Silber 2008). Although most of the adsorption sites carry a negative charge (Ingram et al

1993), these electrical charges can be positive or negative if H^+ or OH^- are adsorbed to the particles and cab be permanent or variable depending on the material. Thus, pH will partially determine the ion exchange capacity of a given medium (Silber 2008).

Cation exchange capacity can be presented in various units such as meq/100 g or cmol/kg (which are equivalent according to Atland et al 2014) or cmol/L. For mineral soils, CEC is most often reported by weight (meq/100 g or cmol/kg), but since soilless substrates are often used in a limited volume, measuring in a volumetric unit (cmol/L) allows a more accurate comparison of media with different bulk densities (Silber 2008).

Silber (2008) presented CEC values for some common substrate components in cmol kg^{-1} which can be found in Table 1.1. As can be seen from the table values, perlite and vermiculite contribute much less to the total CEC than peat and bark in a typical potting mix. According to Ingram et al (1993), if a soilless substrate contains 50-60% peat or pine bark and the particle sizes are moderate (3-9 mm), the CEC will be within an "adequate" range because the exchange capacity partially depends on surface area. Since smaller particles provide more total surface area, it is understandable that they would provide more exchange sites for cations within a substrate. This relationship was observed by Atland et al (2014) in their investigation of pine bark particle size and pH on CEC, where they reported that CEC consistently decreased with increased particle sizes of both peat and pine bark. The highest CEC the researchers measured (74.4 meq/L) was for a pine bark batch with 22% of particles below 0.5mm and more than half of particles below 2mm, which they considered to be fine and medium categories respectively.

Table 1.5.1 CEC values of typical soilless substrate components (Silber 2008)

Substrate Material	CEC (cmol/kg)
Perlite	25-35
Peat	90-140
Pine Bark	~98 (Variable charge)
Vermiculite	15-21

When separating pine bark and peat moss into different particle size ranges, Atland et al (2014) were able to demonstrate not only the effect of particle size, but the influence of bulk density on CEC volumetric measurements. For the particle range <0.71mm, the CEC of pine bark was 73.5 meq/100 g and that of peat moss was 99.6 meq/100 g, but because the bulk density of these materials is so different, the volumetric measurements tell a very different story. When taking into account the bulk density of the pine bark (0.295 g/cm^3) and the peat moss (0.083 g/cm^3) from this experiment and converting to volumetric units, the difference between CEC's of pine bark and peat moss changes dramatically to 216.8 meq/L and 82.7 meq/L respectively. This research shows the importance of understanding the interaction of physical and chemical properties of growth substrates as well as the necessity of using units that best describe them.

In a study conducted by Rippy and Nelson (2007), investigators determined that CEC variability among peat moss samples is mostly due to the species of plants that make up the peat. Higher percentages of *Sphagnum fuscum* in a peat sample increases the CEC significantly compared to samples with other *Sphagnum* species. According to the authors, higher levels of CEC correspond to a greater buffering capacity and therefore lead to less pH drift over time. Since *S. fuscum* is responsible for an increase in CEC of peat, it could be advantageous to control the percentage that is present in a given media to allow growers more control over pH.

1.5.3.2 Substrate pH

Although most media characteristics influence plant growth, pH may be one of the most important chemical factors because it is directly connected to nutrient availability (Bailey et al 2002, Ingram et al 1993). Similar to most other substrate characteristics, optimum levels of pH will vary with the plant species being grown and should be maintained accordingly (Ingram et al 1993). Lower than optimum pH levels can lead to ammonium toxicity as well as deficiencies in calcium and magnesium. If pH is too high (above 6.2), iron and boron deficiencies can become a problem (Bailey et al 2002). Even though there are plants that prefer higher or lower pH levels, Abad et al (2000) published a range (5.3-6.5) which generally allows for good nutrient availability without the danger of toxicity. Bailey et al (2002) were slightly more conservative in the optimum range they gave for most greenhouse crops, stating that a pH between 5.4 and 6.2 should be adequate. Regardless of the target pH, it is important to note that the most important factors influencing pH are the substrate components, the alkalinity of irrigation water, the pH of fertilizer solutions and of course, the plant species (Bailey et al 2002).

The effect of substrate components on pH levels can be very dramatic. For example, raw peat that has not been composted can start with a pH as low as 3.5 but will vary with source. Bark components will vary in pH depending on the tree species and have been reported anywhere between 4.0 and 6.6 (Maher et al 2008) and will tend to decrease over time as particles decompose (Ingram et al 1993). Perlite and vermiculite are pH neutral components, although perlite has no buffering capacity so will not help maintain pH levels. Vermiculite does have a buffering capacity; however, if pH is too low, aluminum ions can be released from particles of both perlite and vermiculite into the soil solution causing Al toxicity (Papadopoulos et al 2008).

According to Bailey et al (2002), if irrigation water has high alkalinity, substrate pH will tend to increase over time and differences will be more dramatic than initial liming adjustments. Fertilizer solutions and nitrogen form can also affect the pH of irrigation water and therefore substrate pH levels. Thus, it is important to monitor irrigation solution pH and substrate pH for changes over the course of time.

The effect of species on substrate pH can be different for each species and does not necessarily correspond to beneficial changes (Bailey et al 2002). According to Avner Silber (2008), there are three primary ways that plant growth can alter the rhizosphere. First, specifically adsorbing ions such as orthophosphates can alter the charge characteristics of previously uncharged particles (International Union of Pure and Applied Chemistry 2014) as they are added to the substrate in fertilizers or removed from the substrate by plant roots. The second way that plants can change media pH is by addition of organic compounds through root growth. Lastly, roots can exude humic and fulvic acids as well as other compounds that can accumulate in the growth substrate and alter the pH.

In their research at North Carolina State University, Bailey et al (2002) noted that different plants tend to change their substrate pH in dramatically different ways. For example, bedding plants such as marigold, vinca and zinnia tend to increase the pH of their rhizosphere, whereas dianthus, celosia and begonia tend to lower the substrate pH over time. Unfortunately, plants like celosia and dianthus actually perform better in a higher pH media, but they alter their substrate in the opposite direction, making it extremely important to monitor pH levels when growing these plants. This information also brings to light the importance of determining the optimum pH for each plant species separately.

Plant available nitrate within a growth substrate can be altered dramatically by nitrifying bacteria present in the medium and the extent of their activity. Lang and Elliott (1991) reported pH as one of the most important factors in NH_4 oxidation rates because nitrifying bacteria are highly pH sensitive. In their research, they determined that oxidation of NH_4 slowed when pH dropped below 6.8 and stopped when pH dropped below 5.6. The researchers found that increased NH_4:NO_3 ratios in the fertilizer solution tended to decrease microbial activity which may have been due to lower pH levels induced by higher NH_4 concentrations. It was also noted during the study that oxidation rates were higher in media that had been grown in than media without plant roots present even when substrates were irrigated and fertilized in the same manner. The results of Lang and Elliott's study showed that media type significantly influenced the amount of microbial activity, although the primary cause is thought to be related to the pH of the substrates.

1.5.3.3 Carbon: Nitrogen Ratio

The ratio by mass of total carbon to total nitrogen (C:N) is a parameter that is measured in order to predict the availability of nitrogen in a substrate. According to the USDA Natural Resources Conservation Service (2011) microorganisms in the soil will consume carbon and nitrogen at a rate of 24:1. When substrate ratios exceed 24:1, indicating there is more carbon present; microorganisms will start using up any available nitrogen in the medium in order to process the extra carbon. This results in nitrogen immobilization and can lead to nutritional deficits (Ingram et al 1993). Because soil microorganisms consume carbon and nitrogen in this ratio, when they break down materials with a C:N lower than 24:1, they will leave the excess

nitrogen in the substrate which will be available for root uptake (USDA NRCS 2011). In order to provide adequate nutrition to plants, it is important to ensure proper C:N ratios (below 24:1) of the growth substrate.

1.5.4 Interactions Between Growth Substrates and Container Size

Physical characteristics of soilless media can be strongly affected by volume and container geometry as well as the material from which the container is made. Fonteno (1993) advised that container capacity and air-filled pore space should be determined independently for different container sizes and shapes. Drzal et al (1999) discussed similar problems when characterizing pore sizes because the definitions are misleading. A "macropore" large enough to drain if located in the top portion of a 15cm tall container, may not be able to drain at all if located near the bottom or middle of a 2cm tall bedding plant cell. In a cell 2.5cm tall, air space can range from 1.2-2.7% depending on the media, but if the cell height is doubled, air space could be up to 10% (Bailey et al 2002).

Water availability will also be impacted by container size because of a gradient of water retention from the substrate surface to the bottom of the container where a "perched water table" exists. Through their research on container geometry and media physical properties, Bilderback and Fonteno (1987) found that the air and water holding capacities of the same substrate will change depending on the container height and width. Therefore, it is more appropriate to choose a substrate and container size that produce the desired properties together than to select these components separately.

1.6 Container Size Studies

Container size has been known for decades to affect plant growth and has been studied in numerous experimental settings revealing that differences in container size can affect the

morphological and physiological properties of plants and that the effects are often more pronounced in smaller containers (NeSmith and Duval 1998). According to Tonutti and Giulivo (1990), who experimented with young Kiwi plants to determine the effect of soil volume, claimed that growth of below ground organs is tied to the growth of the above ground tissues because they rely on each other for different substances. Roots rely on the shoots to provide carbohydrates and hormones such as auxins and gibberellins, but the shoots also rely on the roots for water, nutrients, and cytokinins. Since the success of roots and shoots is interdependent, it is logical that any stress put on the roots will in turn affect the growth of the shoots.

Poorter et al (2012a) created an exceptional resource for plant biologists to aid in choosing the appropriate container sizes for experimental purposes. In this guide, the authors remind those designing greenhouse experiments that not only is the rooting environment extremely important for container grown plants, but it may be even more important than the environmental conditions of the aerial parts of the plant. The same article describes some of the potential problems that can occur when using black containers, such as extreme temperature fluctuations of the root zone and more accelerated water depletion. Dark colored pots can dramatically raise the temperature of the rooting substrate, especially if they are in direct sun, which can damage roots.

Poorter et al (2012b) performed a meta-analysis on 65 studies focusing on the effects of container size and found root restriction occurs in most container grown plants since most species' roots will become longer than the container provides space for, and the effect of container size will increase with the length of time the plant remains in the pot and the increase in root density.

1.6.1 Changes in Shoot Growth and Morphology Due to Limited Container Volume

Although all the mechanisms involved in root restriction stress are not yet known or described, it has become obvious through the studies completed, that plants grown in limited soil volumes or root restricted hydroponic conditions experience varying levels of stress that manifest visibly as a decrease in growth and vigor in the aerial plant tissues.

Poorter et al (2012b) reported that doubling of a container volume will result in an average increase in biomass of 43%, although there is significant species to species variation. In an experiment performed on *Cupressocyparis leylandii*, Rozas et al (1995) observed growth rates of plants in smaller containers were initially similar to those in larger containers, but leveled off by the end of the study. The investigators suggested that this change in growth rate indicated the plant was suffering from root restriction. Growth rates of *Faidherbia albida* increased more over time when grown in larger containers, while the growth rate of plants in smaller containers remained fairly steady (Ameri et al 2017), suggesting they may have been suffering from root restriction. When experimenting with *Salvia splendens*, Van Iersel (1997) also observed a difference in performance over time. He reported that Salvia seedlings in the smallest containers showed signs of stress only 18 days after planting and that the differences between container size treatments increased over time.

Decreased leaf expansion and shoot growth was noted in grape vines, along with delayed leaf emergence and reduced vegetative growth overall when plants were grown in root restricted conditions (Xie et al 2013). In a study conducted on tomato plants, it was noted that smaller container volumes resulted in lower total dry weight as well as reduced leaf area due to smaller and fewer leaves. The authors partially attributed this to hypoxia in the root zone which stimulates ethylene production (Bouzo and Favaro 2015). Similar phenomena were observed in

a root restriction study involving tomatoes as well as a significant decrease in height when compared to unrestricted controls (Nishizawa and Saito 1998).

In addition to a decrease in plant height and dry weight, leaf size and number, other studies identified reactions to root restriction including a decrease in vegetative shoot growth in Kiwi (Tonutti and Giulivo 1990), less lateral branching in *Salvia splendens* (Van Iersel 1997) and changes in the balance of shoot:root ratios in numerous species (Kharkina et al 1999, Shi et al 2007, Tonutti and Giulivo 1990, NeSmith and Duval 1998).

1.6.2 Container Size Effects on Water and Nutrient Relations

Because soil volume varies with container size, smaller containers will have a lower water holding capacity that results in less available nutrients, especially if plants are given the same nutrient solution despite different rooting volumes (van Iersel, 1997). Smaller containers also dry out faster, heat up faster when in the sun, and can indirectly predispose plants to drought. (Poorter et al 2012b). Not only does the container volume affect water and nutrient availability, but shape can be just as important. By determining the characteristic moisture retention curve of two substrates, Bilderback and Fonteno (1987) were able to model the moisture content and distribution for a container of any dimensions. Through this research, they were able to determine that the physical properties of any media can change dramatically with container size and especially height. Bilderback and Fonteno (1987) warned that when growing in containers with drain holes around the periphery of the base, water drains through the soil progressively slower as it approaches the bottom plane of the container where a "perched water table" exists, resulting in a much higher moisture content lower in the container. Increasing the container height will improve aeration and allow more space between the crown of the plant and the saturated anaerobic conditions at the bottom. Through their investigation of container

geometry and media properties, the authors concluded that container and media choices should not be considered separate aspects when growing plants, but they are dependent on one another to such an extent that they should always be selected as a single unit.

The impact of container size on aerial plant parts can be non-existent or subtle initially, but as the roots become restricted by the container walls and eventually by other roots, plants tend to show symptoms similar to that of drought stress. However, as Kharkina et al found in their 1999 study on cucumbers grown in hydroponic culture, the symptoms could not be overcome with additional irrigation. They claimed that root restriction was resulting in some alteration of internal water relations even when water was readily available. Because nutrient absorption is inherently connected to water uptake, it is not surprising that other studies have found that there are negative impacts on nutrient uptake capability that may be related directly or indirectly to water uptake in root restricted plants (Xie et al 2013).

1.6.3 Physiological Effects of Container Size

The nursery industry is constantly trying to maximize the number of plants they can grow in the available space, which has led to numerous experiments investigating the impact of root restriction on the physiological processes of plants grown in containers. Notable findings for root restricted plants include a decrease in net photosynthesis (Poorter et al 2012b), imbalances in root synthesized hormones such as ABA and ethylene (Nishizawa and Saito, 1998), decreased levels of cytokinins (Tonutti and Giulivo, 1990), decreased transpiration rates (Kharkina et al, 1999) as well as reduced respiration, leaf conductance and intercellular CO_2 concentrations (Shi et al, 2007).

For years the effects observed in shoot growth and morphology were attributed primarily to water stress or an inadvertent nutrient deficiency when plants are grown in limited soil

volumes (Poorter et al 2012b). In a 1997 experiment using *Salvia splendens*, the investigator suggests that lower container volumes could create anaerobic conditions when root density increases, resulting in reduction of oxygen diffusion (van Iersel 1997). Kharkina et al (1999) investigated the effect of root restriction on hydroponically grown cucumbers and noted that respiration capacity was reduced which may indicate that root restricted plants actually suffer from an oxygen deficiency because the root density creates a competitive environment within the root zone. A more recent study by Shi et al attempted to identify the primary cause of root restriction stress as a lack of oxygen availability within the root zone. The experiment used a root restricted control that was supplemented with additional oxygen to help determine if the stress reactions could be overcome by aerating the nutrient solution. By collecting data on numerous physiological parameters as well as dissolved oxygen content in the root zone and growth parameters, Shi et al were able to state with confidence that oxygen becomes limiting under root restricted conditions and is likely the primary cause of decreased growth of root restricted tomato plants rather than water stress or nutrient deficiency. Shi et al (2007) concluded that aeration condition is extraordinarily important to the health and success of root restricted plants whether grown in hydroponic or soil culture.

NeSmith and Duval (1998) performed a review of container size experiments and found that many species react differently to stress. Some plant species under root restriction can show more or less dramatic changes in biomass distribution and morphology as well as numerous other parameters. Continued investigation of the responses of different taxa is paramount in developing a more comprehensive understanding of the variety of taxa produced and grown in containers.

1.7 Vegetative Perennial Propagation

Asexual plant propagation from cuttings is a popular method used in the green industry to produce genetically identical daughter plants from a stock plant with a particular set of desirable physical or physiological characteristics such as flower color, or increased pest resistance. This method of propagation is also used when certain taxa are unable to produce viable seed or when seed grown progeny do not come true to type (Mahlstede and Haber 1966). Cutting propagation relies on the ability of the propagule to form adventitious roots and the success of this process is closely related to the propagation environment (Owen and Maynard 2007) and the quality of the cutting. Many Plant Select® propagators reported difficulty rooting stem cuttings that contained reproductive tissue including flowers and unopened flower buds, which may act as a carbohydrate sink such as was found with expanding vegetative buds on hardwood cuttings (Okoro and Grace 1976).

Providing the proper environment for root initiation and elongation is a vital aspect of cutting propagation. The ideal environment will vary with the taxa being propagated and should be tailored accordingly for the best results. Some of the most important environmental factors influencing root formation and growth are air temperature and relative humidity. The environment directly surrounding the base of the cutting is also important and care should be taken to provide proper water and oxygen availability as well as ideal root zone temperatures to help encourage root growth and discourage pathogen infection (Owen and Maynard 2007).

According to Kester (1970), air temperature plays an important role in successful rooting of vegetative cuttings. Warm air temperatures increase metabolism of shoots and leaves, which can become competitive sinks for photosynthates that are needed for root development. Therefore, Kester recommends providing cuttings with air temperatures about 10 °F cooler than

root zone temperatures. Providing a cooler aerial environment around the shoots and leaves discourages over-consumption of limited resources prior to root development.

Bottom heat is often used in cutting propagation in order to elevate the root zone temperature and help speed up enzymatic reactions in the basal portion of the stem since the initiation of roots relies on the production and differentiation of many new cells (Owen and Maynard 2007). Hartmann et al (1997) reported that temperatures around the base of the stem and rooting medium should ideally range between 18 and 25 °C (64.4-77 °F), but that daytime air temperatures would be best kept around 21 °C (69.8 °F), and nighttime around 25 °C (77 °F). These temperatures are a good generic guideline to start with, but optimal temperatures will vary with plant taxa and may need to be altered between the root initiation and root elongation stages (Dykeman 1976).

In order to provide the proper level of humidity to cuttings and prevent the loss of water through transpiration before root formation occurs, growers must introduce additional moisture to the environment. While some propagators use fog systems to increase humidity levels around their propagules, it is probably most common to use intermittent mist as was used in this experiment. According to Owen and Maynard (2007), the industry standard has been 5 seconds every 5 minutes, but ideal misting times and durations will vary with the plant taxa being rooted and the developmental stage of those cuttings. Although intermittent mist is one of the most common methods of increasing relative humidity, mechanical issues often arise that cause mist to be delivered unevenly, which can lead to loss of turgor in cuttings, causing stress and reducing rooting success (Loach 1977).

While not addressed in the present study, rooting medium is very important to the success of root initiation and development as it directly influences water and oxygen availability to the

base of the stem. According to Gislerd (1983), if the moisture content in the rooting media is too high, air content is decreased and resulting lower root numbers could be related to oxygen availability and possible accumulation of ethylene. Therefore, it is imperative to provide cutting propagules with a well-aerated rooting medium that provides adequate oxygen diffusion, while also providing enough available water to maintain the turgidity of the cuttings. Many propagators use perlite as a rooting medium, as it provides a good balance of water and air, but other substrate components include peat, bark, coir, and sometimes sand (Owen and Maynard 2007).

Typically, propagators utilize some form of rooting hormone such as Indolebutryic acid (IBA), 1-Naphthaleneacetic acid (NAA), or sometimes a blend of both (Fretz 1979). Most herbaceous and softwood cuttings can be rooted successfully by applying 500-1,500ppm of an auxin or synthetic auxin compound (Cerveny and Gibson 2005). Based on interviews with regional Plant Select® propagators, it was determined that *Heuchera sanguinea* should only need about 500 $mg \cdot L^{-1}$ (ppm) IBA to help instigate rooting. *Zauschneria garrettii* cuttings were reported to be capable of rooting without hormone and, in fact, the hormone solution could damage the delicate stem tissue of this taxa and should not be used.

As with many processes, it is important to start with a solid foundation. In the case of propagation, this means healthy, productive stock plants from which to obtain viable cuttings. Although less research has been done on stock plants than on the mechanisms of rooting, it remains very important to maintain vigorous and disease free mother plants in order to maximize the rooting potential of cuttings taken from those plants. In a publication by Gibson and Cerveny (2005), the authors review some of the most important practices involved in maintaining high quality stock plants. According to the authors, growing productive stock plants involves every

aspect of plant care including plant selection, pest management, irrigation and fertilization, media and container size, spacing, light and temperature, and of course pinching and trimming. The age of the stock plant and the age of individual tissues will also influence the rooting capability of a cutting, so it is important to encourage new succulent growth with actively growing shoots, as older tissues will not root as readily.

1.8 Study Objectives

The objectives of the stock plant study were to identify the media and container size combination that resulted in the highest number and quality of cuttings for each taxon being grown and to develop a reproducible stock plant protocol for growers to follow in order to improve their success rates. The objective of the rooting study was to determine if the stock plant treatments had any effect on rooting percentages of the cuttings.

CHAPTER 2. MATERIALS AND METHODS

2.1 Stock Plant Care

The study was performed in the greenhouse at the Colorado State University Horticulture Center, located at 1707 Centre Avenue, Fort Collins, Colorado. The first experiment was initiated in October of 2016 and data was collected through March 2017. The second experiment was initiated in July 2017 and terminated in November 2017.

This experiment was designed to examine the effects of container size and media type on stock plant performance. The containers used were black plastic #1 (2.84L), #3 (11.35L), and #5 (14.55L) pots. All containers were soaked in a disinfecting anti-fungal and anti-algae solution for 10 minutes prior to use to avoid contamination from previous use.

Four different types of media were selected for this experiment based on substrates the industry is currently using for their stock plants. Exact scientific formulas for the media are proprietary and not available to publish, but a general list of ingredients is presented below. Prior to planting, samples of the four substrates were submitted to Colorado State University's Soil, Water and Plant Testing Laboratory for analysis. Soil analyses were performed to determine starting levels of nitrogen as ammonium, nitrate, and organic nitrogen, as well as the Ammonium: Nitrate ratios, Carbon: Nitrogen ratios and total carbon. Phosphorus content was measured as P and P_2O_5, while potassium content was measured as K and K_2O. Analyses also included percent lime, soluble salts, pH, Electric Conductivity (EC) and Cation Exchange Capacity (CEC). The same analysis was run on media collected from the root balls after the experiments were terminated and on the second batch of soil acquired for experiment 2 prior to planting. In addition, soil water retention curves were generated for each taxon-media

combination as well as for a sample of each media from the second batch prior to planting. For tests run post-experiment, a single sample was compiled for each taxon-media combination averaging over container size. Abbreviated results of soil analyses are presented in Table 2.1, and water release curves for each media are shown in Figure 2.1. Results of a sieve test on the second batch of media are shown in Table 2.2. Full results of soil analyses can be found in Appendix I.

Table 2.1.1 Soil analysis of the first (B1) and second (B2) batch of media prior to being planted in. BM7 indicates Berger BM-7, M360 indicates Metro Mix 360, M820 indicates Metro Mix 820, and PIN indicates Pindstrup.

	% OM		% Lime ($CaCO_3$)		pH (paste)		NH_4/ NO_3		C:N		CEC Meq/100g	
Media Batch	**B 1**	**B 2**	**B 1**	**B 2**	**B 1**	**B 2**	**B 1**	**B 2**	**B 1**	**B 2**	**B 1**	**B 2**
BM7	65.5	52.1	0.5	0.33	6.1	3.8	0.02	1.52	30.9	81.94	77	3.6
M360	44.7	32.4	0.9	0.26	6.3	3.8	0.83	1.41	13	55.23	59	4.3
M820	52.5	43.7	0.45	0.47	5.6	3.8	0.01	1.31	83.8	73.51	69	5.14
PIN	84.1	59.7	1.4	0.47	6.1	4.7	0.43	1.22	54.6	41.25	97	11.4

Table 2.1.2 Particle size distribution using five different sieve sizes performed on second batch of media only. BM7 indicates Berger BM-7, M360 indicates Metro Mix 360, M820 indicates Metro Mix 820, and PIN indicates Pindstrup.

		% retained by sieve size				
	%< 0.5mm	**0.5mm**	**2.0mm**	**4.0mm**	**6.0mm**	**8.0mm**
BM7	41.24	28.46	9.46	8.54	5.98	6.32
M360	72.8	14.40	5.62	5.30	1.88	0
M820	38.86	39.08	8.84	9.94	2.72	0.56
PIN	33.42	31.22	4.92	0.88	0	29.56

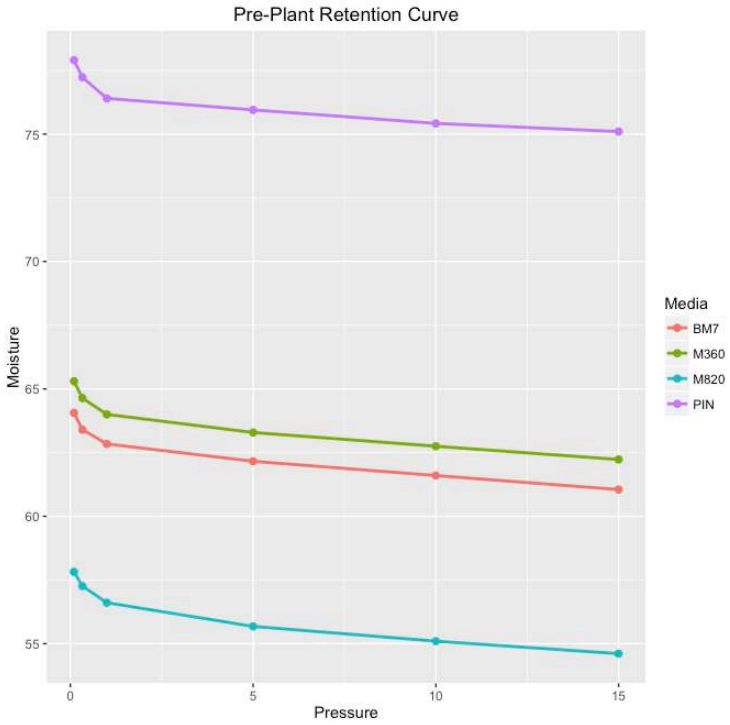

Figure 2.1.1 Moisture retention curves determined by pressure plate technique for second batch of media prior to planting. Pressures used were 1/10, 1/3, 1, 5, 10 and 15 bars. BM7 indicates Berger BM-7, M360 indicates Metro Mix 360, M820 indicates Metro Mix 820, and PIN indicates Pindstrup.

Berger BM-7 (referred to as BM7 in most figures) is a bark mix of small to intermediate particle size that includes coarse peat moss, perlite, dolomitic and calcitic lime, and a non-ionic wetting agent, as well as a pre-plant nutrient charge. Results of the sieve test on BM7 showed that almost 70% of particles were below 2.0mm, while the remaining 30% varied between 4.0 and 8.0mm, and only 6% being larger than 8.0mm. Water retention tests revealed that BM7 has fairly good water holding capacity with 63.4% moisture at field capacity.

Two products from Sun Gro® Horticulture were also researched. The first, Metro-Mix® 360, (referred to as M360 in most figures) is a fine textured media that contains Canadian sphagnum peat moss, bark, vermiculite, dolomitic limestone, bark ash and a wetting agent, as well as a pre-plant nutrient charge. Sieve tests for M360 showed that almost 73% of particles were below 0.5mm, 14% were between 0.5mm and 2.0mm. Only 13% of particles were above

2.0mm and none were above 8mm. Results of the moisture retention tests showed that percent moisture was slightly higher than BM7 at each pressure point, but overall quite similar. At field capacity, M360 retained 64.6% moisture as can be seen in Figure 2.1.

The second is Metro-Mix® 820, (referred to as M820 in most figures) a mix with a medium texture that contains bark, perlite and coarse perlite, Canadian sphagnum peat moss, dolomitic limestone and a wetting agent, as well as a pre-plant nutrient charge. Sieve tests on samples of M820 showed that 39% of particles were below 0.5mm, and another 39% were between 0.5mm and 2.0mm. The remaining 22% was mostly between 2.0mm and 6.0mm with only 0.56% being larger than 8.0mm. By examining the water retention curve for M820, it shows much lower moisture content than any of the other media used in the study, which may be partially due to the coarse perlite used in this recipe. At field capacity, M820 only held 57.3% moisture and dropped below 55% after being subjected to 15 bars of pressure.

The other media used in the study is from Pindstrup (referred to as PIN in most figures) and it is made entirely of blonde peat moss with dolomitic limestone, a starter charge of nutrients, and a wetting agent. Although the ingredients are the same, two different particle sizes of Pindstrup were mixed in a ratio of 1:1 to achieve a medium to coarse textured peat. Particle sizes in the final mix should have ranged from 5 to 40 millimeters based on the manufacturers' label. After completing a sieve test, the results showed that almost 30% of particles were larger than 6.0mm as expected, but 33% were below 0.5mm and 31% were between 0.5mm and 2.0mm. Water retention tests revealed Pindstrup to have the highest moisture content at all pressures, holding 77.2% moisture at field capacity and maintaining 75.1% after being subjected to 15 bars of pressure.

Stock plants of *Heuchera* L. 'Snow Angel' and *Epilobium canum* (Greene) P.H. Raven *ssp. garrettii* (A. Nelson) P.H. Raven *'PWWG01S' ORANGE CARPET*® were grown in one of twelve treatment combinations of media and container size on rolling greenhouse benches with small stands used to raise the smaller containers up and prevent shading between plants. Treatments within each taxon were completely randomized across two adjacent benches and spaced approximately 6" apart with 3 rows per bench (Figure 2.2). Each stock plant was assigned a unique ID and data was collected separately for each plant. Plot plans for Experiments #1 and #2 are presented in Appendix II, Figures A2.1 and A2.2.

Figure 2.1.2 Layout of *Heuchera* during Experiment #1 shortly after transplant into treatment containers.

The greenhouse utilized in this study was heated by forced air and cooled automatically by vents, shade cloths and a pad and fan system. Initially, daytime temperatures were maintained between 16.8 and 21.1 °C, while nighttime temperatures were kept between 14.4 and

21.1 °C. These temperatures were adjusted in late December of 2016 in an attempt to combat fungal growth. The remainder of the experiment was completed with daytime temperatures between 18.3 and 22.8 °C and nighttime temperatures between 16.1 and 22.8 °C. Shade cloths were set to close automatically only when needed for cooling. Before starting the second experiment, greenhouse temperature set points were changed to 16.7-20.0 °C during the day and 12.8-16.7 °C at night in an attempt to suppress flowering on the *Zauschneria* subjects.

Supplemental lighting was provided in two ways. A bank of Light Emitting Diode (LED) fixtures provided approximately 90% Red and 10% Blue light from sunrise to sunset every day. A second set of lights was only used on the *Zauschneria* subjects to help discourage blooming. These lights were used for night interruption and provided red light only from 10pm to 2am daily. Tests were performed using a light sensor to ensure there was not enough red light bleeding across the greenhouse to disrupt the other taxa in the study. During the second experiment, no night interruption lighting was used as it did now show any decrease in flowering over the course of the first experiment. However, due to the needs of other plants in the same greenhouse, supplemental LED lighting was on from 5am to 9pm every day during the second experiment.

Rooted plugs of *Heuchera* in 72 cell flats and *Zauschneria* in 98 cell flats were received in late September 2016 (late June 2017 for the second experiment) grown by Gulley Greenhouse in Fort Collins, Colorado. All plugs were transplanted into square 4” containers to become established in the four treatment substrates. After approximately six weeks, when plant roots were beginning to circle and become matted at the bottom of the 4” containers, they were transplanted into the final container sizes with their respective media treatments.

During the initial establishment period, plants were watered by hand as needed with a 14-4-14 fertilizer at 200 parts per million (ppm) nitrogen every watering. Fertilizer was injected using a Dosatron® model D14MZ2. After transplanting into the final container sizes, drip irrigation was installed and the fertilizer regimen was switched to a 20-10-20 fertilizer at 200 PPM nitrogen continual feed. Using 1-gallon/hour emitters, the irrigation initially ran twice weekly for 30 minutes. When plants were rooted into the larger containers, the frequency was changed to every other day.

2.2 Cutting Protocols

Because each taxon is very different, separate protocols were written for harvesting cuttings for each one. Protocols were based on industry practices and visual guides provided by Gulley Greenhouse (Figures 2.3 and 2.5), but slightly more rigid to keep harvests as similar as possible between rounds of cuttings.

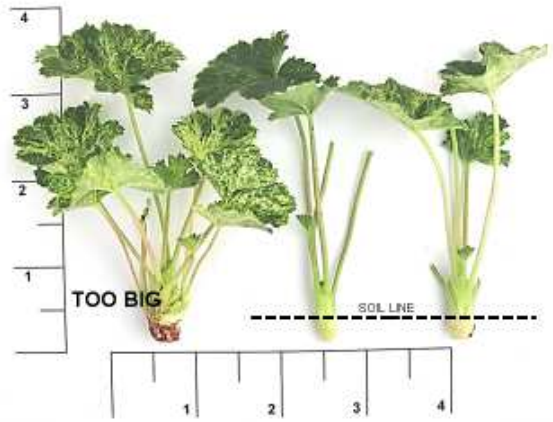

Figure 2.2.1 *Heuchera* 'Snow Angel' cutting size examples provided by Gulley Greenhouse, Fort Collins, Colorado.

The protocol for harvesting cuttings from *Heuchera* 'Snow Angel' is as follows:

Ideal cuttings will be pencil width at base, have ½ -1 inch (1.3-2.5cm) stems, and not have any lateral shoots. Any dead leaves should be stripped, along with any lateral buds, but all other foliage may be retained.

Step by step process:

1. Start by taking the most ideal cuttings first, being careful not to remove more than 1/3 of foliage
2. If you have removed 1/3 of foliage at this point, STOP and move to next plant
3. If you have not removed 1/3 of foliage yet, continue by taking slightly less ideal cuttings until you have removed 1/3 of foliage or no acceptable cuttings remain
4. Remove any dead foliage from the stock plant at this time
5. Cut meristem off any shoots that are too large to take as a cutting

Figure 2.2.2 Stock plants of *Heuchera* 'Snow Angel before cuttings (left) and after (right).

The protocol for harvesting cuttings from *Zauschneria garrettii* 'PWWG01S' ORANGE CARPET® are as follows:

Ideal cuttings will have soft, lush growth, not be too skinny, have at least 2 nodes below terminal with fully expanded leaves, not have any expanded laterals, and not have any expanded flower buds. They should also Have ½ - ¾ inch (1.3-1.9cm) stem at base for anchoring. None of the foliage should be removed.

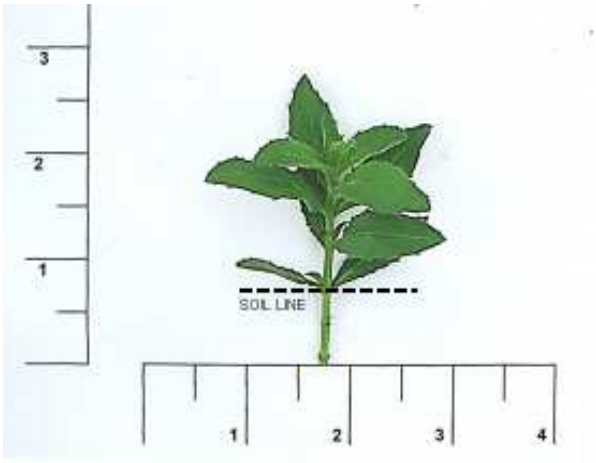

Figure 2.2.3 *Zauschneria garrettii* 'PWWG01S' ORANGE CARPET® cutting size example provided by Gulley Greenhouse, Fort Collins, Colorado.

Step by step process:

1. Start by taking the most ideal cuttings first
2. Pick a thick stem with soft new growth at the tip
3. Feel for stem flexibility below 2nd node (2nd node below apical bud)
4. If soft, take cutting and remove any expanding buds
5. If stem is soft below the 3rd or 4th node, take a larger cutting as long as nodes are not too far apart.
6. Remove stalks that are flowering profusely or pluck off flowers on rest of plant
7. Remove large woody branches if extending very far past container edge
8. Do not remove more than 2/3 of foliage

Although choosing which cuttings to harvest from a stock plant is a very subjective process and, some may argue, an art, every attempt was made to maintain consistency between plants and between harvests by following these protocols.

Figure 2.2.4 Stock plants of *Zauschneria garrettii* 'PWWG01S' ORANGE CARPET® before cuttings (left) and after (right).

2.3 Data Collection

The effects of each treatment were documented in multiple ways. Measured parameters included monthly records of plant height and width which were used to calculate a "size index" by averaging the height and two widths. This way of creating a single size parameter was used by Bi and Evans (2009) and Adam (2005), who used the same formula. Photographs were taken to help document plant health and flowering status. Number of cuttings were counted and harvests weighed before and after drying. Initial data was taken when plants were transplanted to the treatment containers. At that time, plants were measured in centimeters at their highest point from the base of the plant and at two perpendicular widths. Photographs were then taken of the most average sized plant within each treatment combination. After the roots struck the side of the #3 (11.35L) containers, size measurements were repeated, photographs were taken of the same plant from each treatment combination and cuttings were harvested. The cuttings from each stock plant were counted, placed in a paper bag and weighed to determine the fresh weight, then placed in a drying oven at 70 °C for a minimum of 48 hours. After the cuttings were dried,

the bags were weighed again to record dry weights. After harvest, stock plants were allowed to grow for 4 weeks before taking another set of cuttings. The only maintenance done between rounds of cuttings was removing flowering stalks from *Zauschneria* subjects in an attempt to keep stock plants in a vegetative state.

During the first repetition of the study, the first round of cuttings was taken from *Heuchera* subjects between November 22nd and 25th, 2016 and the dominant apical meristem was removed from each plant at that time to stimulate branching before the next round of cuttings. The second round of cuttings was harvested four weeks later between December 19th and 21st, 2016 and the last round between January 16th and 19th, 2017 for a total of 3 harvests. Harvesting cuttings from the *Zauschneria* subjects began one week later because the stock plants were slower to root in. The first round of cuttings was taken between November 30th and December 3rd, 2016. The second round of cuttings was harvested between December 28th and 30th, 2016 and the third round was taken between January 24th and 29th, 2017 for a total of 3 harvests. All flowering stalks were removed or stripped of reproductive buds at each harvest to encourage new vegetative growth.

During the second repetition of the study, the first set of *Heuchera* cuttings was harvested between August 22nd and 25th, 2017, and the dominant apical meristem was removed to encourage branching. The second harvest was completed between September 18th and 19th, 2017, and the final harvest took place between October 16th and 20th, 2017. The first harvest of cuttings from *Zauschneria* subjects were taken between August 29th and September 1st, 2017. The second harvest was done between September 23rd and 27th, 2017 and the final harvest was completed between October 23rd and 27th, 2017. All flowering tissue was removed from *Zauschneria* subjects after each harvest to encourage new vegetative growth.

At the termination of the experiment, a subset of stock plants from each treatment was cut at the crown and top growth was dried and weighed. The root balls were carefully removed from their pots and given a visual rating corresponding to the density of visible roots circling the root ball or matted at the bottom. The root rating scale was found in a study examining the use of pulp mill ash as a substrate component for greenhouse grown marigolds (Bi and Evans). The investigators used a scale of 0-5 where 0 indicated that there were no roots visible on the outside of the root ball and 5 indicated that there were extensive visible roots matted on the bottom of the root ball and the majority of the sides. A visual reference was compiled as root ratings were documented for the plants being harvested in an attempt to keep ratings as consistent as possible (Figure 2.7).

Figure 2.3.1 Visual root ratings of *Zauschneria* subjects after Experiment #1. From top left to bottom right: Root ratings of 0, 1, 2, 3, 4, 5.

2.4 Rooting Experiment

A subset of the stock plants from each treatment combination was randomly selected and grown under the same conditions for a rooting experiment. The only variables of the rooting experiment were the stock plant treatments. Twelve cuttings were harvested from each treatment combination every four weeks. Cuttings were taken in the morning before noon and stuck in trays with Jiffy® Preforma® media and placed under mist with bottom heat. Rooting data was then collected every week for four weeks before removing and discarding top growth and weighing dried root balls to determine differences in root mass. Weekly data collection included rooting status determined by the ability to remove the propagule from the plug. If rooted, the number of visible roots on the outer edge of the Preforma® cube were counted. Roots were only counted up to 50 because it becomes nearly impossible to distinguish one root from another once roots exceed 50.

For the *Heuchera* subjects, four stock plants from each treatment combination were saved and the three most ideal cuttings were taken from each plant, dipped for five seconds in 500 parts per million indolbutyric acid (IBA), using Wood's® rooting compound and stuck in 72 cell trays. Cutting trays were placed on heating mats that maintained a soil temperature of 18.3 °C and mist times were adjusted weekly. Cuttings were watered initially with plain water, and if trays dried out throughout the experiment. The mist system ran for ten seconds every 15 minutes for the first week, every 30 minutes for the second week and every 60 minutes for the third and fourth weeks.

Only three *Zauschneria* stock plants were saved per treatment combination for the cutting experiment because they produce many more cuttings per plant. Every four weeks, the four most ideal cuttings were taken from each plant and immediately stuck in 98 cell trays without any

hormone dip. Trays were placed on a heating mat that maintained soil temperatures at 23.9 °C and watered in with plain water. The misting times were the same starting at ten seconds every 15 minutes for the first week and decreasing each week. Plugs were watered with clear water when substrate appeared dry to prevent the cuttings from wilting.

2.5 Data Analysis

Data analysis was done using R version 3.3.1 "Bug in Your Hair" (R Core Team, 2016) and the car (Fox and Weisberg, 2011) and lsmeans (Lenth, 2016) packages. A 3X4 factorial design was used and run as a Two-Way ANOVA run separately for each response variable. Response variables for the stock plant experiments include: Size Index, average number of cuttings per plant, average number of cuttings per square foot, average fresh weight per cutting, average dry weight per cutting, final dry weight of top growth, and root ratings. Response variables for the rooting experiments include: Rooting status and number of visible roots. Terms included in the model were predictor variables corresponding to Media (With 4 levels) and Size (With 3 levels) as well as a Size by Media interaction. Although the interaction between Size and Media was not statistically significant in all cases, it was retained in the model. Pairwise comparisons and least squares means were calculated using the lsmeans package for each response variable. Significant differences were noted using $P<0.05$ and 95% confidence intervals were constructed.

2.5.1 Dropped Observations

Due to death of a few plants early in the study and a few incidences of incorrect data entry, some observations were dropped to maintain the integrity of the data. During the first *Zauschneria* experiment, a single observation was dropped for one harvest date because the

number of cuttings was entered incorrectly, which greatly skewed the fresh and dry weights from that plant during that harvest. Other observations from that plant were retained.

During the second *Heuchera* experiment a single observation was dropped from the first harvest date because the fresh weight was incorrectly entered into the data table. All other observations for this plant were retained. During the second *Zauschneria* experiment, 2 plants died early in the experiment (broken at crown during measuring) so these plants do not appear in the final analysis. One other plant was dropped from the analysis due to incorrect data entry. None of the dropped observations affected the overall conclusions, but did skew the individual treatment means, so they were removed to give a more accurate representation of the data.

CHAPTER 3. RESULTS AND DISCUSSION

3.1 *Heuchera* 'Snow Angel'

3.1.1 Plant Size

A single parameter for size was calculated to represent overall plant size by averaging the measured height and two widths of each plant. Statistical analysis of size index was done for each time point beginning with initial measurements made after plants had become established in 4" containers but before they were shifted to their treatment container sizes. Statistical analysis was only calculated using treatment media for this time point since the plants had not yet been moved to their treatment container sizes. Subsequent analyses contain media, container size and the size*media interaction.

3.1.1.1 Size Index

Analysis of variance of Experiment #1 revealed a significant effect of media for initial size index and all pairwise comparisons of media were significantly different at the level of 0.05 (Figure 3.1.1). The smallest plants were grown in Berger BM-7 and the largest plants were grown in Metro Mix 820 (Table 3.1.1, Figure 3.1.2). This trend continued through the following three time points although became slightly less dramatic over the course of the experiment (Tables 3.1.2-3.1.4, Figures 3.1.3-3.1.8). By the final measurements, main effect of media was no longer significant, but when averaging over media treatment, the main effect of container size remained significant (Table 3.1.5, Figures 3.1.9-3.1.10). These results suggest that the initial differences in size index could be partially due to differences in pre-plant nutrient charges in the media that were depleted over time and replaced by the liquid feed used in the study which was the same for all plants. Development of a significant effect of size later in the experiment agrees

with research performed by Rozas et al (1995) who reported *Cupressocyparis leylandii* plants that initially showed similar growth in all container sizes tended to decrease in growth as roots became restricted.

```
Response: INITSizeIndex
            Sum Sq  Df  F value    Pr(>F)
(Intercept)  45401   1 24416.86 < 2.2e-16 ***
Media          655   3   117.35 < 2.2e-16 ***
Residuals      216 116
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.1 Experiment #1 one-way ANOVA table for initial size index with "Media" as only predictor.

Table 3.1.1 Experiment #1 initial size index ((height + width 1 + width 2)/3) prior to being shifted to treatment container sizes, and 95% confidence intervals for each media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	16.44	15.94-16.93	1
Metro Mix 360	20.89	20.39-21.38	3
Metro Mix 820	22.41	21.92-22.90	4
Pindstrup	18.07	17.58-18.56	2

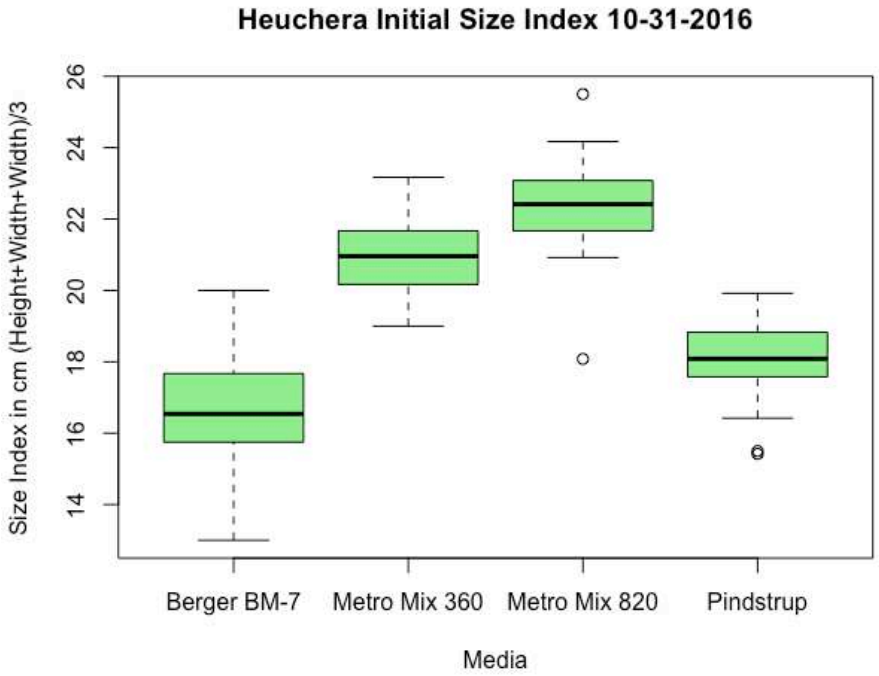

Figure 3.1.2 Experiment #1 boxplots of initial size index with "Media" as only predictor variable.

```
Anova Table (Type III tests)

Response: SizeIndex1
            Sum Sq  Df    F value  Pr(>F)
(Intercept)  55441   1 25004.4106 < 2e-16 ***
Size             2   2     0.5040 0.60555
Media          453   3    68.0766 < 2e-16 ***
Size:Media      28   6     2.0684 0.06282 .
Residuals      239 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.3 Experiment #1 two-way ANOVA table for size index before first harvest.

Table 3.1.2 Experiment #1 mean size index before first harvest (11-21-2016) for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	19.06	18.52-19.59	1
Metro Mix 360	22.84	22.30-23.38	3
Metro Mix 820	23.87	23.34-24.41	4
Pindstrup	20.20	19.67-20.74	2

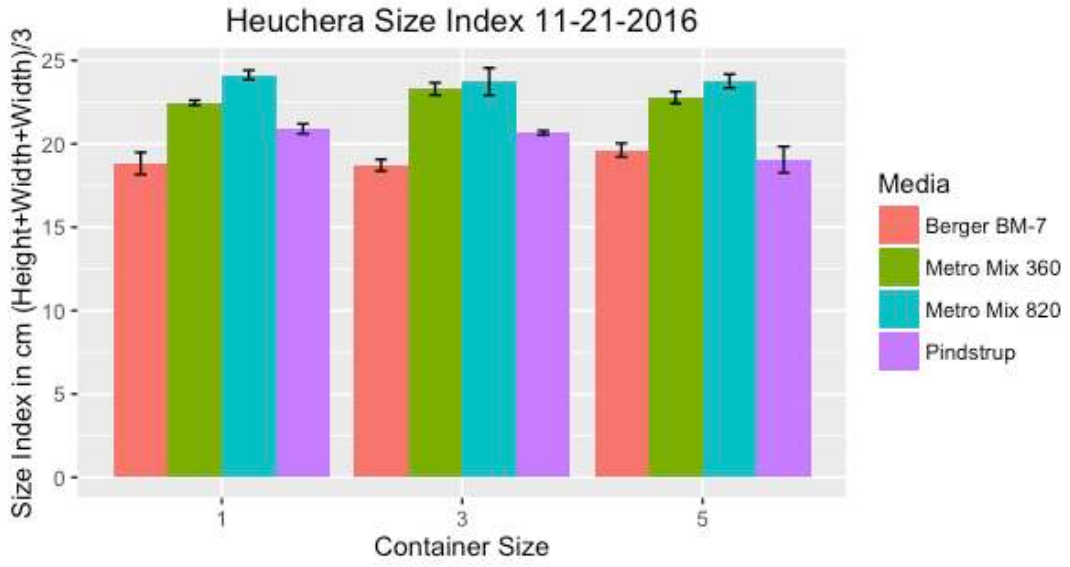

Figure 3.1.4 Experiment #1 bar plot of size index before first harvest (11-21-2016) for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: SizeIndex2
            Sum Sq  Df    F value Pr(>F)
(Intercept)  71337   1 31334.2688 <2e-16 ***
Size             3   2     0.6219 0.5389
Media          320   3    46.7866 <2e-16 ***
Size:Media      12   6     0.8432 0.5394
Residuals      246 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.5 Experiment #1 two-way ANOVA table before second harvest (12-17-2016).

Table 3.1.3 Experiment #1 mean size index before second harvest (12-17-2016) for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	22.30	21.76-22.85	1
Metro Mix 360	25.63	25.09-26.18	2
Metro Mix 820	26.28	25.74-26.83	2
Pindstrup	23.31	22.76-23.86	1

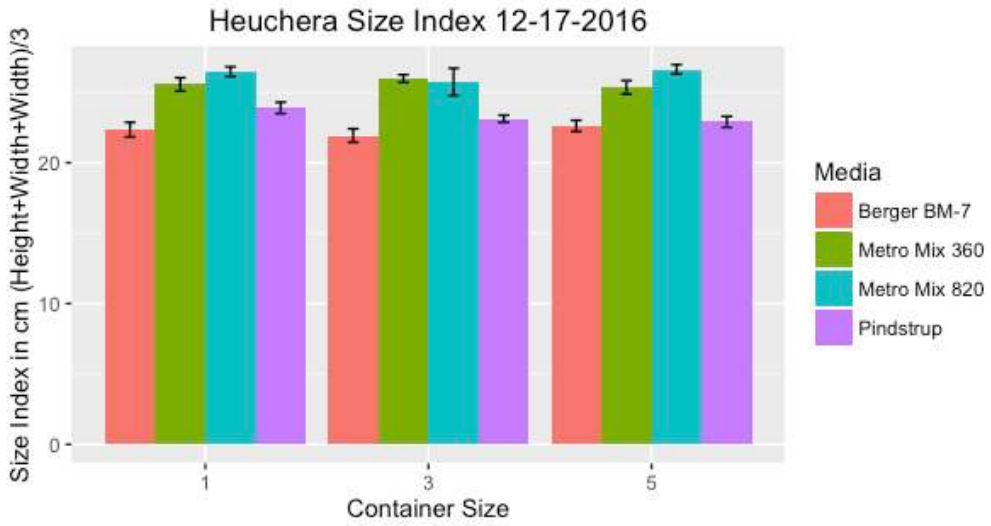

Figure 3.1.6 Experiment #1 bar plot of size index before second harvest (12-17-2016) for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: SizeIndex3
             Sum Sq  Df    F value    Pr(>F)
(Intercept)  85153   1 22462.0764 < 2.2e-16 ***
Size            21   2     2.8036   0.06501 .
Media          155   3    13.6090 1.352e-07 ***
Size:Media      34   6     1.5029   0.18402
Residuals      409 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.7 Experiment #1 two-way ANOVA table for size index before third harvest (1-15-2017).

Table 3.1.4 Experiment #1 mean size index before third harvest (1-15-2017) for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	25.32	24.61-26.02	1
Metro Mix 360	27.57	26.87-28.28	2
Metro Mix 820	27.94	27.24-28.65	2
Pindstrup	25.72	25.02-26.42	1

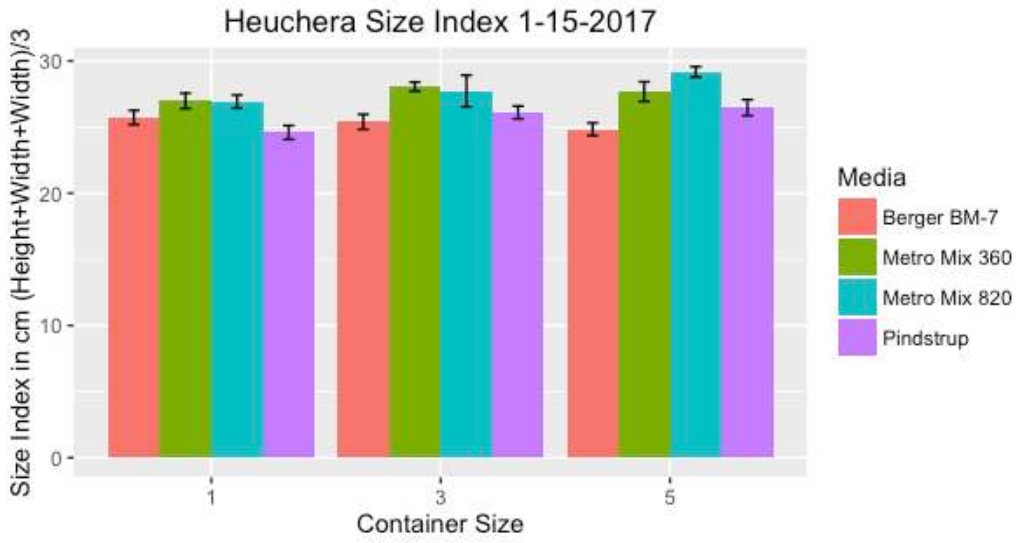

Figure 3.1.8 Experiment #1 bar plot of size index before third harvest (1-15-2017) for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: FINALSizeIndex
             Sum Sq  Df    F value    Pr(>F)
(Intercept) 108856   1 19143.1867 < 2.2e-16 ***
Size           125   2    10.9689 4.604e-05 ***
Media           16   3     0.9221    0.4328
Size:Media      22   6     0.6568    0.6846
Residuals      614 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.1.9 Experiment #1 two-way ANOVA table for final size index (2-22-2017).

Table 3.1.5 Experiment #1 mean size index from final measurement (2-22-2017) for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Size Index	95% Confidence Interval	Significance Group
#1 (2.84L)	28.68	27.93-29.43	1
#3 (11.35L)	30.91	30.16-31.66	2
#5 (14.55L)	30.77	30.02-31-52	2

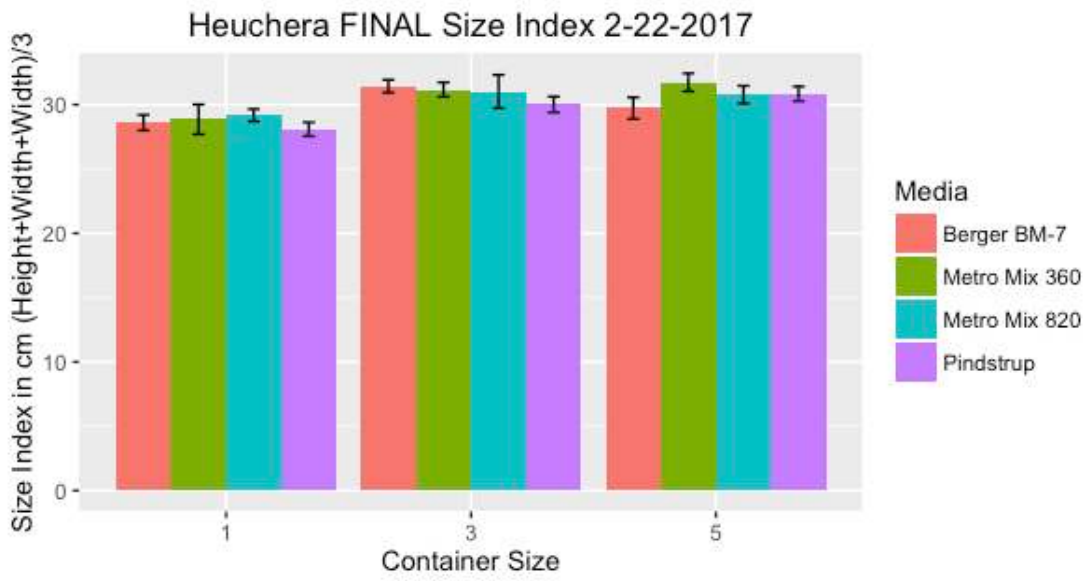

Figure 3.1.10 Experiment #1 bar plot of final size index (2-22-2017) for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Results of Experiment #2 showed slightly different trends. Initial size measurements revealed a significant effect of media treatment (Figure 3.1.11 and 3.1.12) although the relative responses to media were different than the first experiment. Metro Mix 360 and Pindstrup resulted in the largest plants, while Metro Mix 820 and Berger BM-7 resulted in the smallest (Table 3.1.6). By the second measurement, which was taken just before the first harvest of cuttings, both size and media main effects were significant (Figure 3.1.13-3.1.14). All media treatments resulted in significant differences except for Berger BM-7 and Metro Mix 820 which produced the smallest plants (Table 3.1.7). Stock plants being grown in #1 (2.84L) containers were the smallest, while those in the 11.35L and 14.55L containers were significantly larger. While it is unlikely that plants being grown in the #1 (2.84L) containers were suffering from significant root restriction this early in the experiment, it is possible that plants being grown in the larger containers had better drainage and were therefore able to establish more quickly. According to Bilderback and Fonteno (1987), a perched water table creates more saturated

conditions near the base of any container and taller containers provide more well-aerated media than shorter containers because of their height. With a larger volume of media in which the plant can grow under non-saturated conditions, root growth could be enhanced.

Following the first harvest of cuttings, subsequent measurements showed mixed results. Main effect of media was significant at every time point, although container size did not remain so throughout the experiment. Just before the second harvest, plants did not show a significant response to container size (Figure 3.1.15-3.1.16, Table 3.1.8), but just before the third harvest, effect of size was again statistically significant (Figure 3.1.17-3.1.18, Table 3.1.9). At the final measurement before harvesting whole plants, the main effect of container size was no longer significant at the 0.05 level (Figure 3.1.19-3.1.20, Table 3.1.10). The change in response between measurements could be partially due to differences in harvest severity and temperature fluctuations that can cause plant stress. Although every attempt was made to harvest cuttings uniformly from plant to plant and harvest to harvest, it is possible that one harvest period could have been slightly different from another. Additionally, while the experiment was conducted inside a semi-controlled environment, the amount of sun and cloud cover can dramatically change the temperature of the air inside the greenhouse as well as the temperature of the substrate. As Poorter et al (2012a) noted, direct solar radiation can warm up black containers such as those used in the present experiment and cause root stress or damage. Heat damage to the roots is exacerbated in smaller containers because containers with smaller substrate volumes will heat up faster especially when exposed to direct solar radiation.

```
Anova Table (Type III tests)

Response: INITSizeIndex
             Sum Sq  Df    F value    Pr(>F)
(Intercept) 20794.1   1 17868.5878 < 2.2e-16 ***
Media          29.2   3     8.3683 4.398e-05 ***
Residuals     135.0 116
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.11 Experiment #2 one-way ANOVA table for initial size index (7-12-2017) with "Media" as only predictor.

Table 3.1.6 Experiment #2 initial size index ((height + width 1 + width 2)/3) prior to being shifted to treatment container sizes. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	12.80	12.41-13.19	1, 2
Metro Mix 360	13.77	13.38-14.16	3
Metro Mix 820	12.57	12.18-12.96	1
Pindstrup	13.52	13.13-12.91	2, 3

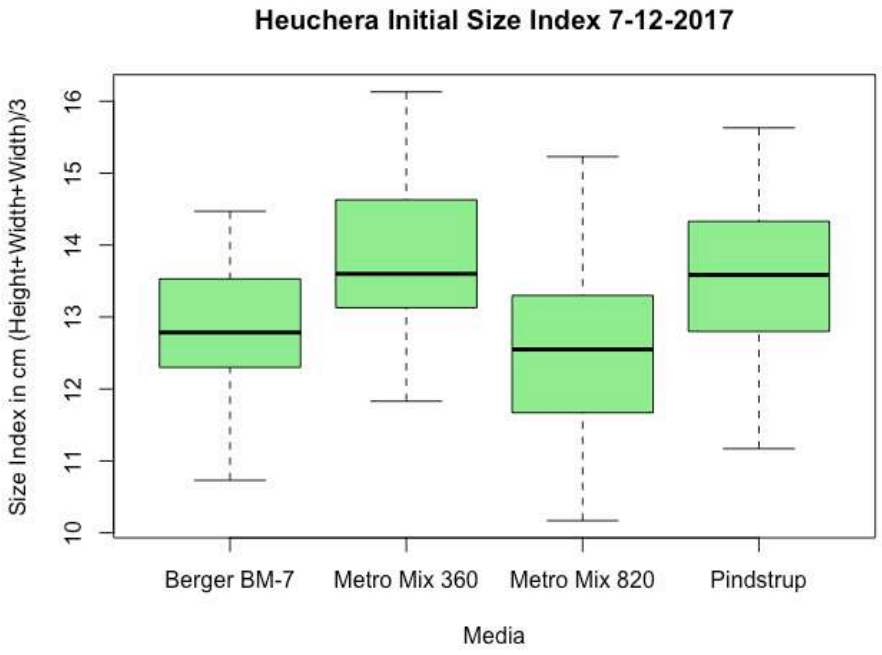

Figure 3.1.12 Experiment #2 Boxplots of initial size index with "Media" as only predictor variable.

```
Anova Table (Type III tests)

Response: X1SizeIndex
             Sum Sq  Df    F value    Pr(>F)
(Intercept)  61338   1 16004.0535 < 2.2e-16 ***
Size            47   2     6.0923  0.003112 **
Media          323   3    28.1028 1.646e-13 ***
Size:Media       1   6     0.0616  0.999039
Residuals      414 108
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.13 Experiment #2 two-way ANOVA table for size index before first harvest.

Table 3.1.7 Experiment #2 mean size index and 95% confidence intervals prior to first harvest for each media treatment averaged over size and each container size treatment averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	21.63	20.92-22.34	1
Metro Mix 360	23.29	22.58-24.00	2
Metro Mix 820	20.60	19.89-21.31	1
Pindstrup	24.91	24.21-25.62	3
#1 Container	21.73	21.11-22.34	1
#3 Container	23.03	22.42-23.64	2
#5 Container	23.07	22.46-23.68	2

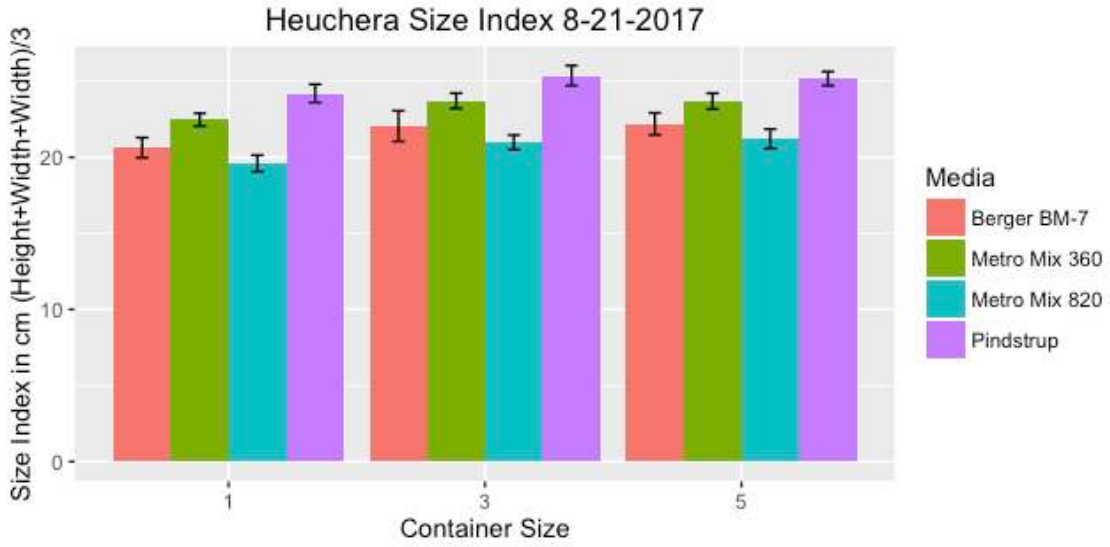

Figure 3.1.14 Experiment #2 bar plots of mean size index for each treatment combination prior to first harvest (8-21-2017). Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: XZSizeIndex
             Sum Sq  Df    F value    Pr(>F)
(Intercept)  84352   1 12233.6880 < 2.2e-16 ***
Size            34   2     2.4329 0.0925829 .
Media          128   3     6.2029 0.0006287 ***
Size:Media      36   6     0.8637 0.5241813
Residuals      745 108
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.15 Experiment #2 two-way ANOVA table for size index prior to second harvest (9-15-2017).

Table 3.1.8 Experiment #2 mean size index prior to second harvest of each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	25.67	24.72-26.62	1
Metro Mix 360	27.06	26.11-28-01	1, 2
Metro Mix 820	25.40	24.44-26.35	1
Pindstrup	27.93	26.98-28.88	2

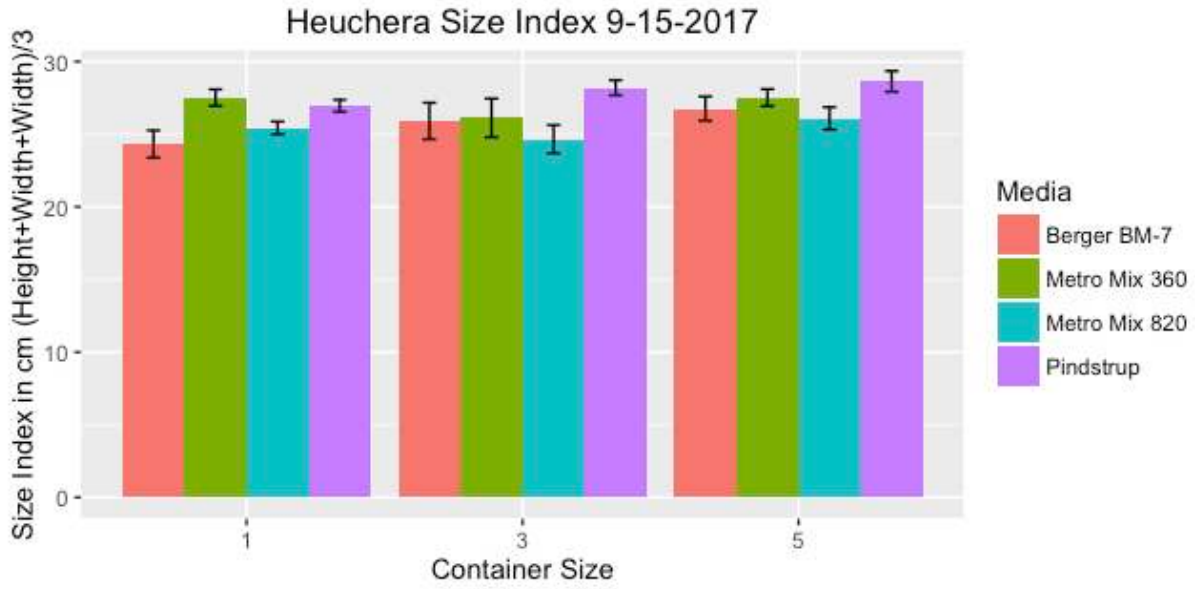

Figure 3.1.16 Experiment #2 bar plots of size index prior to second harvest (9-15-2017) for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: X3SizeIndex
             Sum Sq  Df    F value    Pr(>F)
(Intercept) 119330   1 26485.5735 < 2.2e-16 ***
Size           123   2    13.6994 4.985e-06 ***
Media           74   3     5.4558  0.001571 **
Size:Media      32   6     1.1801  0.322331
Residuals      487 108
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.17 Experiment #2 two-way ANOVA table for size index prior to third harvest (10-13-2017).

Table 3.1.9 Experiment #2 mean size index prior to third harvest (10-13-2017) for each media treatment averaged over size and each container size treatment averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	30.56	29.79-31.33	1
Metro Mix 360	32.69	31.93-33.46	2
Metro Mix 820	31.17	30.41-31.94	1
Pindstrup	31.71	30.94-32.48	1, 2
#1 Container	30.25	29.59-30.92	1
#3 Container	31.61	30.95-32.28	2
#5 Container	32.73	32.07-33.40	2

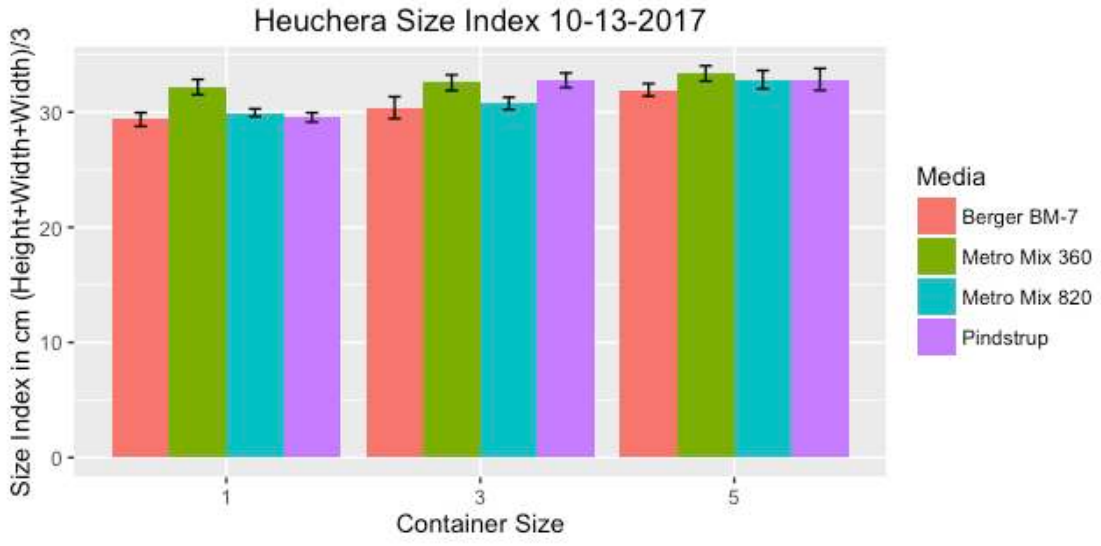

Figure 3.1.18 Experiment #2 bar plots of mean size index prior to third harvest (10-13-2017) for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: FINALSizeIndex
             Sum Sq  Df    F value    Pr(>F)
(Intercept) 120070   1 31846.9993 < 2.2e-16 ***
Size            21   2     2.7439   0.06881 .
Media          109   3     9.6630 1.053e-05 ***
Size:Media      24   6     1.0684   0.38604
Residuals      407 108
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.19 Experiment #2 two-way ANOVA table for final size index (11-10-2017).

Table 3.1.10 Experiment #2 mean final size index (11-10-2017) for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	30.58	29.88-31.28	1
Metro Mix 360	33.17	32.47-33.88	2
Metro Mix 820	31.24	30.54-31.94	1
Pindstrup	31.54	30.83-32.24	1

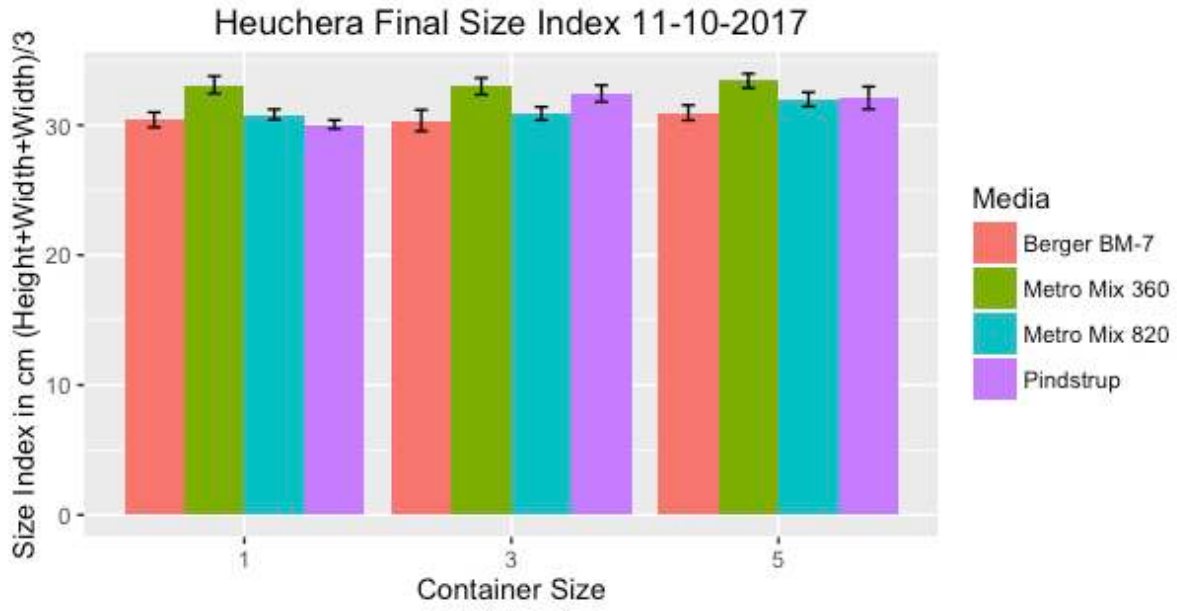

Figure 3.1.20 Experiment #2 bar plots of final size index (11-10-2017) for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.1.1.2 Final Dry Weight

Final Dry weight of stock plants was determined by cutting off all top growth at the crown and drying at 70 °C for at least 4 days in paper bags before weighing.

Results of Experiment #1 showed a significant main effect of container size (Figure 3.1.21 and 3.1.22) with the smallest plants being those grown in #1 (2.84L) containers and the largest being those grown in #3 (11.35L) containers (Table 3.1.11) when results were averaged over media treatment. Stock plant dry weights were significantly lower in #1 (2.84L) containers than both larger containers, but there was no significant difference between the #3 (11.35L) and #5 (14.55L) containers. There was no significant main effect of media nor the media*size interaction. These results agree with other research done on the subject of root restriction and container size such as a study done by Nishizawa and Saito (1998) who reported a decrease in dry mass of tomato plant parts in smaller containers. Stevenson and Fisher (1975), who also researched tomato plants, found an increase in dry mass of the plant top when plants were grown in larger containers, and more recently, Bouzo and Favaro (2015) demonstrated an exponential relationship between dry weight and container volume.

Because there was no significant difference between the #3 (11.35L) and #5 (14.55L) containers, it seems the duration of the study may not have given the plants enough time to develop root restricted conditions in either of the larger containers sizes. According to Poorter et al (2012b), while the effect of container size may be small initially, or even non-existent at the beginning of an experiment, the effect will increase with time as the roots grow and become more restricted.

Results of Experiment #2 demonstrated a significant main effect of media, but not of container size, nor the interaction of media and size. Pairwise comparisons showed that while averaging over container size, Metro Mix 360 resulted in significantly higher dry weights than

the other 3 media (Table 3.1.12 and Figure 3.1.23). As can be seen from Figure 3.1.24, differences were more dramatic in the smaller container sizes. No other pairwise comparisons were significant, however Berger BM-7 resulted in the lowest dry weights overall. Although results of final dry weight agreed with those of the final size index, analysis of the substrates prior to and after growth reveal little insight into the increased response to Metro Mix 360 during Experiment #2.

Of the substrate properties that were analyzed for the second batch of media, Metro Mix 360 showed no major differences from the other media. Starting levels of potassium were higher than the other media because it contains vermiculite, although they did not remain the highest, so it is difficult to determine if that had an effect on growth parameters (Appendix I, Tables A1.5 and A1.6). The initial pH of the second batch of Metro Mix 360 was very low (3.8), but similar to the other substrates' starting levels (3.8-4.7). After Experiment #2 was completed, the pH of Metro Mix 360 remained the lowest (4.7 as compared to 5.1-5.8 for other media). This alone does not explain much, but by examining the results of size index from Experiment #1, it seems that *Heuchera* may prefer a lower pH since the largest plants were grown in Metro Mix 820 which started and ended the first experiment with the lowest pH of all the substrates. According to Bailey et al (2002) and Ingram et al (1993), plants will respond best when grown in the optimum pH for that species, and ideal levels can vary dramatically between species. While this does not completely explain the results of the present study, it may give some guidance in further studies when attempting to identify the best pH for *Heuchera* growth.

```
Anova Table (Type III tests)

Response: PlantDryWeight
            Sum Sq Df   F value    Pr(>F)
(Intercept) 257757  1 1437.5310 < 2.2e-16 ***
Size          7309  2   20.3811  1.76e-07 ***
Media          820  3    1.5244    0.2174
Size:Media     484  6    0.4498    0.8423
Residuals    10758 60
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.21 Experiment #1 two-way ANOVA table for final dry weight of top growth.

Table 3.1.11 Experiment #1 mean final dry weight for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of $P<0.05$.

Container Size	Mean Dry Weight of Top Growth (g)	95% Confidence Interval	Significance Group
#1 (2.84L)	45.63	40.16-51.09	1
#3 (11.35L)	67.88	62.41-73.35	2
#5 (14.55L)	65.99	60.53-71.46	2

Figure 3.1.22 Experiment #1 bar plots of mean final dry weight for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: FINALDry
            Sum Sq Df   F value    Pr(>F)
(Intercept)  86057  1 1970.2311 < 2.2e-16 ***
Size           247  2    2.8241   0.06727 .
Media         1241  3    9.4733 3.251e-05 ***
Size:Media     508  6    1.9368   0.08939 .
Residuals     2621 60
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.23 Experiment #2 two-way ANOVA table for final dry weight of top growth.

Table 3.1.12 Experiment #2 mean final dry weight for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Dry Weight of Top Growth (g)	95% Confidence Interval	Significance Group
Berger BM-7	30.84	27.72-33.95	1
Metro Mix 360	41.43	38.31-44.54	2
Metro Mix 820	34.27	31.15-37.38	1
Pindstrup	31.76	28.64-34.87	1

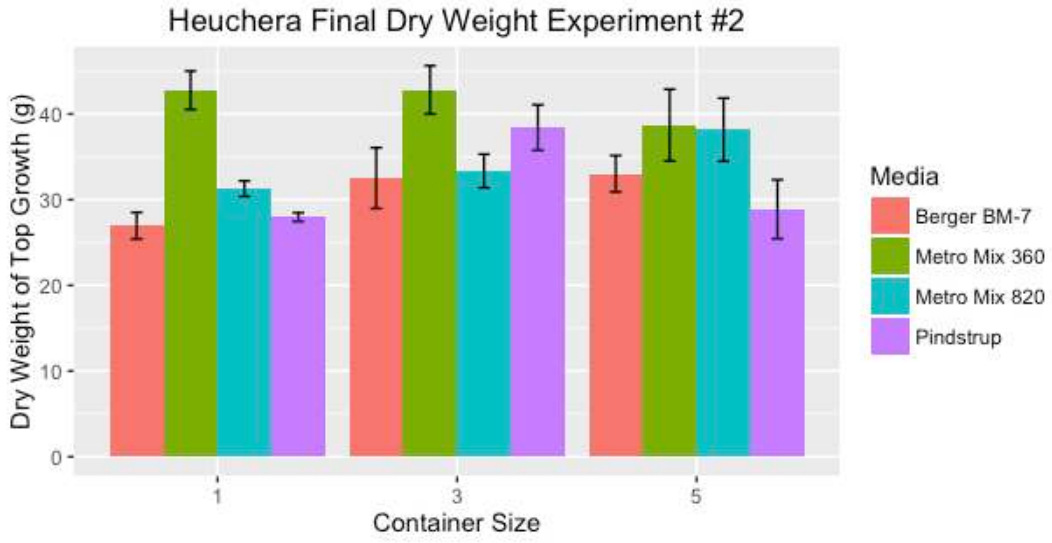

Figure 3.1.24 Experiment #2 bar plot of mean final dry weight of each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.1.2 Average Number of Cuttings per Plant

Number of cuttings harvested was examined for each individual harvest date as well as averaged over the three harvest dates before analysis. Because the results of each individual harvest agreed with the averaged data for Experiment #1, the data from separate harvest dates are presented in Appendix III (Figures A3.1.1-A3.1.6 and Tables A3.1.1-A3.1.3). During the first experiment, *Heuchera* plants showed a strong affinity for the two Metro Mix treatments, regardless of container size, although both media and size treatments were statistically significant (Figure 3.1.25). As can be seen in Figure 3.1.26, stock plants grown in Metro Mix 820 produced the largest average number of cuttings per plant, while those grown in Berger BM7 produced the fewest (Table 3.1.13). Pairwise comparisons of least squares means showed that all media treatments were significantly different at the 0.05 level except for the two Metro Mixes which were quite similar. When data were averaged over media to examine the effects of container size, only the #1 (2.84L) and 11.35L containers differed significantly with means of 7.31 and 6.70 cuttings per plant respectively. The size*media interaction was not significant.

As with the final dry weights, it seems that larger numbers of cuttings produced by stock plants grown in Metro Mix 820 and Metro Mix 360 could be due to the pH of those substrates. Metro Mix 820 started and ended Experiment #1 with the lowest pH (5.6 and 5.3 respectively) and while Metro Mix 360 started with the highest pH (6.3), it ended with the second lowest (5.4). The other two substrates did not experience the drop in pH during Experiment #1, remaining above 6.1 in both pre and post growth analyses, and may have been above the ideal range for this taxon. Since pH directly influences nutrient availability (Bailey et al 2002), even small changes in pH can cause changes in plant growth responses.

Although the response to container size was statistically significant, the differences in mean response were very small and the highest number of cuttings was obtained from the smallest containers. Since this contradicts the results of container size studies done on grapes (Xie et al 2013), tomatoes (Bouzo and Favaro 2015, and Nishizawa and Saito 1998), *Salvia* (van Iersel 1997), and kiwi (Tonutti and Giulivo 1990), among others, it is possible the duration of the present experiment was not long enough to result in decreased growth in the smaller container sizes.

```
Anova Table (Type III tests)

Response: AVGCut
            Sum Sq  Df   F value    Pr(>F)
(Intercept) 5861.0   1 6634.8662 < 2.2e-16 ***
Size           7.5   2    4.2294   0.01704 *
Media         94.9   3   35.8182 3.786e-16 ***
Size:Media     5.4   6    1.0135   0.42050
Residuals     95.4 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.25 Experiment #1 two-way ANOVA table for number of cuttings per plant averaged over harvest date.

Table 3.1.13 Experiment #1 mean cuttings per plant averaged over harvest date for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	5.78	5.44-6.12	1
Metro Mix 360	7.60	7.26-7.94	3
Metro Mix 820	8.04	7.70-8.38	3
Pindstrup	6.53	6.19-6.87	2
#1 Container	7.31	7.01-7.60	2
#3 Container	6.70	6.41-6.99	1
#5 Container	6.96	6.66-7.25	1, 2

Figure 3.1.26 Experiment #1 bar plot of mean cuttings per plant averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Results of the second experiment showed different trends when averaged over harvest date, although main effects of both size and media were statistically significant (Figure 3.1.27). Because of Tukey adjustments for multiple testing, the pairwise comparisons of media show no significant differences; however, Metro Mix 360 and Pindstrup had the highest means (Table 3.1.14). During the second experiment Metro Mix 820 had the lowest mean response, which may be due to differences in media batch that were not identified in the substrate analyses. Figure 3.1.28 shows the effect of container size within the second experiment where average number of cuttings was significantly lower in #1 (2.84L) than #3 (11.35L) or #5 (14.55L) containers. Differences between #3 (11.35L) and #5 (14.55L) containers were not significant, nor was the size*media interaction.

When data were analyzed for each harvest date separately, the main effect of media was only significant for the first harvest (Figure 3.1.15). Pindstrup resulted in significantly more cuttings than Berger BM-7 and Metro Mix 820 with no other significant pairwise comparisons

(Table 3.1.30). This could be due to a more ideal starting pH of the second batch of Pindstrup (4.7 as compared to 3.8 for the other substrates). This could have aided in earlier establishment of plants being grown in Pindstrup that was overcome as the pH of other substrates adjusted with irrigation, fertilization, and addition of plant exudates.

The second harvest from Experiment #2 showed only a significant main effect of container size, although because of Tukey adjustments for multiple testing, no pairwise comparisons were significant, and this data is presented in Appendix III (Figures A3.1.7 and A3.1.8, Table A3.1.4). The third harvest again only showed a significant main effect of container size (Figures 3.1.31 and 3.1.32), with #5 (14.55L) containers producing significantly more cuttings per plant that #1 (2.84L) containers (Table 3.1.16). No other pairwise comparisons were significant at this harvest date. The significant effect of container size during Experiment #2 agrees with the results of container size studies done on multiple species and demonstrates the typical increase in growth in larger containers (Xie et al 2013, Bouzo and Favaro 2015, Nishizawa and Saito 1998, Van Iersel 1997, and Tonutti and Giulivo 1990).

```
Anova Table (Type III tests)

Response: AVGCut
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 2344.90   1 1391.0699 < 2.2e-16 ***
Size          29.33   2    8.6990 0.0003142 ***
Media         16.51   3    3.2649 0.0242121 *
Size:Media     4.97   6    0.4917 0.8133681
Residuals    182.05 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.27 Experiment #2 two-way ANOVA table for average cuttings per plant averaged over harvest date.

Table 3.1.14 Experiment #2 mean cuttings per plant averaged over harvest date for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	4.22	3.75-4.69	1
Metro Mix 360	4.78	4.31-5.25	1
Metro Mix 820	3.91	3.44-4.38	1
Pindstrup	4.77	4.30-5.24	1
#1 Container	3.74	3.33-4.15	1
#3 Container	4.62	4.21-5.02	2
#5 Container	4.90	4.50-5.31	2

Figure 3.1.28 Experiment #2 bar plot of mean cuttings per plant averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: Cuttings1
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 1056.13   1 1145.2048 < 2.2e-16 ***
Size           8.27   2    4.4819 0.0134925 *
Media         16.73   3    6.0482 0.0007593 ***
Size:Media     3.27   6    0.5904 0.7373996
Residuals     99.60 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.1.29 Experiment #2 two-way ANOVA table for mean cuttings per plant during the first harvest.

Table 3.1.15 Experiment #2 mean cuttings per plant during first harvest for each treatment media averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	2.60	2.25-2.95	1
Metro Mix 360	3.23	2.89-3.58	1, 2
Metro Mix 820	2.60	2.25-2.95	1
Pindstrup	3.43	3.09-3.78	2
#1 Container	2.60	2.30-2.90	1
#3 Container	3.20	2.90-3.50	2
#5 Container	3.10	2.80-3.40	1, 2

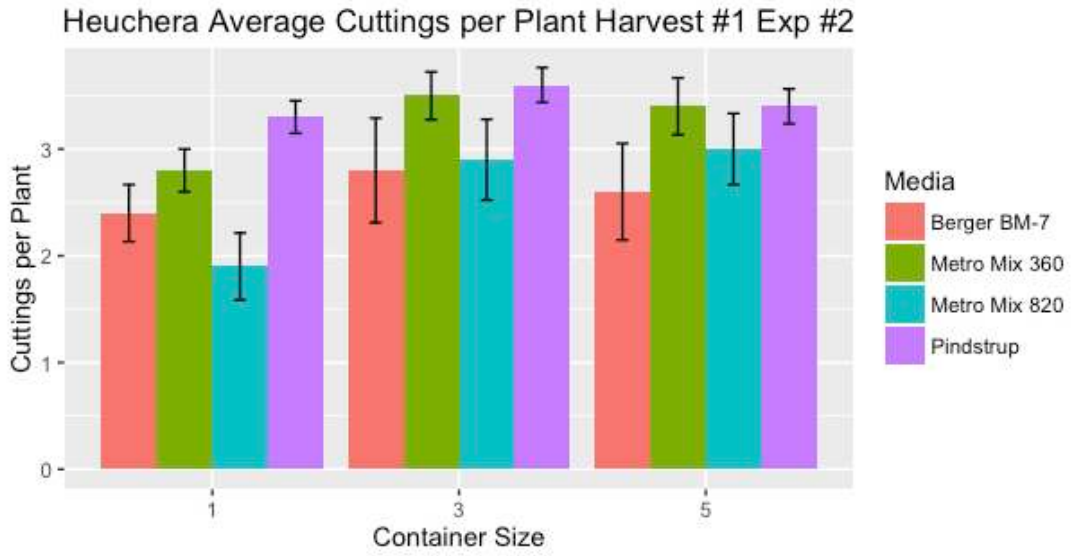

Figure 3.1.30 Experiment #2 bar plot of mean cuttings per plant during first harvest for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: Cuttings3
            Sum Sq  Df  F value    Pr(>F)
(Intercept) 4986.9   1 452.7438 < 2.2e-16 ***
Size         132.8   2   6.0299  0.003292 **
Media         70.1   3   2.1226  0.101578
Size:Media    33.4   6   0.5053  0.803170
Residuals   1189.6 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.1.31 Experiment #2 two-way ANOVA table for cuttings per plant during third harvest.

Table 3.1.16 Experiment #2 mean cuttings per plant during third harvest for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
#1 (2.84L)	5.05	4.01-6.09	1
#3 (11.35L)	6.70	5.66-7.74	1, 2
#5 (14.55L)	7.59	6.55-8.63	2

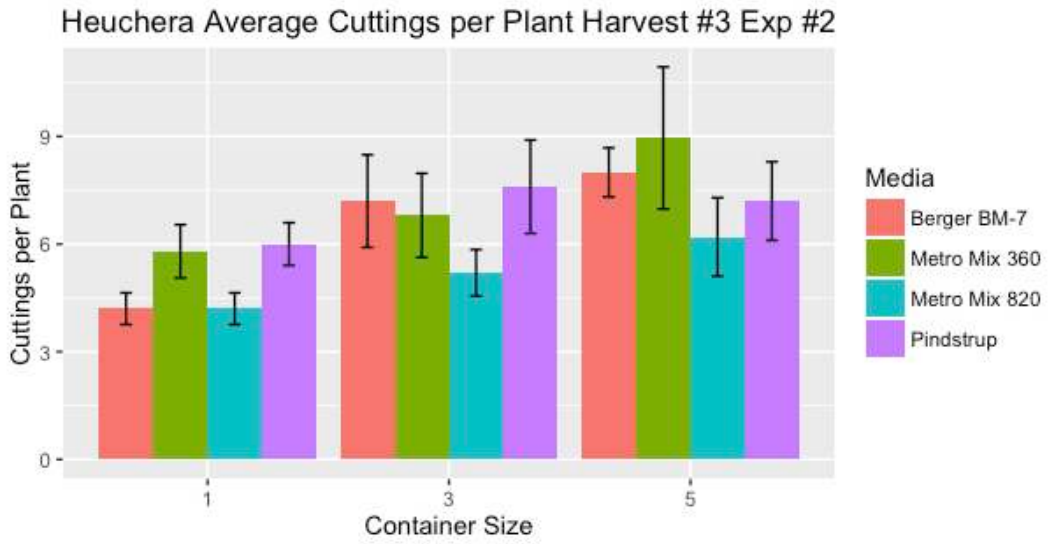

Figure 3.1.32 Experiment #2 bar plot of mean cuttings per plant during third harvest for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.1.3 Average Number of Cuttings per Square Foot

Cuttings per square foot were calculated by dividing the average number of cuttings per plant by the area occupied by each container size allowing adequate space for growth. For this experiment, each plant was given six inches (15.24cm) of space between containers to allow for air circulation and canopy expansion. Based on this measurement, #1 (2.84L) containers occupied 1.0 ft^2 while #3 (11.35L) and #5 (14.55L) containers occupied 2.25 ft^2 because the containers were the same width. Analysis of cuttings per square foot was based on this spacing with the intention of discerning the value of using larger containers for stock plants.

Results of the first experiment revealed that the main effects of media and size, as well as the interaction of size*media were all significant (Figure 3.1.33). As can be seen from Figure 3.1.34, the number of cuttings per square foot is dramatically higher in the #1 (2.84L) containers as compared to the #3 (11.35L) and #5 (14.55L) containers because the larger containers take up more space. Because of the significant interaction, and to better interpret the data, pairwise comparisons were calculated for each container size separately (Table 3.1.17). Within the #1 (2.84L) container size, all pairwise comparisons of media were significant, with Metro Mix 820 resulting in the highest number of cuttings per square foot (8.35 - 9.12), and Berger BM7 resulting in the lowest number (5.48 - 6.25). When comparing media effects of media in #3 (11.35L) containers, the trends of media were the same. Berger BM7 resulted in the lowest number of cuttings per square foot, while Metro Mix 820 resulted in the highest number. The only significant comparisons were between Berger BM7 and Metro Mix 360, as well as Berger BM7 and Metro Mix 820. The results of pairwise comparisons within #5 (14.55L) containers were very similar with Metro Mix 820 and Metro Mix 360 producing significantly more cuttings per square foot than Berger BM7 or Pindstrup.

```
Anova Table (Type III tests)

Response: CPSF
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 2386.19   1 6420.5937 < 2.2e-16 ***
Size         487.27   2  655.5597 < 2.2e-16 ***
Media         42.58   3   38.1898 < 2.2e-16 ***
Size:Media    15.07   6    6.7569 4.233e-06 ***
Residuals     40.14 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.33 Experiment #1 two-way ANOVA table for cuttings per square foot averaged over harvest date.

Table 3.1.17 Experiment #1 mean cuttings per square foot and 95% confidence intervals for the means averaged over harvest date for each level of media at each level of container size. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Media	Mean Cuttings per Square Foot	95% Confidence Interval	Significance Group
#1 (2.84L) Container	Berger BM-7	5.87	5.48-6.25	1
	Metro Mix 360	7.87	7.48-8.25	3
	Metro Mix 820	8.73	8.35-9.12	4
	Pindstrup	6.77	6.38-7.15	2
#3 (11.35L) Container	Berger BM-7	2.50	2.12-2.88	1
	Metro Mix 360	3.24	2.86-3.63	2
	Metro Mix 820	3.26	2.88-3.64	2
	Pindstrup	2.90	2.52-3.29	1, 2
#5 (14.55L) Container	Berger BM-7	2.59	2.21-2.97	1
	Metro Mix 360	3.39	3.01-3.78	2, 3
	Metro Mix 820	3.59	3.20-3.97	3
	Pindstrup	2.80	2.42-3.18	1, 2

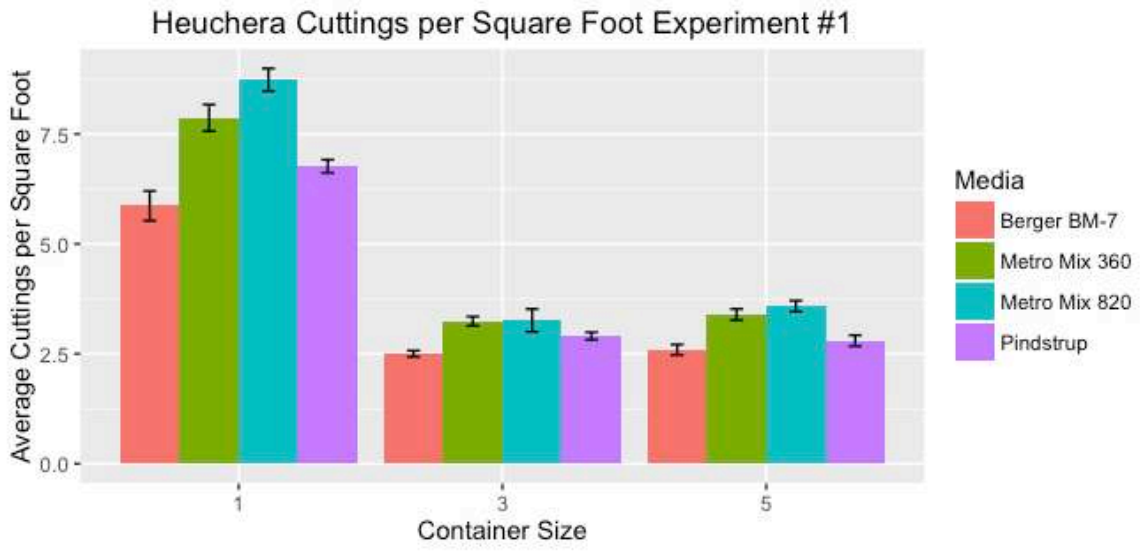

Figure 3.1.34 Experiment #1 bar plot of mean cuttings per square foot averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Experiment 2 showed the same trend for container size, although the interaction of size*media was not significant (Figure 3.1.35). Similar to the first experiment, #1 (2.84L)

containers produced the largest number of cuttings per square foot and differed significantly from both #3 (11.35L) and #5 (14.55L) containers. There was no significant difference between #3 (11.35L) and #5 (14.55L) containers for this parameter. The main effects of media showed different trends from experiment one. Metro Mix 820 resulted in the lowest response, producing significantly less cuttings per square foot than Pindstrup or Metro Mix 360 (Table 3.1.18).

When analyzed based on cuttings per square foot, main effects of media followed the same trends as analysis done on cuttings per plant and results can likely be explained by the same mechanisms. However, when looking at Figure 3.1.34 (Experiment #1) and Figure 3.1.36 (Experiment #2), it can be seen that differences between media are much more pronounced in the smaller containers, which is probably due to water holding capacity and oxygen availability in the smaller substrate volumes. Despite an increase in number of cuttings per plant in the larger container sizes, the magnitude of difference was not enough to compensate for the amount of space taken up by the larger containers during this study. More research may be needed to understand the effect of container size over a longer period of time.

```
Anova Table (Type III tests)

Response: CPSF
            Sum Sq  Df   F value    Pr(>F)
(Intercept) 847.64   1 1684.9254 < 2.2e-16 ***
Size         70.77   2   70.3341 < 2.2e-16 ***
Media         6.88   3    4.5571  0.004787 **
Size:Media    3.09   6    1.0221  0.414912
Residuals    54.33 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.35 Experiment #2 two-way ANOVA table for cuttings per square foot averaged over harvest date.

Table 3.1.18 Experiment #2 mean cuttings per square foot averaged over harvest date for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Cuttings Per Square Foot	95% Confidence Interval	Significance Group
Berger BM-7	2.50	2.24-2.76	1, 2
Metro Mix 360	2.87	2.61-3.12	2
Metro Mix 820	2.35	2.09-2.61	1
Pindstrup	2.91	2.66-3.17	2
#1 Container	3.74	3.52-3.96	2
#3 Container	2.05	1.83-2.27	1
#5 Container	2.18	1.96-2.40	1

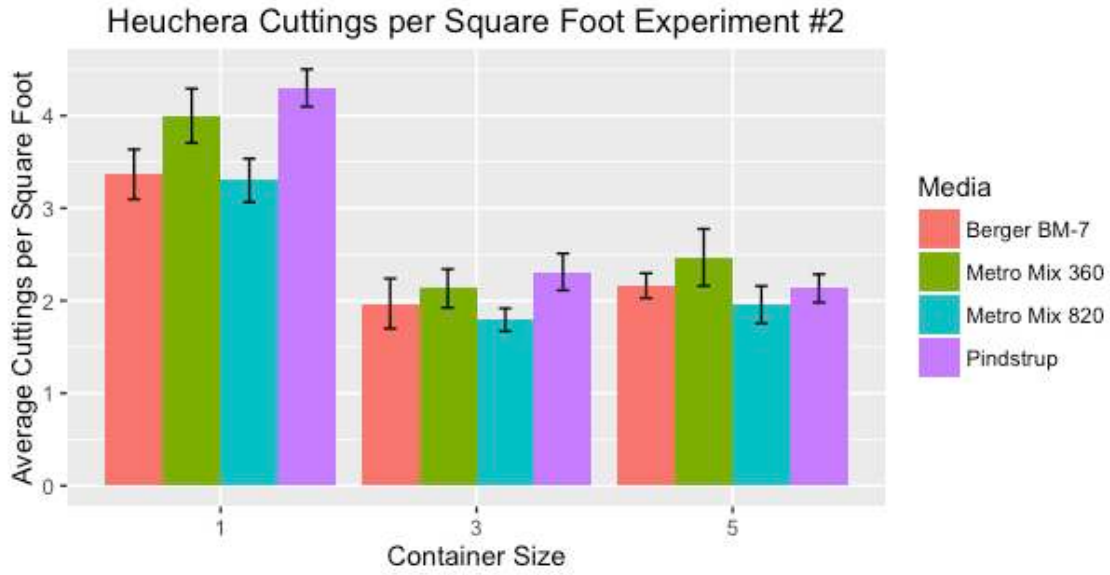

Figure 3.1.36 Experiment #2 bar plot of mean cuttings per square foot averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.1.4 Average Fresh Weight per Cutting

Average fresh weights per cutting were calculated by dividing the total fresh weight of cuttings by the total number of cuttings harvested for each plant over the three harvest dates. Additionally, data were analyzed for each harvest time separately to determine if there were changes over time.

While all the mean responses from Experiment #1 were between 3 and 4 grams/cutting with seemingly very low variability, even small differences can be practically significant when it comes to the quality of a cutting and how well it will root. The results of ANOVA testing of the data averaged over harvest date showed that main effects of media were significant, but size was not (Figure 3.1.27). There was also no significant interaction between size and media for this parameter which can be seen when looking at Figure 3.1.28. When averaging over size, the highest fresh weight per cutting was from stock plants grown in Metro Mix 820 (3.61 - 3.90 g/cutting), although Metro Mix 360 was very similar (3.60 - 3.89 g/cutting). The two Metro Mixes produced cuttings that were significantly larger than Berger BM7 (3.26 - 3.55 g/cutting), which had the lowest mean response (Table 3.1.19). No other pairwise comparisons of media were significant.

When the data were analyzed separately for each harvest date, the results showed that the only significant differences between average fresh weights per cutting were found during the first harvest (Figures 3.1.29 and 3.1.30). The first harvest of cuttings resulted in a significant main effect of media, with Metro Mix 360 and Metro Mix 820 producing significantly larger fresh weights than Berger BM-7 or Pindstrup (Table 3.1.20). Subsequent harvests showed no significant differences between treatments and are presented in Appendix III (Figures A3.1.9-A3.1.12 and Tables A3.1.5 and A3.1.6). One possible explanation for seeing an initially higher response from Metro Mix 360 could be a higher starting level of nitrogen in the pre-plant nutrient charges which would have equalized over the course of the experiment. According to Argo and Biernbaum (1996), nutrients added to soilless substrates as a pre-plant charge will be depleted rapidly over the course of the first 14 days. Analysis of Metro Mix 360 prior to planting showed more than twice the total nitrogen found in the other substrates prior to planting.

Although the stock plants in the present experiment were grown for much longer than that before the first harvest, and were getting the same application of fertilizer regardless of treatment, an initial spike in growth due to the pre-plant charge could have resulted in increased fresh weights of cuttings during the first harvest. As the applied fertilizer solution replaced the pre-plant charge, growth may have become more similar between treatments. Although this explanation doesn't hold true for Metro Mix 820, which had the lowest starting level of nitrogen, it had the lowest starting pH (5.6 compared to 6.1-6.3), which could have allowed for better nutrient availability (Bailey et al 2002) and been closer to the optimum level for *Heuchera*.

```
Anova Table (Type III tests)

Response: AVGFresh
             Sum Sq  Df    F value    Pr(>F)
(Intercept) 1571.88   1 10117.6696 < 2.2e-16 ***
Size           0.18   2     0.5853  0.558702
Media          2.50   3     5.3551  0.001778 **
Size:Media     0.57   6     0.6081  0.723348
Residuals     16.78 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.37 Experiment #1 two-way ANOVA table for mean fresh weight per cutting averaged over harvest date.

Table 3.1.19 Experiment #1 mean fresh weight per cutting averaged over harvest date for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of $P<0.05$.

Media	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	3.40	3.26-3.55	1
Metro Mix 360	3.74	3.60-3.89	2
Metro Mix 820	3.76	3.61-3.90	2
Pindstrup	3.57	3.43-3.72	1, 2

Figure 3.1.38 Experiment #1 bar plot of mean fresh weights averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh1
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 1240.09   1 3679.4480 < 2.2e-16 ***
Size           1.12   2    1.6546    0.1960
Media         23.27   3   23.0173 1.351e-11 ***
Size:Media     0.51   6    0.2498    0.9584
Residuals     36.40 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.39 Experiment #1 two-way ANOVA table for mean fresh weight during harvest #1.

Table 3.1.20 Experiment #1 mean fresh weight per cutting during harvest #1 for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	2.64	2.43-2.85	1
Metro Mix 360	3.55	3.34-3.76	2
Metro Mix 820	3.72	3.51-3.93	2
Pindstrup	2.94	2.73-3.15	1

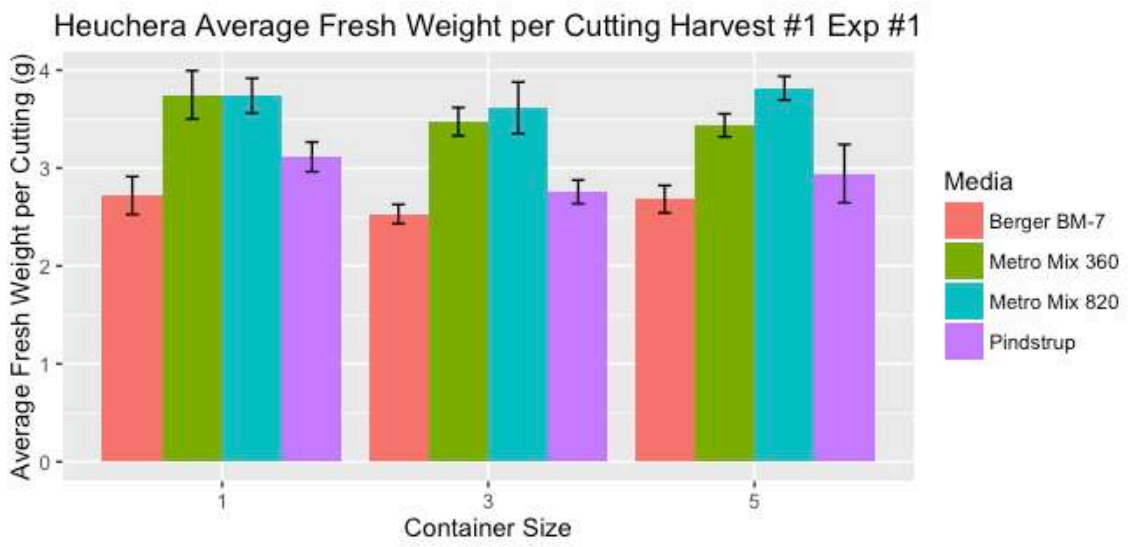

Figure 3.1.40 Experiment #1 bar plot of mean fresh weight per cutting during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Experiment #2 showed different trends when examining pairwise comparisons. Just as in Experiment #1, size and size*media were not significant for data averaged over harvest date, but main effects of media were significant (Figures 3.1.31 and 3.1.32). Pairwise comparisons showed that all media were significantly different except Berger BM7 and Metro Mix 820, which had the lowest mean responses (Table 3.1.21). Pindstrup had the highest mean response and the average fresh weight per cutting was significantly larger than all other media treatments (4.21 - 4.55 g/cutting).

When examining the fresh weights of cuttings from each harvest separately, there was no significant effect of container size at any time point, and only the first two harvests showed a significant effect of media, while the third harvest showed no significant differences. The media trends at each time point were the same as the averaged data, so results are presented in Appendix III (Figures A3.1.13-A3.1.18, Tables A3.1.7-A3.1.9). Substrate analysis prior to planting (Appendix I, Figure A1.5) suggests that Pindstrup may have produced larger cuttings

initially because of a more ideal starting pH which could allow for better nutrient availability (Bailey et al 2002). It could also be partially due to higher total nitrogen and a lower ammonium: nitrate ratio which has been shown to increase stem dry weight in peppers (Bar-Tal et al 2001). Prior to being planted in, Pindstrup also had the lowest carbon: nitrogen ratio (41.25), which can influence nitrogen availability. When substrate ratios exceed 24:1, indicating there is more carbon present, it results in nitrogen immobilization and can lead to nutritional deficits (Ingram et al 1993). While the C:N ratio of Pindstrup was still considered higher than ideal, it was the lowest of the substrates used in this experiment.

Regardless of treatment, all mean fresh weights from Experiment #2 were higher than Experiment #1, which may be due to temperature differences between the experiments and the time of year.

```
Anova Table (Type III tests)

Response: AVGFresh
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 1861.18   1 8131.0787 < 2.2e-16 ***
Size           0.54   2    1.1862    0.3093
Media         10.15   3   14.7738 3.969e-08 ***
Size:Media     0.50   6    0.3657    0.8992
Residuals     24.72 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.41 Experiment #2 two-way ANOVA table for mean fresh weight per cutting averaged over harvest date.

Table 3.1.21 Experiment #2 mean fresh weight per cutting averaged over harvest date for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of $P<0.05$.

Media	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	3.69	3.52-3.87	1
Metro Mix 360	4.02	3.84-4.19	2
Metro Mix 820	3.66	3.49-3.84	1
Pindstrup	4.38	4.21-4.55	3

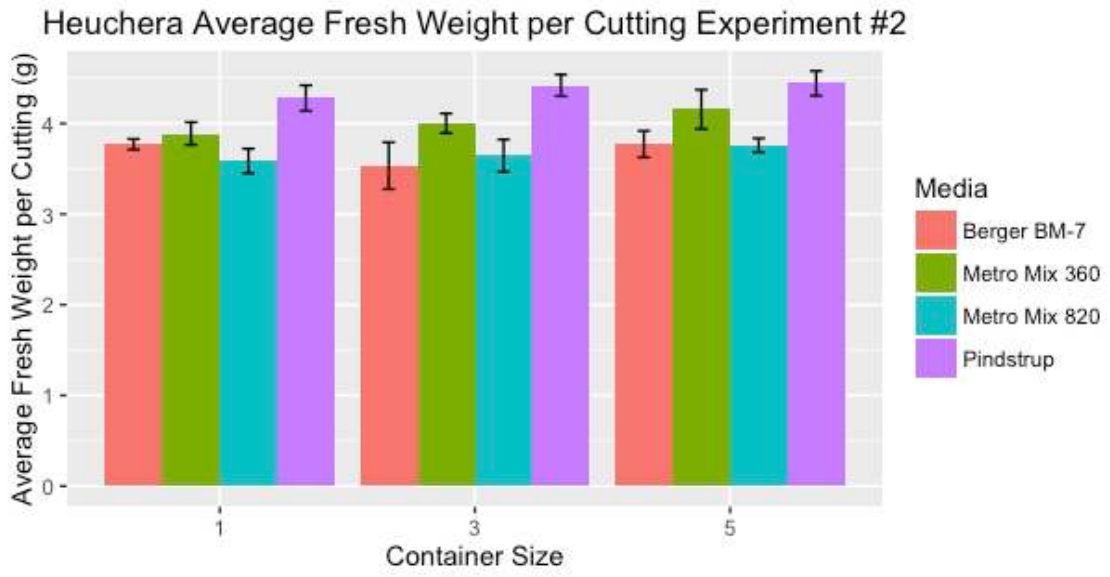

Figure 3.1.42 Experiment #2 bar plot for mean fresh weight averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.1.5 Average Dry Weight per Cutting

Average dry weights per cutting were calculated by dividing the total dry weight of cuttings by the total number of cuttings harvested for each plant over the three harvest dates. Data were also analyzed for each harvest date separately. For data that were averaged over harvest date, Experiment #1 showed no significant interaction between size and media, nor a significant main effect of container size (Figures 3.1.33 and 3.1.34). However, main effect of media was significant and the highest average dry weights were produced by stock plants grown in Metro Mix 360 and Metro Mix 820 (Table 3.1.22). Both Metro Mixes resulted in cuttings with significantly higher dry weights than Berger BM7 and Pindstrup, which produced the smallest cuttings. No other pairwise comparisons were statistically significant.

When data were analyzed for each harvest separately, Experiment #1 results were similar to the fresh weights. The first harvest date showed a significant main effect of media (Figures 3.1.35 and 3.1.36), with Metro Mix 360 and Metro Mix 820 producing cuttings with significantly higher dry weights than Pindstrup or Berger BM-7 (Table 3.1.23). While the ANOVA testing

showed a significant main effect of container size, no pairwise comparisons were significant due to Tukey adjustment for multiple comparisons. Because subsequent harvests showed no significant differences in dry weights, the data is presented in Appendix III (Figures A3.1.19-A3.1.22, Tables A3.1.10-A3.1.11). Similar to the results of fresh weights, this could be due to differences in pre-plant nutrient charges in the treatment media or starting pH.

```
Anova Table (Type III tests)

Response: AVGDry
            Sum Sq  Df    F value    Pr(>F)
(Intercept) 49.833   1 10265.5807 < 2.2e-16 ***
Size         0.008   2     0.8582 0.4268097
Media        0.091   3     6.2232 0.0006134 ***
Size:Media   0.022   6     0.7391 0.6192376
Residuals    0.524 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.43 Experiment #1 two-way ANOVA table for mean dry weight per cutting averaged over harvest date.

Table 3.1.22 Experiment #1 mean dry weight per cutting averaged over harvest date for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of $P<0.05$.

Media	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.610	0.584-0.635	1
Metro Mix 360	0.672	0.646-0.697	2
Metro Mix 820	0.671	0.646-0.696	2
Pindstrup	0.625	0.600-0.651	1, 2

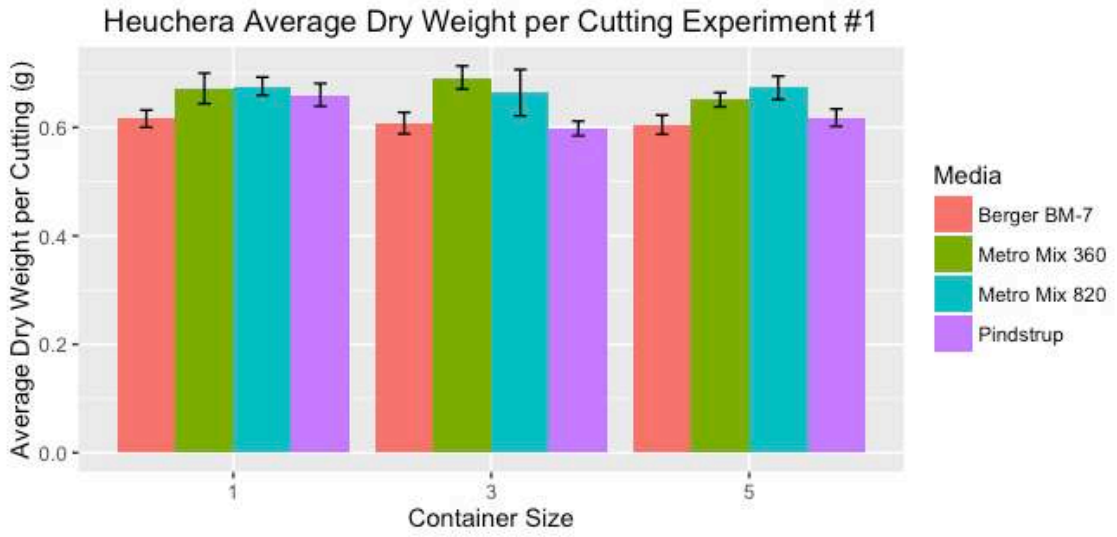

Figure 3.1.44 Experiment #1 bar plot of mean dry weight per cutting averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry1
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 40.915   1 3788.7870 < 2.2e-16 ***
Size         0.068   2    3.1337   0.04754 *
Media        0.910   3   28.0935 1.659e-13 ***
Size:Media   0.056   6    0.8603   0.52663
Residuals    1.166 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.45 Experiment #1 two-way ANOVA table for mean dry weight per cutting during first harvest.

Table 3.1.23 Experiment #1 mean dry weight per cutting during harvest #1 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.494	0.457-0.532	1
Metro Mix 360	0.652	0.614-0.689	2
Metro Mix 820	0.688	0.651-0.726	2
Pindstrup	0.501	0.464-0.539	1
#1 Container	0.618	0.585-0.650	1
#3 Container	0.568	0.535-0.600	1
#5 Container	0.567	0.534-0.599	1

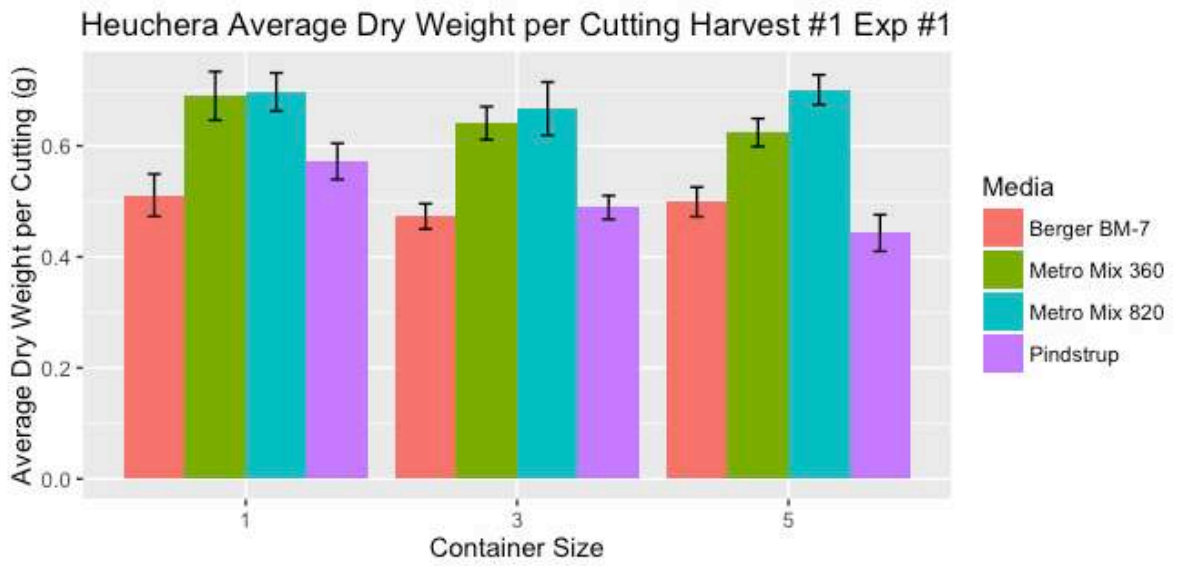

Figure 3.1.46 Experiment #1 bar plot of mean dry weight per cutting during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Results from Experiment #2 followed a similar trend as the results of average fresh weight per cutting from the second experiment. For data that were averaged over harvest date, main effect of media was significant while size and size*media were not (Figures 3.1.37 and 3.1.28). When examining pairwise comparisons of media averaged over container size, stock plants grown in Pindstrup produced the largest cuttings (0.917 - 0.992 g/cutting) which were significantly larger than all other media treatments (Table 3.1.24). Stock plants grown in Metro Mix 820 produced the smallest cuttings (0.778 - 0.853 g/cutting).

When data were analyzed separately for each harvest date, the results mirrored those of the fresh weights from Experiment #2. The main effect of media was significant only for the first two harvests, main effect of size was only significant at the second harvest and there were no significant differences by the third harvest. At the first harvest date, Pindstrup resulted in significantly larger average dry weights per cutting than any other media, while Metro Mix 360 also resulted in significantly larger cuttings than Metro Mix 820 (Figures 3.1.39 and 3.1.40, Table 3.1.25). At the second harvest date, Pindstrup resulted in larger dry weights than Metro

Mix 820, although no other pairwise comparisons of media were significant (Figures 3.1.41 and 3.1.42, Table 3.1.26). The second harvest also revealed a significant main effect of size with #1 (2.84L) containers resulting in significantly higher dry weights than #5 (14.55L) containers. By the third harvest, most differences had equalized and there was no statistically significant effect of media or container size treatment (Appendix III, Figures A3.1.23-A3.1.24, Table A3.1.12).

The significant increase in average cutting dry weight from plants grown in Pindstrup is likely due to better chemical properties that improved the fresh weights of the same cuttings. Because the effect of container size was only significant at the second harvest date, it is difficult to determine the cause of this response. However, it is possible that it was related to the severity of the previous harvest of cuttings, or the plants' ability to recover from the previous harvest.

```
Anova Table (Type III tests)

Response: AVGDry
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 89.853   1 8380.8426 < 2.2e-16 ***
Size         0.024   2    1.1037    0.3354
Media        0.360   3   11.1993 1.859e-06 ***
Size:Media   0.054   6    0.8436    0.5391
Residuals    1.158 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.47 Experiment #2 two-way ANOVA table for mean dry weight per cutting averaged over harvest date.

Table 3.1.24 Experiment #2 mean dry weight per cutting averaged over harvest date for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of $P<0.05$.

Media	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.826	0.788-0.863	1
Metro Mix 360	0.865	0.827-0.902	1
Metro Mix 820	0.816	0.778-0.853	1
Pindstrup	0.955	0.917-0.992	2

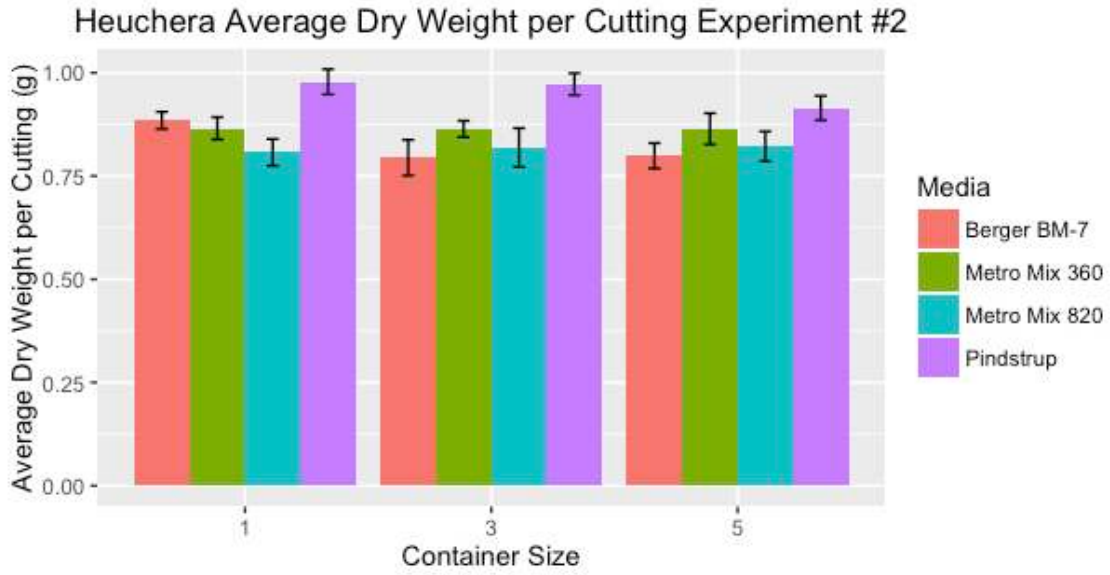

Figure 3.1.48 Experiment #2 bar plot of mean dry weight per cutting averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry1
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 51.995   1 1520.6882 < 2.2e-16 ***
Size         0.010   2    0.1525    0.8588
Media        1.799   3   17.5367 2.401e-09 ***
Size:Media   0.071   6    0.3456    0.9111
Residuals    3.693 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.49 Experiment #2 two-way ANOVA table for mean dry weight per cutting during harvest #1.

Table 3.1.25 Experiment #2 mean dry weight per cutting during harvest #1 for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.591	0.524-0.658	1, 2
Metro Mix 360	0.684	0.617-0.751	2
Metro Mix 820	0.515	0.448-0.582	1
Pindstrup	0.843	0.777-0.910	3

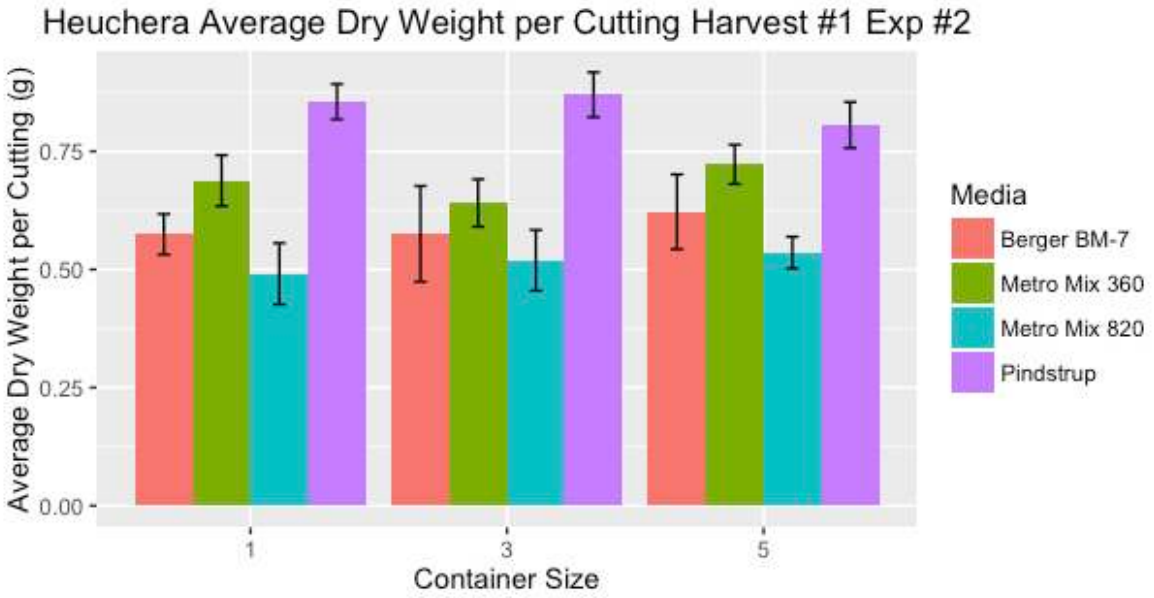

Figure 3.1.50 Experiment #2 bar plot of mean dry weight per cutting during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry2
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 135.573   1 6019.6017 < 2.2e-16 ***
Size          0.176   2    3.9142  0.022850 *
Media         0.308   3    4.5641  0.004746 **
Size:Media    0.152   6    1.1275  0.351277
Residuals     2.432 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.51 Experiment #2 two-way ANOVA table for mean dry weight during second harvest.

Table 3.1.26 Experiment #2 mean dry weight per cutting during second harvest for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of $P<0.05$.

Treatment	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	1.051	0.997-1.106	1, 2
Metro Mix 360	1.062	1.008-1.116	1, 2
Metro Mix 820	0.998	0.944-1.053	1
Pindstrup	1.140	1.086-1.194	2
#1 Container	1.115	1.068-1.162	2
#3 Container	1.050	1.003-1.07	1, 2
#5 Container	1.024	0.977-1.071	1

Figure 3.1.52 Experiment #2 bar plot of mean dry weight per cutting during second harvest for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.1.6 Root Ratings

Root ratings from Experiment #1 demonstrated a significant interaction between media and container size (Figure 3.1.43), so analysis was split by size for easier interpretation. As can be seen from Figure 3.1.44, relative response to media was different in #1 (2.84L) containers than in the larger container sizes. It is also apparent in the graph that there is a dramatic difference in root density between container sizes with #1 (2.84L) containers having the highest root ratings. Means and 95% confidence intervals are presented in Table 3.1.27 for each media at each level of container size.

Although not significantly different from other media treatments, results of root ratings in #1 (2.84L) containers showed that plants grown in Metro Mix 820 had the highest average root rating, which indicates a higher density of roots and a more developed root system. Based on research by Van Iersel (1997), who claimed smaller containers can create anaerobic conditions when root density is high, and research by Shi et al (2007), who demonstrated that oxygen

deficiency is likely the primary cause of plant stress under root restriction, it is likely the media physical properties that resulted in higher root ratings in the present experiment. A more developed root system in Metro Mix 820 may be due to increased oxygen availability to the roots because of increased drainage capability provided by the coarse perlite in the mix. Metro mix 820 holds less water than any other media used in this experiment, which could provide the needed oxygen in smaller containers that inherently have poorer drainage.

Root ratings in the larger container sizes were significantly lower than the #1 (2.84L) containers regardless of media treatment. This indicates lower root density and less root restriction due to being grown in a larger substrate volume. Given the plants were the same age as those grown in #1 (2.84L) containers, it is expected that over time, they would reach root restriction conditions as seen by Poorter et al (2012b), who asserted that the effect of container size will increase with the length of time plants remain in a single container.

Relative response to media in the #3 (11.35L) and #5 (14.55L) containers was very similar to each other, though different from responses #1 (2.84L) containers, with Pindstrup resulting in the highest root rating in both container sizes. Because larger container sizes inherently provide better drainage than smaller containers, it is possible that higher root ratings in Pindstrup were actually due to higher water potential, similar to the findings of Nkongolo and Caron (2006) who found higher root dry weights when water potentials were higher.

```
Anova Table (Type III tests)

Response: RootRate
            Sum Sq Df   F value    Pr(>F)
(Intercept) 606.68  1 1323.6667 < 2.2e-16 ***
Size         87.19  2   95.1212 < 2.2e-16 ***
Media         6.71  3    4.8788  0.004217 **
Size:Media    6.92  6    2.5152  0.030810 *
Residuals    27.50 60
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.53 Experiment #1 two-way ANOVA table for root ratings.

Table 3.1.27 Experiment #1 mean root rating for each level of media at each level of container size. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Media	Mean Root Rating	95% Confidence Interval	Significance Group
#1 (2.84L) Container	Berger BM-7	4.33	3.78-4.89	1
	Metro Mix 360	4.17	3.61-4.72	1
	Metro Mix 820	4.83	4.28-5.39*	1
	Pindstrup	4.33	3.78-4.89	1
#3 (11.35L) Container	Berger BM-7	2.67	2.11-3.22	1, 2
	Metro Mix 360	2.17	1.61-2.72	1, 2
	Metro Mix 820	1.83	1.28-2.39	1
	Pindstrup	3.17	2.61-3.72	2
#5 (14.55L) Container	Berger BM-7	1.67	1.11-2.22	1, 2
	Metro Mix 360	1.33	0.78-1.89	1
	Metro Mix 820	1.67	1.11-2.22	1, 2
	Pindstrup	2.67	2.11-3.22	2

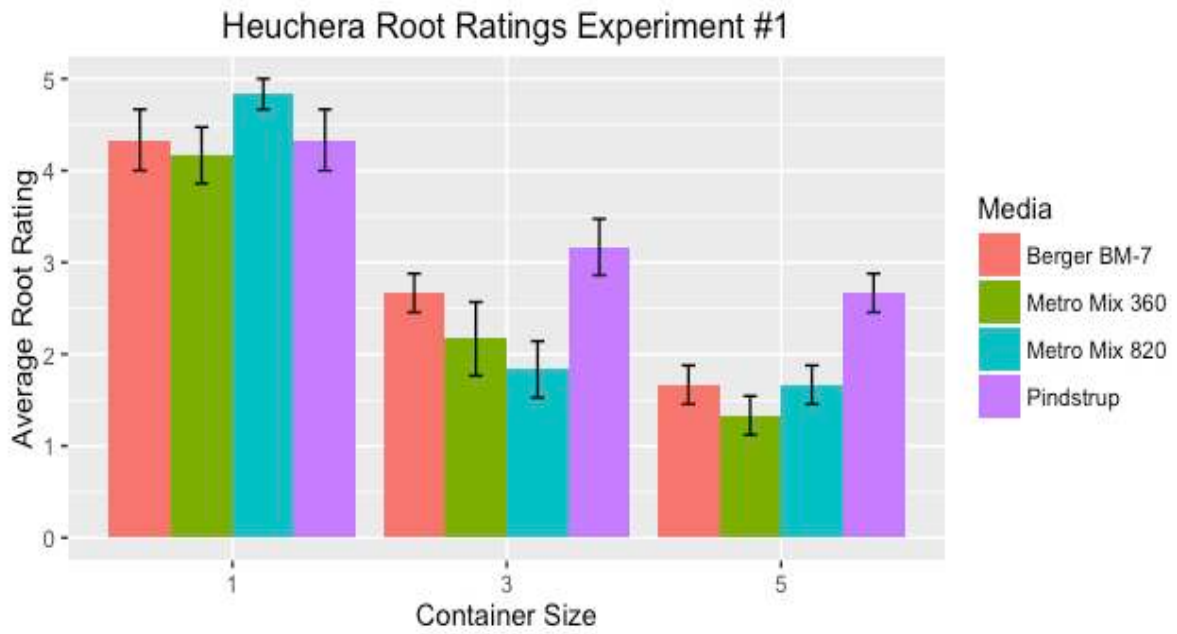

Figure 3.1.54 Experiment #1 bar plot of mean root rating for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Results of experiment #2 also showed a significant interaction between media and container size and analysis was split by size for interpretation (Figure 3.1.45). As can be seen

from Table 3.1.28, plants grown in #1 (2.84L) containers had higher average root ratings just as in Experiment #1, although relative responses to media were different in each container size.

Within #1 (2.84L) containers Pindstrup resulted in the lowest average root rating and was significantly lower than both Metro Mix 820 and Berger BM-7. No other pairwise comparisons were statistically significant, although looking at figure 3.1.46, it can be seen that root ratings from Metro Mix 360 were also much higher than Pindstrup if not significantly so. Since Pindstrup holds the highest amount of water (See Moisture Retention Curves, Appendix I, Figure A1.2), and smaller containers have inherently poorer drainage (Bilderback and Fonteno 1987), it may be that the perched water table and higher water retention capability of the Pindstrup media created saturated and therefore anaerobic conditions in the smaller containers, inhibiting root growth.

Within the #3 (11.35L) containers, Metro Mix 820 resulted in significantly lower root ratings than any other media, and no other pairwise comparisons were significant. Similar to Experiment #1, this decrease in response to Metro Mix 820 in the taller containers could be an effect of increased drainage and therefore lower water availability. The highest root ratings in #3 (11.35L) containers were from plants grown in Metro Mix 360 and Pindstrup, both of which retain more water than Metro Mix 820 (Appendix I, Figure A1.2).

Within the #5 (14.55L) containers, Metro Mix 360 resulted in the highest root ratings and provided significantly higher ratings than Metro Mix 820 and Pindstrup. No other pairwise comparisons were significant, although it can be seen in Figure 3.1.46 that Berger BM-7 also resulted in lower ratings than Metro Mix 360. Root ratings in the #5 (14.55L) containers were very similar in value to those in #3 (11.35L) containers with the exception of plants grown in

Pindstrup, which had much lower root ratings in the #5 (14.55L) containers. Because this response doesn't follow the trends associated with physical properties of the media in the rest of the experiment, it is difficult to explain this anomaly.

Root ratings from Experiment #1 were higher overall than Experiment #2, which is probably a result of being in the containers for a shorter period of time. The first experiment lasted 24 weeks from transplant into treatment containers to harvest, while Experiment #2 lasted only 18 weeks from transplant to harvest. The plants in Experiment #1 therefore had 6 more weeks of root development before ratings were taken.

```
Anova Table (Type III tests)

Response: RootRate
            Sum Sq Df   F value    Pr(>F)
(Intercept) 442.53  1 1528.1655 < 2.2e-16 ***
Size         21.81  2   37.6619 2.531e-11 ***
Media         7.12  3    8.1974 0.0001172 ***
Size:Media    7.41  6    4.2646 0.0012142 **
Residuals    17.38 60
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.55 Experiment #2 two-way ANOVA table for root rating.

Table 3.1.28 Experiment #2 mean root rating for each level of media at each level of container size. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Media	Mean Root Rating	95% Confidence Interval	Significance Group
#1 (2.84L) Container	Berger BM-7	3.50	3.06-3.94	2
	Metro Mix 360	3.33	2.89-3.77	1, 2
	Metro Mix 820	3.50	3.06-3.94	2
	Pindstrup	2.67	2.23-3.11	1
#3 (11.35L) Container	Berger BM-7	2.25	1.81-2.69	2
	Metro Mix 360	2.75	2.31-3.19	2
	Metro Mix 820	1.33	0.89-1.77	1
	Pindstrup	2.42	1.98-2.86	2
#5 (14.55L) Container	Berger BM-7	2.00	1.56-2.44	1, 2
	Metro Mix 360	2.75	2.31-3.19	2
	Metro Mix 820	1.58	1.14-2.02	1
	Pindstrup	1.67	1.23-2.11	1

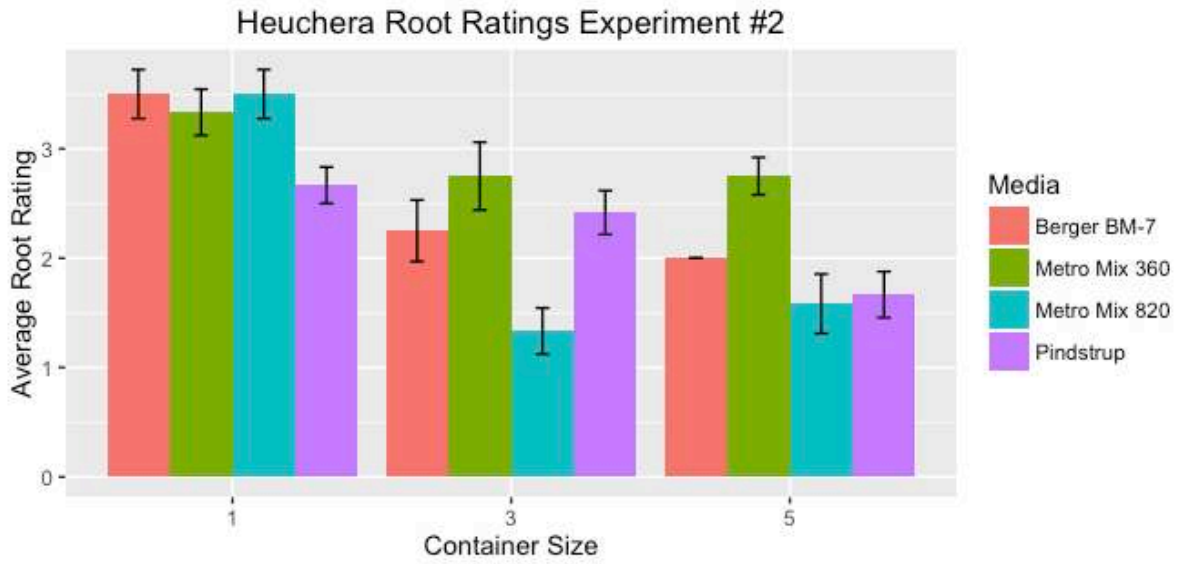

Figure 3.1.56 Experiment #2 bar plot of mean root rating for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.1.7 Differences between Experiments 1 and 2

Dramatic differences in mean response between Experiment #1 and #2 are probably due in part to the time of year the experiment was carried out. The first experiment was initiated in October, while the second was initiated in July. It is possible that fewer cuttings were produced per plant in the second study because of lower temperatures in the greenhouse which were adjusted for the second study and the natural difference in photoperiod.

There were also dramatic differences between media batches in terms of their chemical properties (Appendix I), which could have impacted the growth of stock plants. Because differences between the batches were large for some parameters such as pH (5.6-6.3 for Experiment #1, compared to 3.8-4.7 for Experiment #2), and CEC (59-97 for Experiment #1 and 3.6-11.4 for Experiment #2), it is difficult to identify the primary cause of the response to media throughout the present experiment.

3.1.8 Rooting Experiment Results

Rooting proportions were averaged over 3 harvests but analyzed after 1, 2, 3, and 4 weeks on the mist bench to examine the speed of rooting. Data was subjected to a Chi-Square test to determine if there was an association between rooting status and treatment.

The results of Experiment #1 showed the there was an association between treatment and rooting status during week 3 (Table 3.1.29 and Figure 3.1.49), but no association during week 1 (Figure 3.1.47), week 2 (Figure 3.1.48), or week 4 (Figure 3.1.50). It seems that differences at week 3 were overcome by week 4. It is difficult to determine the primary cause of differences during week 3 because all rooting rates were very high, but less than 100% rates were only found in the smaller container sizes. Although no data or measurements were taken on the stock plants during the rooting study, it was observed that plants in the larger container sizes stayed healthier as the experiment progressed, and those growing in the smaller containers tended to decline in health, which could have contributed to poorer rooting rates.

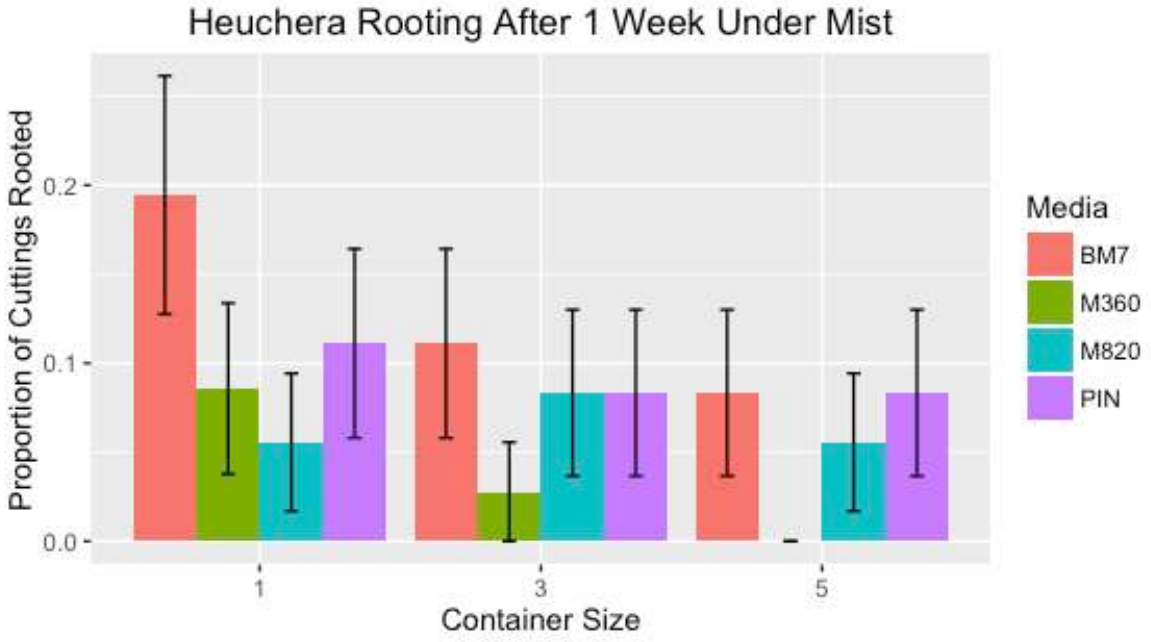

Figure 3.1.57 Experiment #1 bar plot of mean rooting proportions after 1 week under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

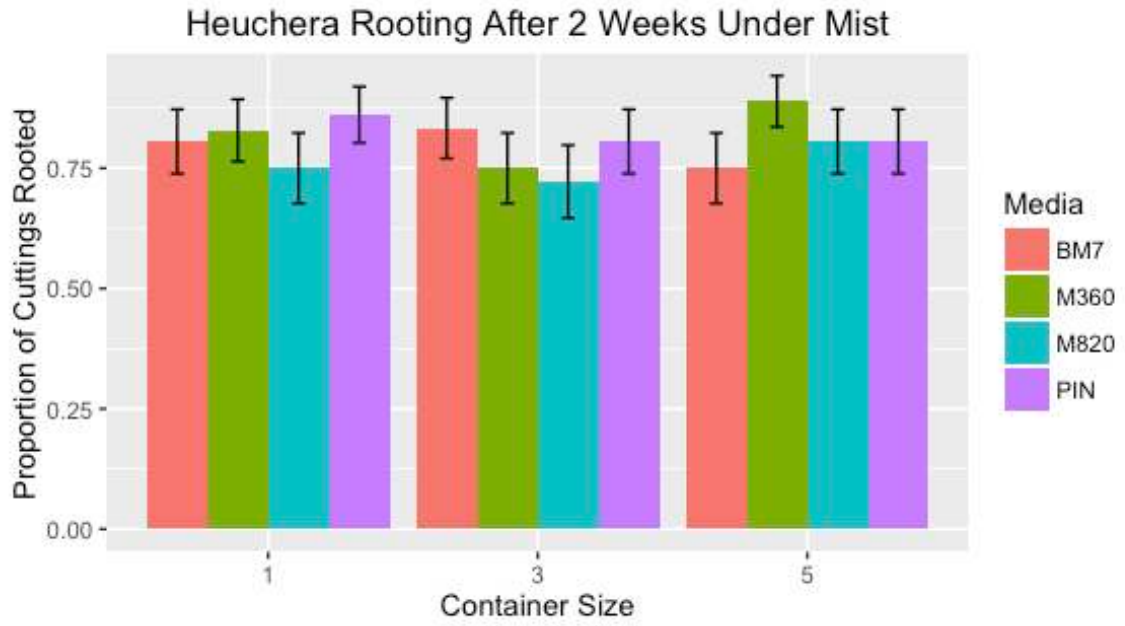

Figure 3.1.58 Experiment #1 bar plot of mean rooting proportions after 2 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Table 3.1.29 Experiment #1 percent of cuttings rooted in each treatment combination after 3 weeks under mist.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	86.1
#1 (2.84L)	Metro Mix 360	100.0
#1 (2.84L)	Metro Mix 820	94.4
#1 (2.84L)	Pindstrup	97.2
#3 (11.35L)	Berger BM-7	97.2
#3 (11.35L)	Metro Mix 360	94.4
#3 (11.35L)	Metro Mix 820	97.2
#3 (11.35L)	Pindstrup	100.0
#5 (14.55L)	Berger BM-7	100.0
#5 (14.55L)	Metro Mix 360	100.0
#5 (14.55L)	Metro Mix 820	100.0
#5 (14.55L)	Pindstrup	100.0

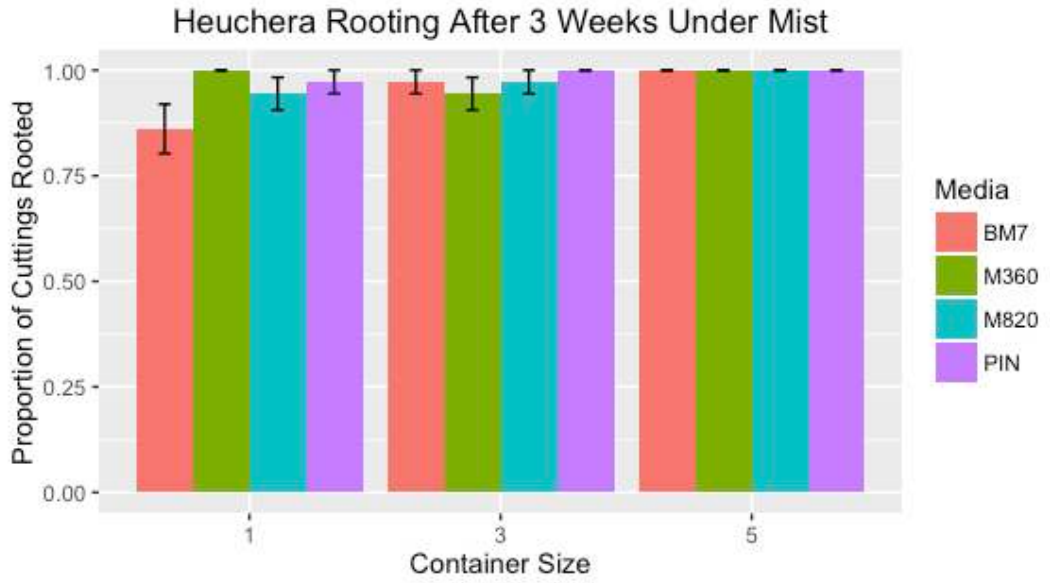

Figure 3.1.59 Experiment #1 bar plot of mean rooting proportions after 3 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

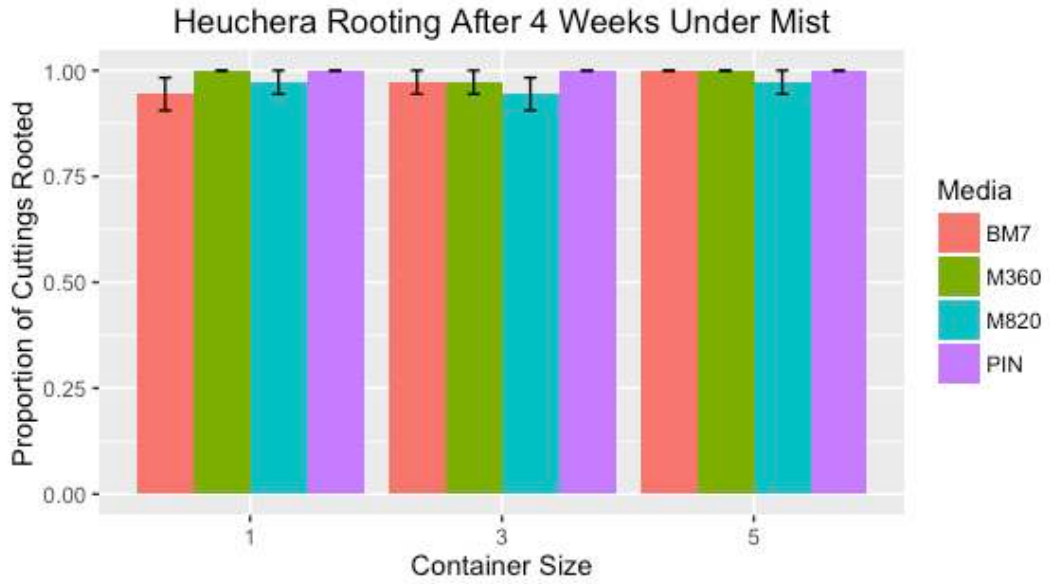

Figure 3.1.60 Experiment #1 bar plot of mean rooting proportions after 4 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Number of visible roots were analyzed by averaging over harvest time to include all three harvests. No roots were counted above 50 because they became indistinguishable from one

another. The results of Experiment #1 showed that regardless of treatment, no visible roots were present after one week under mist. After 2 weeks on the mist bench, ANOVA analysis showed a significant interaction between Size and Media (Figures 3.1.51 and 3.1.52), so pairwise comparisons were examined for each size separately (Table 3.1.30). There were no significant differences between media treatments in #1 (2.84L) or #3 (11.35L) containers. Within #5 (14.55L) containers, Metro Mix 360 developed significantly more roots than Metro Mix 820 with means of (3.3 - 6.6 roots and 0.0 - 2.5 roots respectively). After 3 weeks on the mist bench, only container size showed a significant effect (Figures 3.1.53 and 3.1.54) with the greatest number of roots produced by stock plants grown in #5 (14.55L) containers and the lowest number produced in #1 (2.84L) containers (Table 3.1.31). After 4 weeks under mist, both size and media main effects were significant, although the interaction was not (Figures 3.1.55 and 3.1. 56). Pairwise comparisons of container size were all significant when averaging over media type, with #5 (14.55L) containers producing the largest number of visible roots, and #1 (2.84L) containers producing the fewest (Table 3.1.32). When averaged over container size, Pindstrup produced the largest number of roots, while Metro Mix 360 produced the fewest.

Because the initial trend for media treatment did not continue through all 4 weeks of rooting, it is difficult to determine the primary cause of increased root production by cuttings from Metro Mix 360 after two and three weeks under mist. Since cuttings from stock plants grown in Pindstrup ultimately grew the most roots after 4 weeks under mist and Metro Mix 360 grew significantly less, it is hard to find an explanation that fits this trend. Although the conditions on the mist bench were controlled in an attempt to provide a uniform growth environment, it is possible that a change in mist distribution due to ventilation could have created a non-uniform rooting environment based on the location of cuttings within a single tray.

Response to stock plant container size aligns with rooting percentage data, indicating that cuttings taken from #5 (14.55L) containers rooted more successfully. This could be due to better overall health of stock plants as they aged, resulting in cuttings with higher nutrient and carbohydrate contents. Zerche and Druege (2009) demonstrated increased levels of sucrose and total sugar content in the leaves of cuttings as well as increased tissue nitrogen levels were correlated with an increase in total root length of poinsettia cuttings.

```
Anova Table (Type III tests)

Response: RootNum
             Sum Sq  Df F value    Pr(>F)
(Intercept)  1637.1   1 65.4976 6.368e-15 ***
Size           69.3   2  1.3866   0.25106
Media          97.4   3  1.2991   0.27427
Size:Media    356.7   6  2.3782   0.02856 *
Residuals   10472.9 419
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.61 Experiment #1 two-way ANOVA table for mean number of visible roots after 2 weeks under mist, averaged over harvest date.

Table 3.1.30 Experiment #1 mean number of visible roots after 2 weeks under mist averaged over harvest date for each level of media at each level of container size. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Media	Mean Visible Roots	95% Confidence Interval	Significance Group
#1 (2.84L) Container	Berger BM-7	0.4	0.0-2.0	1
	Metro Mix 360	2.0	0.3-3.6	1
	Metro Mix 820	2.4	0.8-4.0	1
	Pindstrup	1.8	0.1-3.4	1
#3 (11.35L) Container	Berger BM-7	1.5	0.0-3.2	1
	Metro Mix 360	0.8	0.0-2.5	1
	Metro Mix 820	2.1	0.5-3.8	1
	Pindstrup	2.3	0.7-4.0	1
#5 (14.55L) Container	Berger BM-7	1.9	0.3-3.6	1, 2
	Metro Mix 360	4.9	3.3-6.6	2
	Metro Mix 820	0.9	0.0-2.5	1
	Pindstrup	2.3	0.6-3.9	1, 2

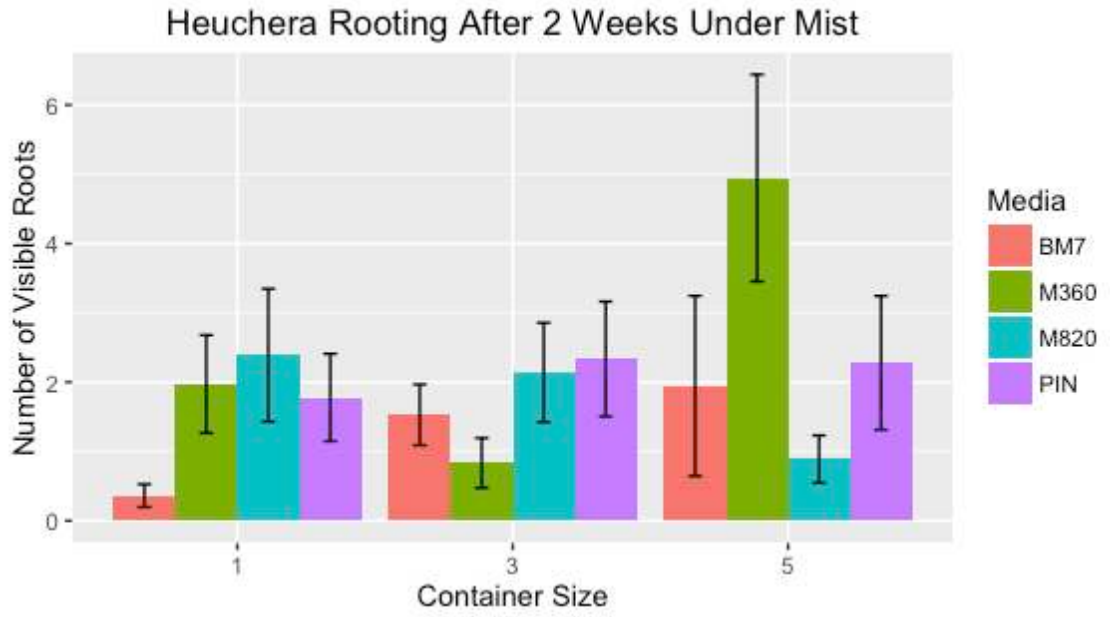

Figure 3.1.62 Experiment #1 bar plot of mean number of visible roots after 2 weeks under mist averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: RootNum
             Sum Sq  Df  F value  Pr(>F)
(Intercept) 236716   1 653.5502 < 2e-16 ***
Size          3525   2   4.8666 0.00814 **
Media         2108   3   1.9396 0.12251
Size:Media    4540   6   2.0892 0.05342 .
Residuals   151762 419
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.63 Experiment #1 two-way ANOVA table for mean visible roots after 3 weeks under mist averaged over harvest date.

Table 3.1.31 Experiment #1 mean number of visible roots after 3 weeks under mist averaged over harvest date for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Visible Roots	95% Confidence Interval	Significance Group
#1 (2.84L)	20.6	17.5-23.7	1
#3 (11.35L)	22.3	19.2-25.5	1, 2
#5 (14.55L)	27.4	24.2-30.5	2

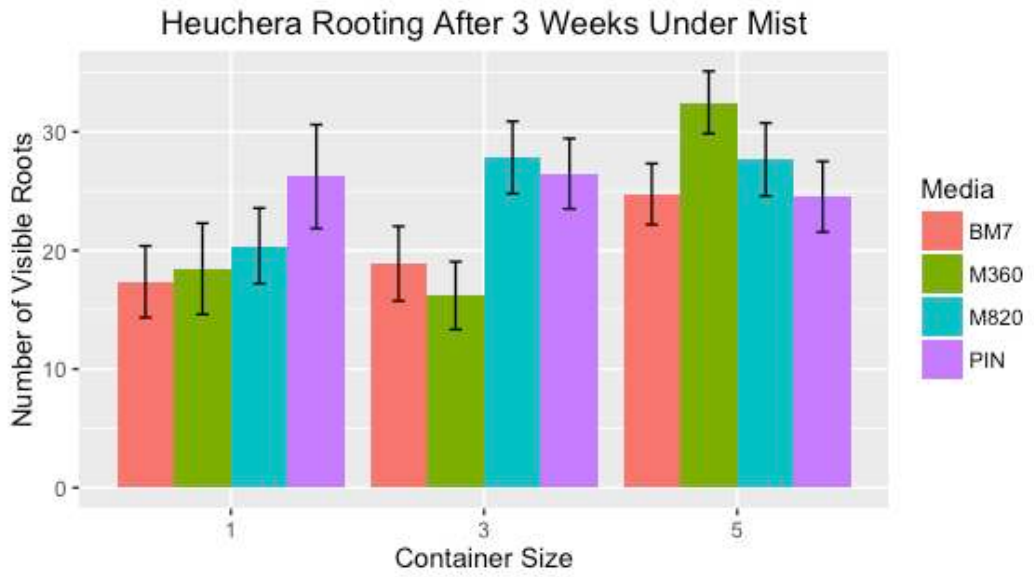

Figure 3.1.64 Experiment #1 bar plot of mean number of visible roots after 3 weeks under mist averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: RootNum
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 699708   1 2858.7836 < 2.2e-16 ***
Size         13348   2   27.2682 7.367e-12 ***
Media         2968   3    4.0425  0.007489 **
Size:Media    2139   6    1.4566  0.191725
Residuals   102553 419
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.65 Experiment #1 two-way ANOVA table for mean number of visible roots after 4 weeks under mist averaged over harvest date.

Table 3.1.32 Experiment #1 mean number of visible roots after 4 weeks under mist averaged over harvest date for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of $P<0.05$.

Treatment	Mean Visible Roots	95% Confidence Interval	Significance Group
Berger BM-7	39.3	36.3-42.2	1, 2
Metro Mix 360	36.8	33.9-39.8	1
Metro Mix 820	41.0	38.1-44.0	1, 2
Pindstrup	44.0	41.1-47.0	2
#1 Container	33.9	31.3-36.5	1
#3 Container	39.5	37.0-42.1	2
#5 Container	47.5	44.9-50.00	3

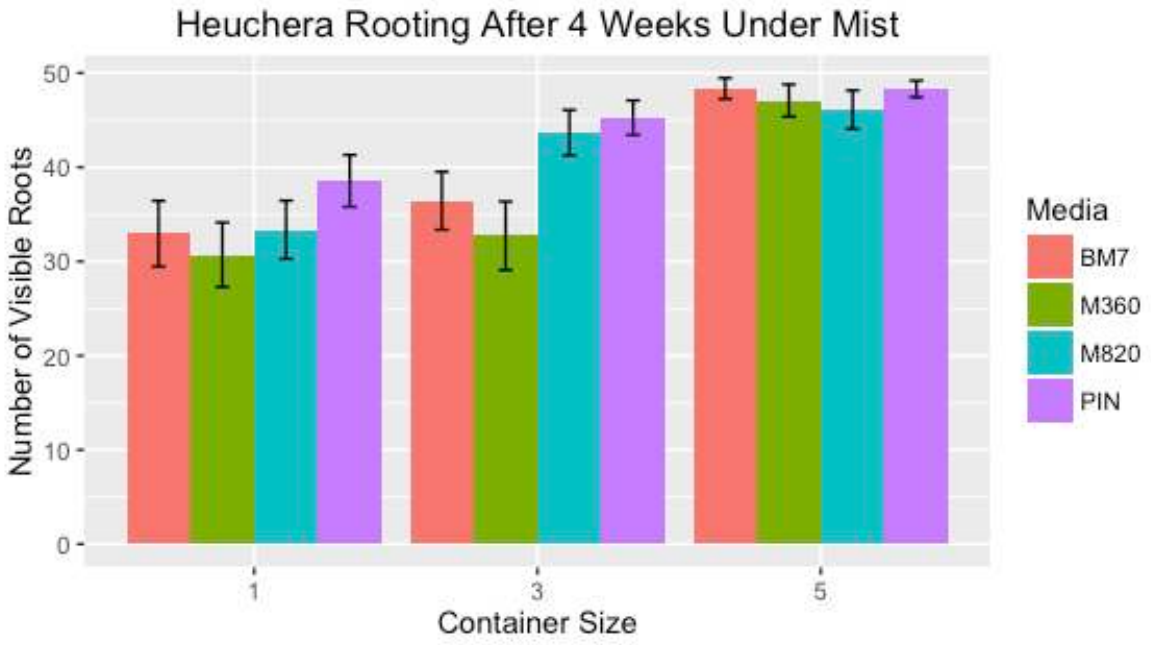

Figure 3.1.66 Experiment #1 bar plot of mean number of visible roots after 4 weeks under mist averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Results of the second experiment showed no significant association between treatment and rooting status during week 1 (Table 3.1.33 and Figure 3.1.57), week 3, or week 4 (Appendix III, Tables A3.1.13-A3.1.14, Figures A3.1.25-A3.1.26). The only significant association between treatment and rooting status was found during week 2 (Table 3.1.34 and Figure 3.1.58), at which point 100% of cuttings taken from stock plants in #3 (11.35L) containers with Metro Mix 820 had rooted. The lowest rooting percentage (75%) after two weeks was found in cuttings taken from #3 (11.35L) containers with Pindstrup. By the third week under mist, all treatments had resulted in 100% rooting, so this data is presented in the appendix.

By examining the rooting status data, there seems to be no advantage of any treatment over another in terms of the speed of rooting, although more information can be ascertained by analyzing the number of roots produced.

Table 3.1.33 Experiment #2 percent of cuttings rooted after 1 week under mist for each treatment combination. Chi Square p-value = 0.8559

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	5.6
#1 (2.84L)	Metro Mix 360	8.3
#1 (2.84L)	Metro Mix 820	14.3
#1 (2.84L)	Pindstrup	11.1
#3 (11.35L)	Berger BM-7	11.1
#3 (11.35L)	Metro Mix 360	13.9
#3 (11.35L)	Metro Mix 820	8.3
#3 (11.35L)	Pindstrup	2.8
#5 (14.55L)	Berger BM-7	5.6
#5 (14.55L)	Metro Mix 360	5.6
#5 (14.55L)	Metro Mix 820	11.1
#5 (14.55L)	Pindstrup	8.3

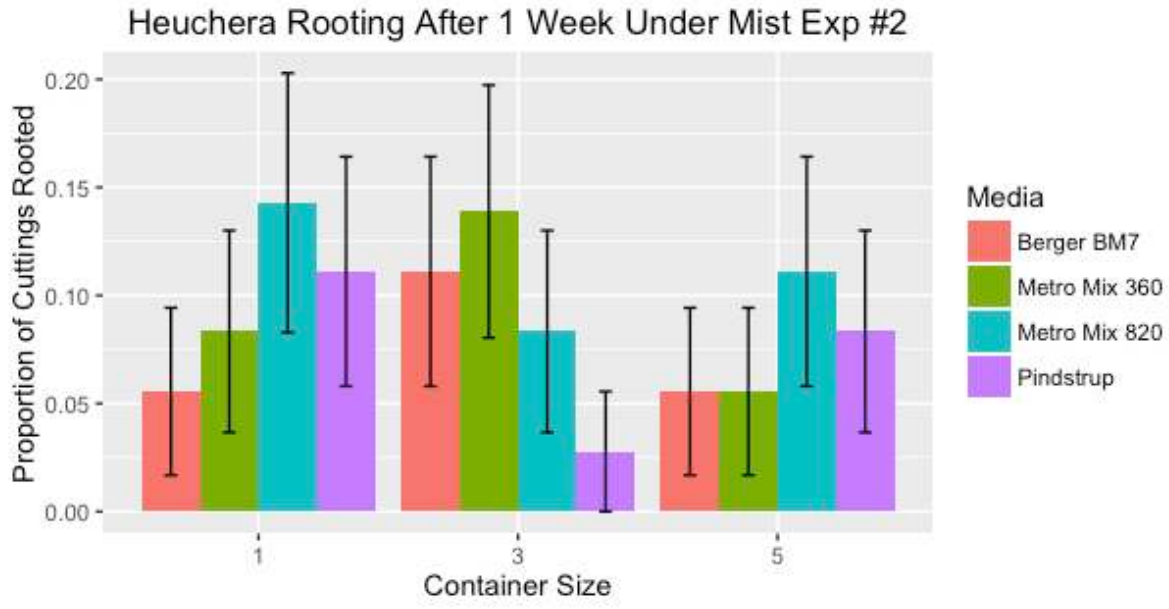

Figure 3.1.67 Experiment #2 bar plot of mean proportion of cuttings rooted after 1 week under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Table 3.1.34 Experiment #2 percent of cuttings rooted after 2 weeks under mist for each treatment combination. Significant association was found between treatment and rooting status, Chi Square p-value = 0.006141.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	88.9
#1 (2.84L)	Metro Mix 360	91.7
#1 (2.84L)	Metro Mix 820	97.1
#1 (2.84L)	Pindstrup	91.7
#3 (11.35L)	Berger BM-7	86.1
#3 (11.35L)	Metro Mix 360	97.2
#3 (11.35L)	Metro Mix 820	100.0
#3 (11.35L)	Pindstrup	77.8
#5 (14.55L)	Berger BM-7	94.4
#5 (14.55L)	Metro Mix 360	75.0
#5 (14.55L)	Metro Mix 820	86.1
#5 (14.55L)	Pindstrup	94.4

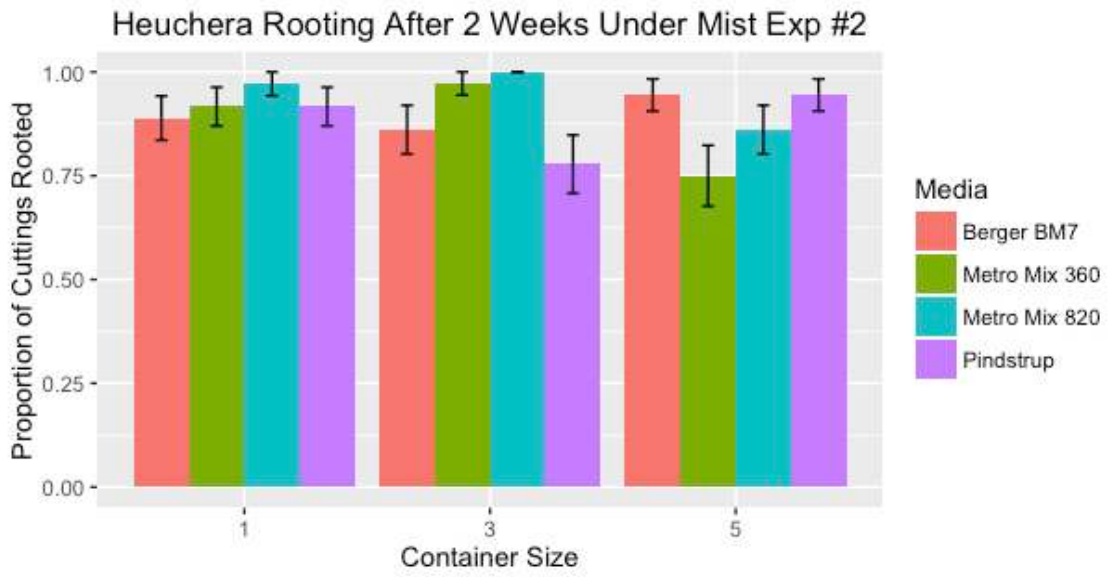

Figure 3.1.68 Experiment #2 bar plot of mean proportion of cuttings rooted after 2 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

When statistical analysis was performed on the number of visible roots, more dramatic trends were discovered than simply looking at the rooting status. Similar to Experiment #1, there

were no visible roots after one week under mist, so this data is not presented. After 2 weeks under mist, there was no significant main effect of either media or container size (Appendix III Figures A3.1.27-A3.1.28, Tables A3.1.15). However, after 3 weeks under mist, a significant main effect of container size had developed (Figures 3.1.59 and 3.1.60), with cuttings from #1 (2.84L) containers producing the largest number of visible roots and cuttings from #5 (14.55L) containers producing the fewest (Table 3.1.35). After 4 weeks under mist, the trends remained the same (Figures 3.1.61 and 3.1.62), although the number of roots had increased dramatically (Table 3.2.36).

These results contradict those of Experiment #1 which showed a significant increase in number of visible roots correlated with an increase in container size. Since there was an opposite correlation found in Experiment #2, and the results of Experiment #1 and #2 did not agree, it is possible that environmental factors may have altered the plants' performance. The second experiment was completed during the winter months and greenhouse temperatures were cooler, which could have allowed stock plants in the smaller containers to avoid some of the stresses associated with smaller container volumes such as extreme temperature fluctuations of the root zone and more accelerated water depletion (Poorter et al 2012a).

```
Anova Table (Type III tests)

Response: RootNum
            Sum Sq  Df   F value    Pr(>F)
(Intercept) 280014   1 1013.7618 < 2.2e-16 ***
Size          6116   2   11.0708 2.064e-05 ***
Media         1276   3    1.5403    0.2034
Size:Media    1676   6    1.0111    0.4174
Residuals   115733 419
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.1.69 Experiment #2 two-way ANOVA table for mean number of visible roots after 3 weeks under mist.

Table 3.1.35 Experiment #2 mean number of visible roots after 3 weeks under mist for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Visible Roots	95% Confidence Interval	Significance Group
#1 (2.84L)	30.53	27.80-33.26	2
#3 (11.35L)	24.47	21.75-27.19	1
#5 (14.55L)	21.47	18.74-24.19	1

Figure 3.1.70 Experiment #2 bar plot of mean number of visible roots after 3 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: RootNum
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 887494   1 8011.9518 < 2.2e-16 ***
Size          2438   2   11.0065 2.194e-05 ***
Media          457   3    1.3763   0.24947
Size:Media    1208   6    1.8179   0.09413 .
Residuals    46413 419
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.1.71 Experiment #2 two-way ANOVA table for mean number of visible roots after 4 weeks under mist.

Table 3.1.36 Experiment #2 mean number of visible roots after 4 weeks under mist for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Visible Roots	95% Confidence Interval	Significance Group
#1 (2.84L)	48.42	46.69-50.15	2
#3 (11.35L)	45.10	43.38-46.83	1
#5 (14.55L)	42.61	40.89-44.34	1

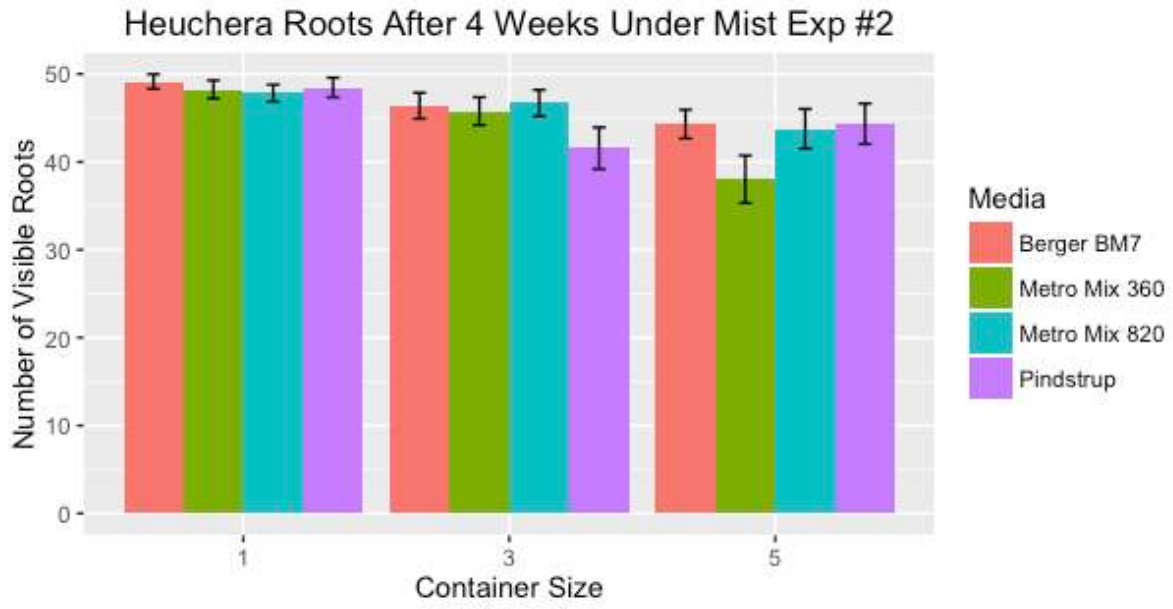

Figure 3.1.72 Experiment #2 bar plot of mean number of visible roots after 4 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.2. *Zauschneria garrettii* 'PWWG01S' ORANGE CARPET®

3.2.1 Plant Size

A single parameter for size was calculated to represent overall plant size by averaging the measured height and two widths of each plant. Statistical analysis of size index was done for each time point beginning with initial measurements made after plants had become established in 4" containers but before they were shifted to their treatment container sizes. Statistical analysis

was only calculated using treatment media for this time point since the plants had not yet been moved to their treatment container sizes. Subsequent analyses contain media, container size and the size*media interaction.

3.2.1.1 Size Index

Results of size index from Experiment #1 demonstrated a significant increase in stock plant size when grown in Pindstrup media and when grown in larger container sizes. Initial measurements made before plants were shifted to treatment containers showed a significant main effect of media (Figures 3.2.1 and 3.2.2), with Pindstrup and Berger BM-7 producing significantly larger plants than Metro Mix 820 (Table 3.2.1).

Measurements taken prior to the first harvest of cuttings showed a significant main effect of both media and container size (Figure 3.2.3). When averaging over container size, Pindstrup resulted in significantly larger plants than those grown in Metro Mix 360 or Metro Mix 820 (Table 3.2.2) and differences appeared to be more dramatic in the larger container sizes (Figure 3.2.4). When averaging over media treatment, stock plants grown in #3 (11.35L) containers were significantly larger than those grown in #1 (2.84L) containers, although the actual difference in size index is only about 2.5 cm. Measurements taken prior to the second round of cuttings followed the same trends with both container size and media effects being significant (Figures 3.2.5 and 3.2.6). Pindstrup continued to result in significantly larger plants than both Metro Mix substrates when averaged over container size. When averaged over media treatment, both #3 (11.35L) and #5 (14.55L) containers produced significantly larger plants than #1 (2.84L) containers at this time point. Measurements taken prior to the third harvest of cuttings only showed a significant main effect of container size (Figure 3.2.7), and it can be seen from Figure 3.2.8 that the difference in size index between container sizes increased over the course of the

experiment. When averaging over media treatment, #3 (11.35L) and #5 (14.55L) containers produced significantly larger plants than #1 (2.84L) containers (Table 3.2.4).

Final measurements were taken prior to harvesting the top growth of stock plants and results showed both a significant main effect of media treatment and container size (Figure 3.2.9), although differences between media treatments had become much smaller (Figure 3.2.10). Data averaged over container size revealed that Pindstrup produced significantly larger stock plants than Metro Mix 820, although no other pairwise comparisons of media were significant. When data were averaged over media, both #3 (11.35L) and #5 (14.55L) containers resulted in significantly larger stock plants than #1 (2.84L) containers.

While Pindstrup media resulted in the largest plants at most time points, the difference between media treatments decreased over the course of the experiment. The initial soil analysis done prior to Experiment #1 (Appendix I, Table A1.2) showed that Pindstrup started with higher phosphorus levels than any other media treatment whether in the form of P (0.456% as compared to 0.0142-0.334%) or P_2O_5 (0.1044% as compared to 0.0325-0.0923%). Since P is an essential nutrient for plant growth used in energy molecules like ATP, and higher levels of available phosphorus can encourage earlier plant growth and quicker development (Pagliari et al 2017), it is possible that the pre-plant nutrient charge in Pindstrup stimulated more initial growth in stock plants. When examining the phosphorus levels of media after *Zauschneria* Experiment #1 (Appendix I, Table A1.4), it can be seen that the percent phosphorus declined to a very similar level to the other media. Although it is unknown whether it was because of leaching, plant uptake, or other chemical processes, the equalization in phosphorus levels between media treatments over the course of the experiment could be partially responsible for the equalization of plant size index.

Another possible reason for the increase in size index of stock plants grown in Pindstrup is the media started with the highest relative CEC (97 meq/100g as compared to 59-77 meq/100g) and ended the experiment with the highest relative CEC (8.01 meq/100g as compared to 4.41-6.11 meq/100g). Higher CEC levels contribute to better nutrient availability and uptake by plants and could be partially responsible for the increased response within the Pindstrup media treatment.

The effect of container size on plant size index of *Zauschneria* is similar to results summarized by Poorter et al (2012b) and demonstrated by Rozas et al (1995) with the effect increasing with the length of time the plants were grown in the treatment containers. While ANOVA testing initially showed a significant effect of container size, the magnitude of differences was quite small during the first measurements (Table 3.2.2) and became much more pronounced by the end of the experiment (Table 3.2.5). Mean size index for the #5 (14.55L) containers was only 2.53 cm larger than #1 (2.84L) containers during the first measurement, but by the final measurement, plants grown in #5 (14.55L) containers were 13.81 cm larger on average than those in #1 (2.84L) containers. The negligible difference between size index of plants grown in #3 (11.35L) and #5 (14.55L) containers is probably due to the length of the study. It is expected that with more time, stock plants grown in #3 (11.35L) containers would start to show a notable effect of root restriction, slowing their growth, and stock plants grown in #5 (14.55L) containers would continue to increase in size more quickly until the roots of those plants became restricted.

```
Anova Table (Type III tests)

Response: INITSizeIndex
            Sum Sq  Df   F value    Pr(>F)
(Intercept)  55560   1 3441.5294 < 2.2e-16 ***
Media          237   3    4.9006  0.003043 **
Residuals     1873 116
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.1 Experiment #1 one-way ANOVA table for initial size index with “Media” as only predictor variable.

Table 3.2.1 Experiment #1 mean size index for each media treatment prior to shifting plants to treatment containers. Means with different significance groups are significantly different at the level of $P<0.05$.

Media	Mean Size Index (cm)	95% Confidence Interval	Significance Group
Berger BM-7	22.52	21.07-23.98	2
Metro Mix 360	21.12	19.67-22.57	1, 2
Metro Mix 820	19.40	17.95-20.86	1
Pindstrup	23.02	21.57-24.48	2

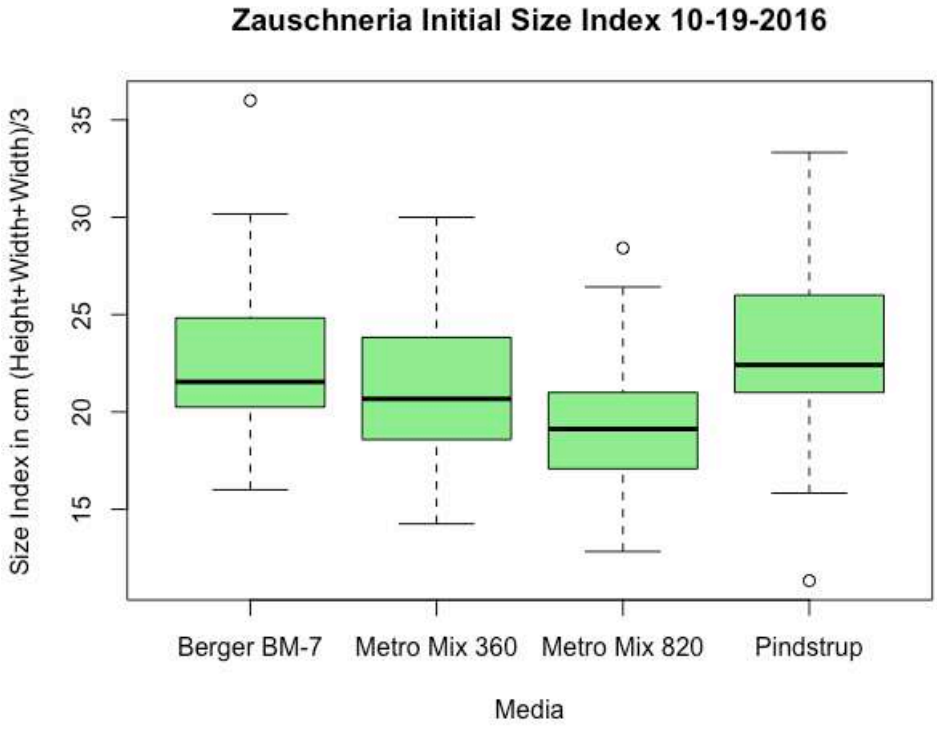

Figure 3.2.2 Experiment #1 box plots of mean size index for each media treatment prior to shifting plants to treatment containers.

```
Anova Table (Type III tests)

Response: SizeIndex1
            Sum Sq  Df   F value    Pr(>F)
(Intercept)  90807   1 4968.8231 < 2.2e-16 ***
Size           135   2    3.6961 0.0280132 *
Media          343   3    6.2603 0.0005863 ***
Size:Media      68   6    0.6179 0.7155491
Residuals     1974 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.3 Experiment #1 two-way ANOVA table for mean size index prior to first harvest of cuttings.

Table 3.2.2 Experiment #1 mean size index prior to the first harvest of cuttings for each media averaged over container size and each size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Size Index (cm)	95% Confidence Interval	Significance Group
Berger BM-7	27.58	26.03-29.13	1, 2
Metro Mix 360	26.94	25.39-28.48	1
Metro Mix 820	25.42	23.87-26.96	1
Pindstrup	30.10	28.56-31.65	2
#1 Container	26.07	24.73-27.41	1
#3 Container	28.60	27.26-29.94	2
#5 Container	27.85	26.51-29.19	1, 2

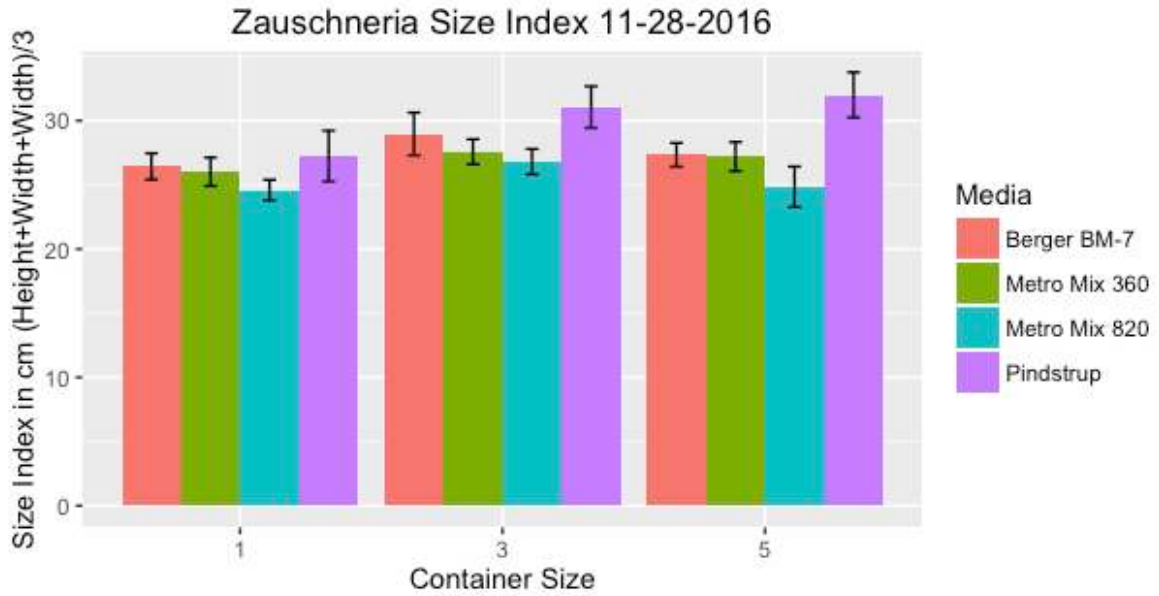

Figure 3.2.4 Experiment #1 bar plot of mean size index for each treatment combination prior to first harvest of cuttings. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: SizeIndex2
            Sum Sq  Df   F value    Pr(>F)
(Intercept) 175359   1 7764.3603 < 2.2e-16 ***
Size           619   2   13.6974 4.993e-06 ***
Media          444   3    6.5555 0.0004097 ***
Size:Media     130   6    0.9630 0.4539087
Residuals     2439 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.5 Experiment #1 two-way ANOVA table for mean size index prior to second harvest of cuttings.

Table 3.2.3 Experiment #1 mean size index prior to second harvest of cuttings for each media treatment averaged over size and each size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	38.45	36.73-40.17	1, 2
Metro Mix 360	37.78	36.06-39.50	1
Metro Mix 820	35.64	33.92-37.36	1
Pindstrup	41.03	39.31-42.75	2
#1 Container	35.04	33.55-36.52	1
#3 Container	39.52	38.03-41.01	2
#5 Container	40.13	38.64-41.62	2

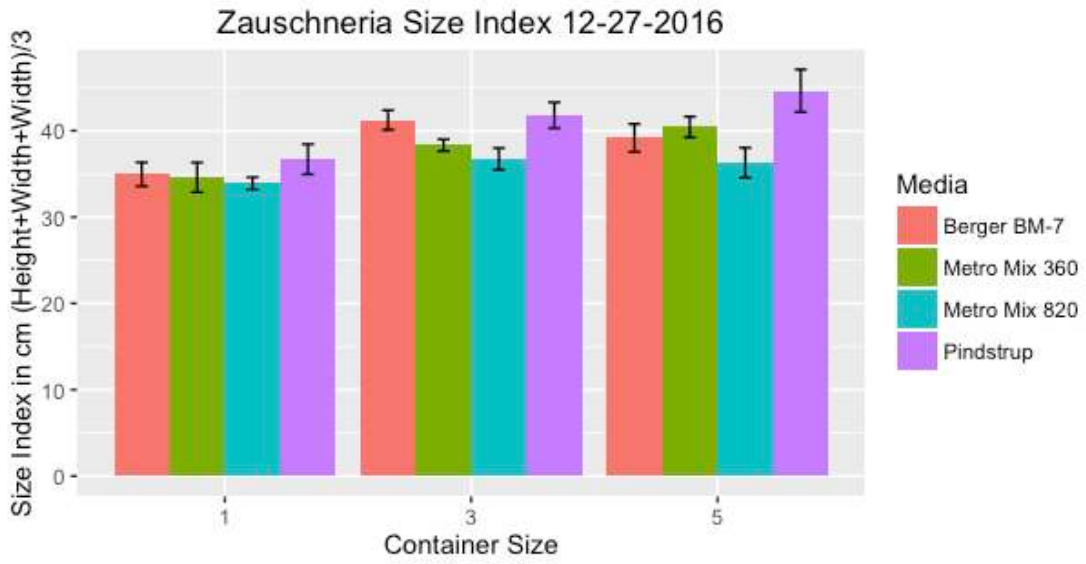

Figure 3.2.6 Experiment #1 bar plot of mean size index prior to second harvest of cuttings for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: SizeIndex3
             Sum Sq  Df    F value Pr(>F)
(Intercept) 192555   1 13342.9011 <2e-16 ***
Size          2423   2    83.9396 <2e-16 ***
Media          115   3     2.6468 0.0527 .
Size:Media      50   6     0.5805 0.7452
Residuals     1559 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.7 Experiment #1 two-way ANOVA table for mean size index prior to third harvest of cuttings.

Table 3.2.4 Experiment #1 mean size index prior to third harvest for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Size Index (cm)	95% Confidence Interval	Significance Group
#1 (2.84L)	33.75	32.56-34.94	1
#3 (11.35L)	42.55	41.36-43.74	2
#5 (14.55L)	43.88	42.69-45.07	2

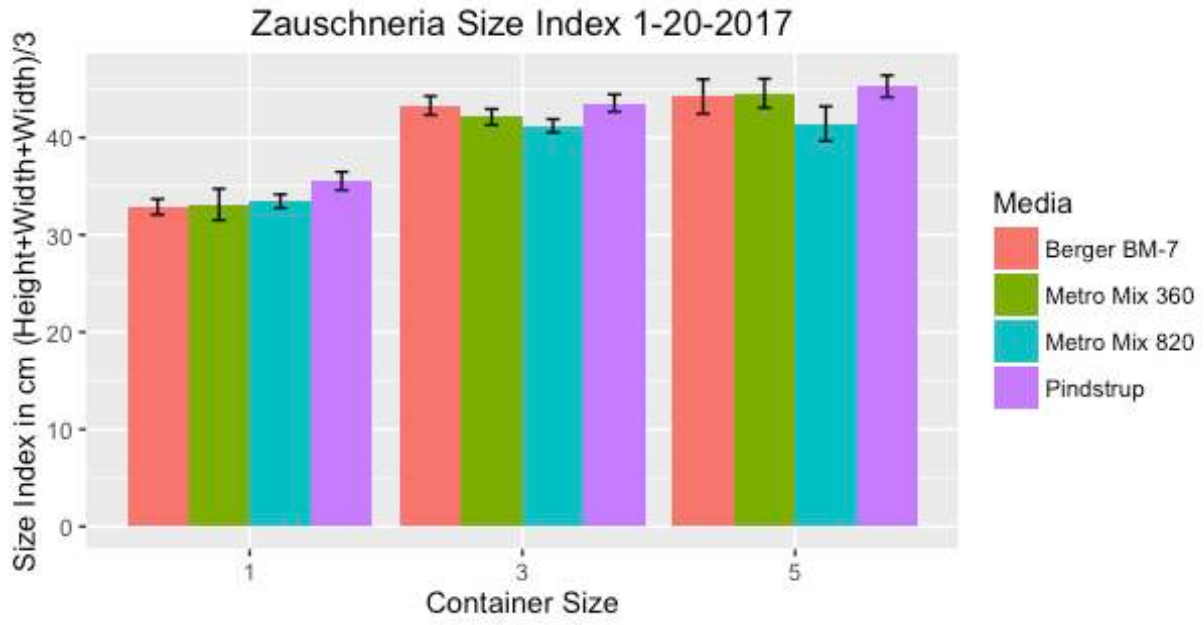

Figure 3.2.8 Experiment #1 bar plot of mean size index prior to third harvest of cuttings for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: FINALSizeIndex
            Sum Sq  Df    F value  Pr(>F)
(Intercept) 197769   1 12745.4940 < 2e-16 ***
Size          4562   2   146.9976 < 2e-16 ***
Media          152   3     3.2582 0.02442 *
Size:Media     106   6     1.1357 0.34667
Residuals     1676 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.9 Experiment #1 two-way ANOVA table of mean final size index prior to harvesting all top growth.

Table 3.2.5 Experiment #1 mean final size index prior to harvest of all top growth for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Size Index	95% Confidence Interval	Significance Group
Berger BM-7	41.15	39.73-42.58	1, 2
Metro Mix 360	41.26	39.84-42.69	1, 2
Metro Mix 820	38.65	37.23-40.08	1
Pindstrup	41.32	39.89-42.74	2
#1 Container	31.93	30.69-33.16	1
#3 Container	44.13	42.89-45.36	2
#5 Container	45.74	44.50-46.97	2

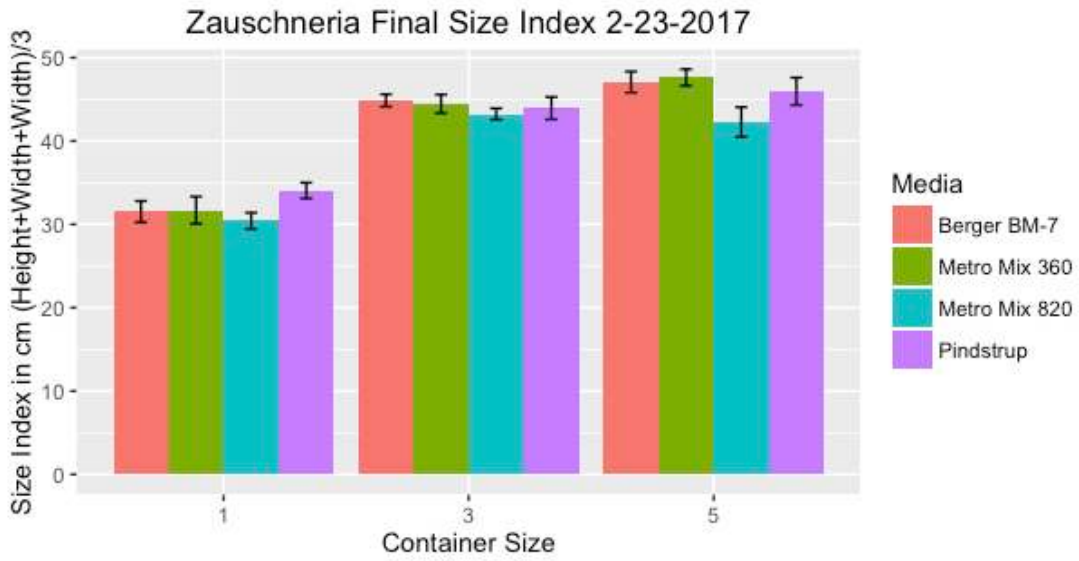

Figure 3.2.10 Experiment #1 bar plot of mean final size index prior to harvesting all top growth for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Results of the second experiment showed no significant effect of media at any time point after the initial measurements, but there was a significant effect of container size for all measurements. As with the first experiment, the effect of container size was subtle initially and became more pronounced with time. Initial measurements were taken prior to plants being shifted into treatment containers, and ANOVA testing showed a significant effect of media treatment (Figures 3.2.11 and 3.2.12). Plants grown in Metro Mix 360 were significantly larger than those grown in the other three treatment media, but no other pairwise comparisons were significant (Table 3.2.6).

Measurements taken prior to the first harvest of cuttings showed only a significant main effect of media (Figures 3.2.13 and 3.2.14) with #1 (2.84L) containers producing significantly smaller plants than #3 (11.35L) or #5 (14.55L) containers (Table 3.2.7). Size index measurements taken prior to the second harvest of cuttings showed the same trend (Figures 3.2.15 and 3.2.16) with #1 (2.84L) containers producing significantly smaller plants than the two larger container sizes. Although the significance and direction of differences was the same as the previous measurement, the magnitude of the difference was larger (Table 3.2.8). Prior to the third harvest of cuttings, ANOVA testing of size index showed a significant effect of container size (Figures 3.2.17 and 3.2.18), but this time all three container sizes were significantly different with #1 (2.84L) containers producing the smallest plants and #5 (14.55L) containers producing the largest (Table 3.2.9).

The final measurements taken prior to harvesting the top growth of all stock plants showed that while the trends remained the same, the difference between size index of plants grown in all three container sizes had become larger. Main effect of container size was still

significant (Figures 3.2.19 and 3.2.20) with #5 (14.55L) containers producing the largest plants and #1 (2.84L) containers producing the smallest. All pairwise comparisons of container size were significant (Table 3.2.10).

Differences in stock plant size index during Experiment #2 can likely be attributed to the effect of container size and root restriction that results from limited root volumes. The increase in container size effect over the course of this experiment agrees with researcher such as that by Van Iersel (1997) who noted differences in *Salvia splendens* performance over time when grown in different container sizes. Once plant roots start to become restricted by the walls of a container, researchers noted a decrease in leaf expansion and shoot growth (Xie et al 2013) which would contribute to smaller plants.

Unlike the first experiment, the #5 (14.55L) containers started to produce stock plants with larger size indices by the end of Experiment #2. Although the differences were still small by the time top growth was harvested, it is expected that this trend would continue if stock plants were grown for a longer period of time.

```
Anova Table (Type III tests)

Response: INITSizeIndex
            Sum Sq  Df    F value    Pr(>F)
(Intercept)  46041   1 10370.1709 < 2.2e-16 ***
Media           82   3     6.1413 0.0006577 ***
Residuals      506 114
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.11 Experiment #2 one-way ANOVA table for initial size index prior to plants being shifted to treatment containers with "Media" as only predictor variable.

Table 3.2.6 Experiment #2 mean initial size index prior to plants being shifted to treatment containers for each treatment media. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Size Index (cm)	95% Confidence Interval	Significance Group
Berger BM-7	19.52	18.75-20.30	1
Metro Mix 360	21.17	20.40-21.95	2
Metro Mix 820	19.02	18.26-19.78	1
Pindstrup	19.31	18.55-20.07	1

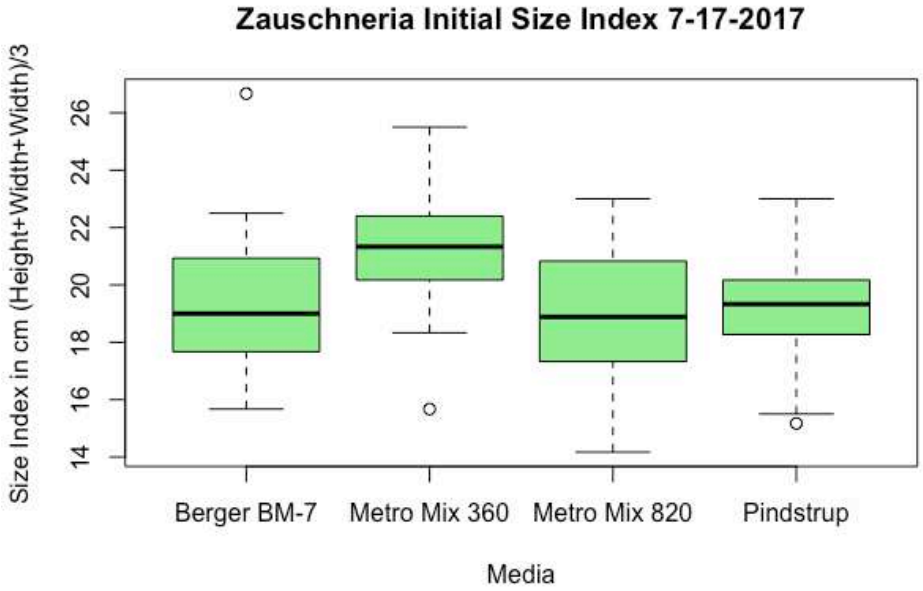

Figure 3.2.12 Experiment #2 box plot of mean initial size index prior to plants being shifted to treatment containers for each treatment media.

```
Anova Table (Type III tests)

Response: SizeIndex1
             Sum Sq  Df   F value    Pr(>F)
(Intercept)  87880   1 8977.4294 < 2.2e-16 ***
Size           110   2    5.6049  0.004854 **
Media           16   3    0.5310  0.661969
Size:Media      62   6    1.0476  0.398978
Residuals     1038 106
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.13 Experiment #2 two-way ANOVA table for mean size index prior to harvest #1.

Table 3.2.7 Experiment #2 mean size index prior to first cutting harvest for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Size Index (cm)	95% Confidence Interval	Significance Group
#1 (2.84L)	25.93	24.93-26.94	1
#3 (11.35L)	27.95	26.97-28.93	2
#5 (14.55L)	28.05	27.06-29.03	2

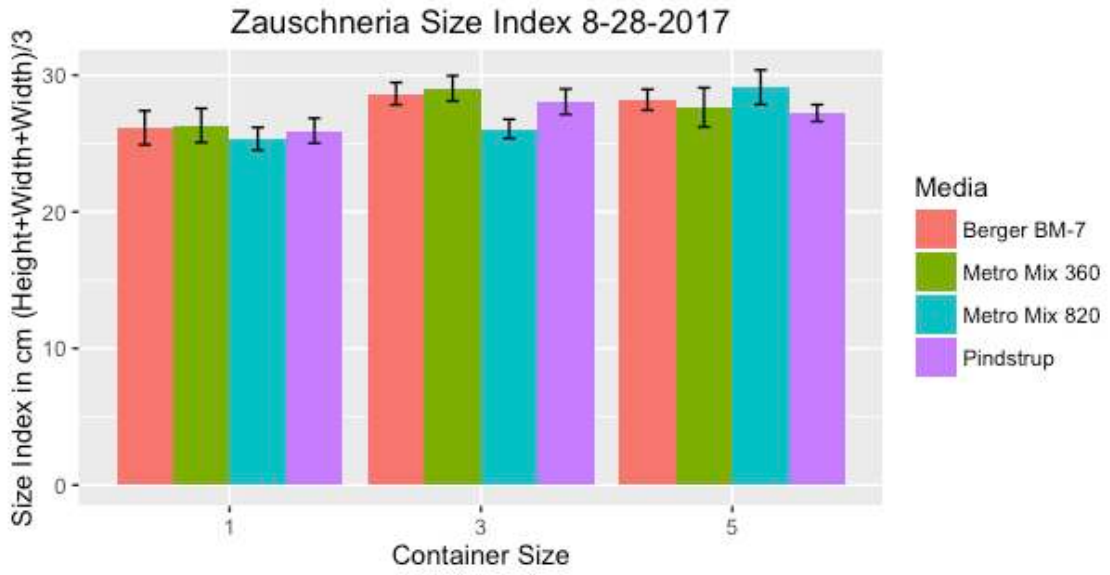

Figure 3.2.14 Experiment #2 bar plot of mean size index prior to first cutting harvest for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: SizeIndex2
             Sum Sq  Df    F value    Pr(>F)
(Intercept) 185325   1 12497.1696 < 2.2e-16 ***
Size           948   2    31.9554 1.379e-11 ***
Media           32   3     0.7201    0.5421
Size:Media      74   6     0.8316    0.5481
Residuals     1572 106
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.15 Experiment #2 two-way ANOVA table for mean size index prior to second cutting harvest.

Table 3.2.8 Experiment #2 mean size index prior to second cutting harvest for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Size Index (cm)	95% Confidence Interval	Significance Group
#1 (2.84L)	35.79	34.55-37.03	1
#3 (11.35L)	40.59	39.38-41.79	2
#5 (14.55L)	42.61	41.40-43.81	2

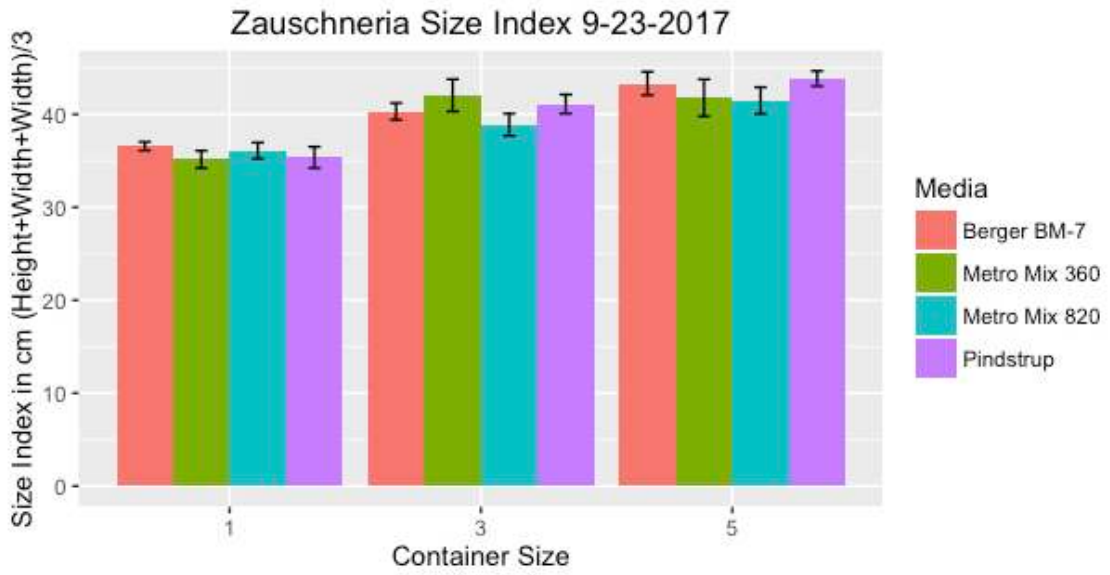

Figure 3.2.16 Experiment #2 bar plot of mean size index prior to second cutting harvest for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: SizeIndex3
             Sum Sq  Df    F value  Pr(>F)
(Intercept) 167937   1 21313.0053 < 2e-16 ***
Size          1752   2   111.1452 < 2e-16 ***
Media           56   3     2.3656 0.07511 .
Size:Media      42   6     0.8887 0.50604
Residuals      835 106
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.17 Experiment #2 two-way ANOVA table for mean size index prior to cutting harvest #3.

Table 3.2.9 Experiment #2 mean size index prior to cutting harvest #3 for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Size Index (cm)	95% Confidence Interval	Significance Group
#1 (2.84L)	32.41	31.51-33.32	1
#3 (11.35L)	39.30	38.42-40.18	2
#5 (14.55L)	41.55	40.67-42.43	3

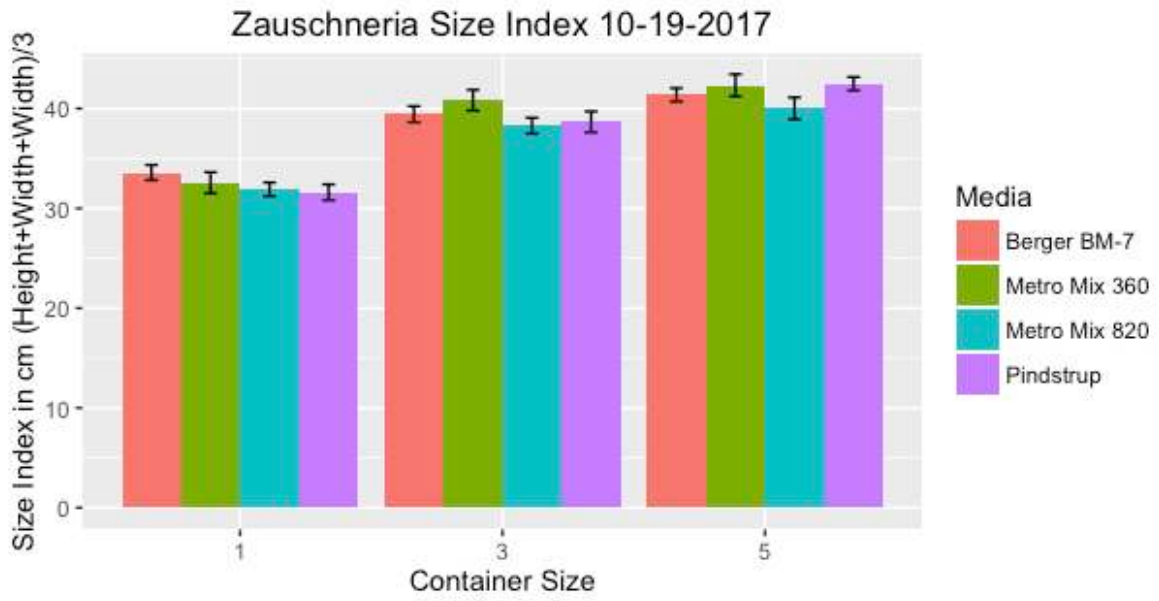

Figure 3.2.18 Experiment #2 bar plot of mean size index prior to third cutting harvest for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: FINALSizeIndex
            Sum Sq  Df    F value Pr(>F)
(Intercept) 188588   1 17303.8659 <2e-16 ***
Size          1859   2    85.2896 <2e-16 ***
Media            2   3     0.0759 0.9729
Size:Media      55   6     0.8399 0.5419
Residuals     1155 106
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.19 Experiment #2 two-way ANOVA table for mean final size index prior to harvesting all top growth.

Table 3.2.10 Experiment #2 mean final size index prior to harvesting all top growth for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Size Index (cm)	95% Confidence Interval	Significance Group
#1 (2.84L)	34.56	33.49-35.62	1
#3 (11.35L)	41.41	40.38-42.45	2
#5 (14.55L)	44.06	43.02-45.09	3

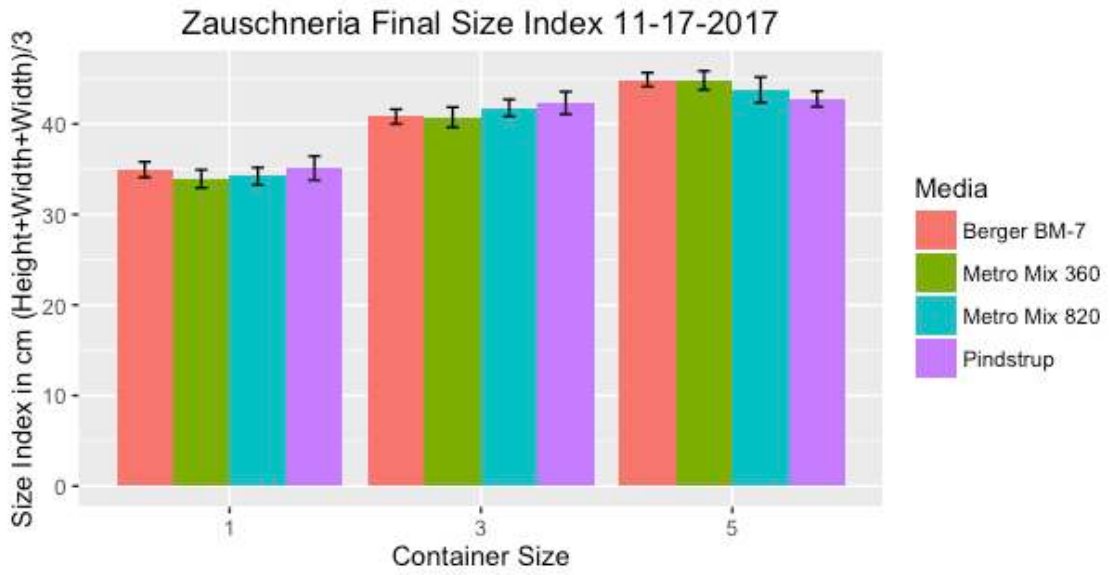

Figure 3.2.20 Experiment #2 bar plot of mean final size index prior to harvesting all top growth for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.1.1.2 Final Dry Weight

Final Dry weight of stock plants was determined by cutting off all top growth at the crown before drying and weighing. Results of the first experiment demonstrated a significant main effect of both media and containers size (Figure 3.2.21) with media differences being more dramatic in the larger containers (Figure 3.2.22). When averaged over container size, Metro Mix 820 resulted in significantly smaller dry weights than Pindstrup or Berger BM-7 (Table 3.2.11). Although not significantly different, Metro Mix 820 also resulted in smaller dry weights than Metro Mix 360 by over 9 grams. The low response to Metro Mix 820 in this experiment may be

partially due to a high carbon:nitrogen ratio which is known to immobilize nitrogen and lead to nutrient deficiencies (Ingram et al 1993). Analysis of Metro Mix 820 prior to Experiment #1 (Appendix I Table A1.2) showed the starting C:N ratio of 83.8:1 to be much higher than the 24:1 ratio recommended by the USDA Natural Resources Conservation Service (2011). This was much higher than the other three treatment substrates which ranged from 13.0:1 to 54.6:1 prior to growth. Analysis after Experiment #1 showed Metro Mix 820 maintained a higher C:N, ending the experiment with a ratio of 86.98:1 as compared to the other media ranging from 50.62:1 to 55.98:1.

When averaged over media treatment, dry weights of top growth for plants grown in #1 (2.84L) containers were significantly lower than both #3 (11.35L) and #5 (14.55L) containers. The larger two container sizes were not significantly different and means only differed by 1.16 grams. These results agree with previous studies of container size in which larger containers resulted in higher biomass (Poorter et al 2012b). The larger container sizes likely had similar mean dry weights because the experiment was not long enough for the #3 (11.35L) containers to become root restricted.

```
Anova Table (Type III tests)

Response: PlantDryWeight
            Sum Sq Df   F value    Pr(>F)
(Intercept) 262498  1 1618.4268 < 2.2e-16 ***
Size         34796  2  107.2664 < 2.2e-16 ***
Media         3089  3    6.3476 0.0007115 ***
Size:Media     753  6    0.7736 0.5932673
Residuals    11516 71
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.21 Experiment #1 two-way ANOVA table for final dry weight of plant top growth.

Table 3.2.11 Experiment #1 mean dry weight of plant top growth for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Final Dry Weight	95% Confidence Interval	Significance Group
Berger BM-7	57.71	52.17-63.25	2
Metro Mix 360	56.18	50.49-61.88	1, 2
Metro Mix 820	47.14	41.60-52.68	1
Pindstrup	64.12	58.58-69.66	2
#1 Container	27.42	22.62-32.22	1
#3 Container	70.14	65.25-75.04	2
#5 Container	71.30	66.50-76.10	2

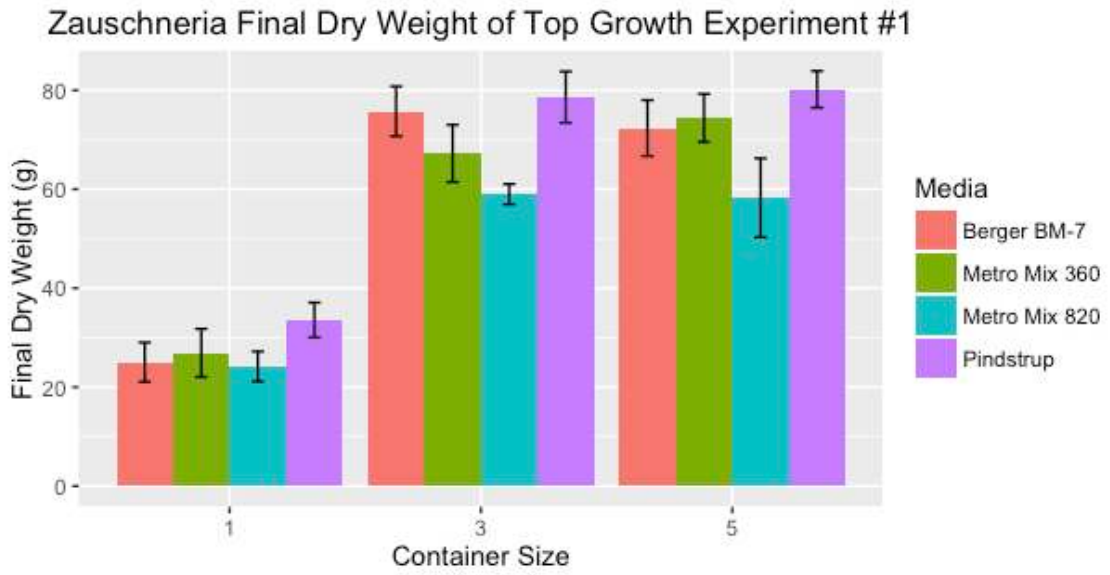

Figure 3.2.22 Experiment #1 mean final dry weight of top growth for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Results of the second experiment showed no significant effect of media, though differences can be seen in Figure 3.2.24. The main effect of container size was statistically significant (Figure 3.2.23) with #1 (2.84L) containers producing the smallest final dry weights and #5 (14.55L) containers producing the largest (Table 3.2.12). All pairwise comparisons were significant. These results agree with previous studies of container size in which larger containers resulted in higher biomass (Poorter et al 2012b). Although the #3 (11.35L) and #5 (14.55L)

containers were significantly different in the second experiment, the difference between means was less than the difference between #1 (2.84L) and #3 (11.35L) containers. It is expected that with longer exposure to root restricted conditions, the differences between dry weight in the #3 (11.35L) and #5 (14.55L) containers would become greater.

```
Anova Table (Type III tests)

Response: PlantDryWeight
             Sum Sq Df   F value Pr(>F)
(Intercept) 25877.4  1 1240.6518 <2e-16 ***
Size         3562.3  2   85.3952 <2e-16 ***
Media          18.4  3    0.2939 0.8297
Size:Media    215.3  6    1.7201 0.1289
Residuals    1480.9 71
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.23 Experiment #2 two-way ANOVA table for mean final dry weight of top growth.

Table 3.2.12 Experiment #2 mean final dry weight of plant top growth for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of $P<0.05$.

Container Size	Mean Final Dry Weight	95% Confidence Interval	Significance Group
#1 (2.84L)	9.03	7.31-10.75	1
#3 (11.35L)	19.06	17.34-20.78	2
#5 (14.55L)	24.93	23.18-26.69	3

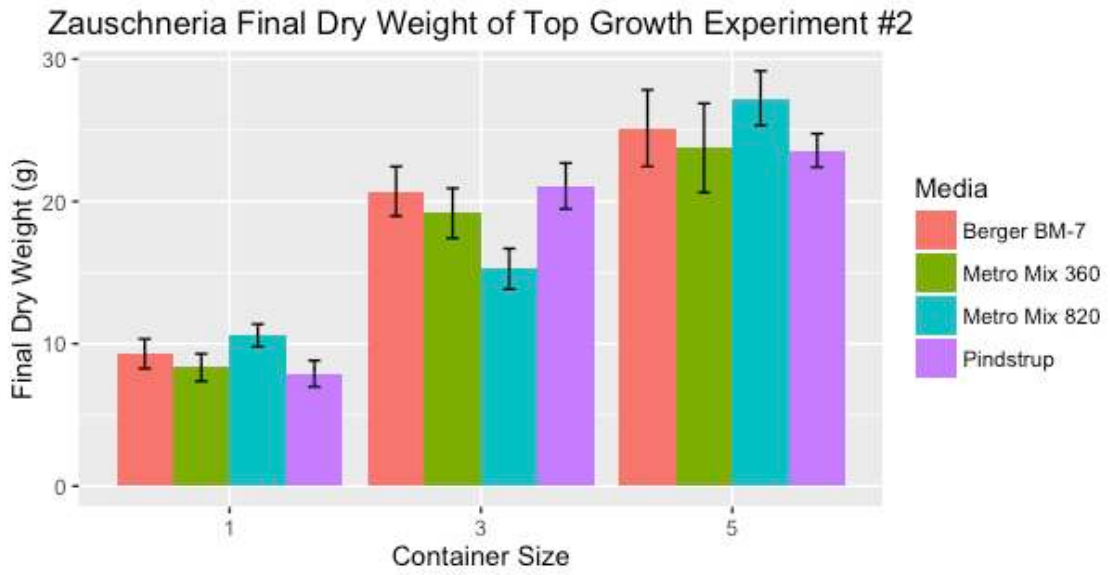

Figure 3.2.24 Experiment #2 mean final dry weight of plant top growth for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.2.2 Average Number of Cuttings per Plant

Number of harvested cuttings was averaged over the three harvest dates for analysis, but also separated by harvest date for additional analyses. The results of the first experiment show significant effects of both media and size treatments when averaging over harvest date, though the interaction was not significant (Figures 3.2.25 and 3.2.26). When averaged over container size, Metro Mix 820 and Pindstrup treatments differed significantly with Pindstrup having the highest mean response and Metro Mix 820 having the lowest (Table 3.2.13). Pairwise comparisons revealed only one other significant difference which was between Pindstrup and Berger BM7. When examining the main effects of container size averaged over media type, #1 (2.84L) containers produced significantly fewer cuttings per plant than the larger containers. There was no significant difference between #3 (11.35L) and #5 (14.55L) container sizes.

When examining data for each harvest separately, results of the first harvest showed a significant main effect of both media and container size (Figure 3.2.27), although pairwise comparisons of media were not significant due to a Tukey adjustment for multiple testing.

As can be seen from Figure 3.2.28, stock plants in the larger container sizes produced more cuttings per plant than the #1 (2.84L) containers, although there was no significant difference between #3 (11.35L) and #5 (14.55L) containers (Table 3.2.14). The second harvest of cuttings demonstrated a significant main effect of both media and container size with differences in media being more dramatic in the larger container sizes (Figures 3.2.29 and 3.2.30). When averaged over container size, stock plants grown in Pindstrup produced significantly more cuttings than the other three media treatments (Table 3.2.15) by more than 10 cuttings. When averaging over media treatment, stock plants grown in both #3 (11.35L) and #5 (14.55L) containers produced significantly more cuttings than the #1 (2.84L) containers, but remained very similar to each other. The third harvest produced similar results with significant main effects of both media and container size (Figures 3.2.31 and 3.2.32) although significant differences in media changed slightly. Stock plants grown in Pindstrup still produced the highest number of cuttings by more than 9 cuttings, which was significantly more than both Metro Mix 820 and Berger BM7 (Table 3.2.16).

The reason Pindstrup produced dramatically more cuttings than other media even though the plant size index was only slightly higher than other media may be a combination of characteristics that encouraged more supple growth. Initial pH of the first batch of Pindstrup was 6.1 and generally considered within the ideal range for most plants (Abad et al 2000), but decreased to 3.8 by the end of the experiment. Pindstrup also holds more water than any of the other media and maintains a higher water potential (Appendix I Figure A1.2). Since the number of cuttings produced by plants grown in Pindstrup was initially similar to other media, but the difference increased over time, it is possible that *Zauschneria garrettii* prefers a lower pH soil,

and or a higher moisture content. Because many *Epilobium* species are native to wet sites or peaty grasslands (Raven 1974), it is possible that a high peat content substrate with a low pH and high water content may encourage softer tissue growth in this species.

```
Anova Table (Type III tests)

Response: AVGCut
            Sum Sq  Df  F value    Pr(>F)
(Intercept) 109063   1 585.4509 < 2.2e-16 ***
Size          8931   2  23.9696 2.428e-09 ***
Media         3425   3   6.1287 0.0006883 ***
Size:Media     693   6   0.6204 0.7136159
Residuals    20119 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.25 Experiment #1 two-way ANOVA table of mean cuttings per plant averaged over harvest date.

Table 3.2.13 Experiment #1 mean cuttings per plant averaged over harvest date for each media averaged over container size and each size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	25.65	20.71-30.58	1
Metro Mix 360	31.01	26.07-35.95	1, 2
Metro Mix 820	25.39	20.45-30.33	1
Pindstrup	38.54	33.60-43.48	2
#1 Container	18.05	13.78-22.33	1
#3 Container	34.83	30.55-39.10	2
#5 Container	37.57	33.29-41.84	2

Figure 3.2.26 Experiment #1 bar plot of mean cuttings per plant averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: Cuttings1
            Sum Sq  Df  F value    Pr(>F)
(Intercept)  58742   1 549.3365 < 2.2e-16 ***
Size          3698   2  17.2906 3.059e-07 ***
Media          898   3   2.8002   0.04346 *
Size:Media     652   6   1.0167   0.41843
Residuals    11549 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.27 Experiment #1 two-way ANOVA table of mean cuttings per plant during harvest #1.

Table 3.2.14 Experiment #1 mean cuttings per plant during harvest #1for each media averaged over container size and each size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	19.80	16.06-23.54	1
Metro Mix 360	24.07	20.32-27.81	1
Metro Mix 820	19.10	15.36-22.84	1
Pindstrup	25.53	21.79-29.28	1
#1 Container	14.60	11.36-17.84	1
#3 Container	23.95	20.71-27.19	2
#5 Container	27.83	24.58-31.07	2

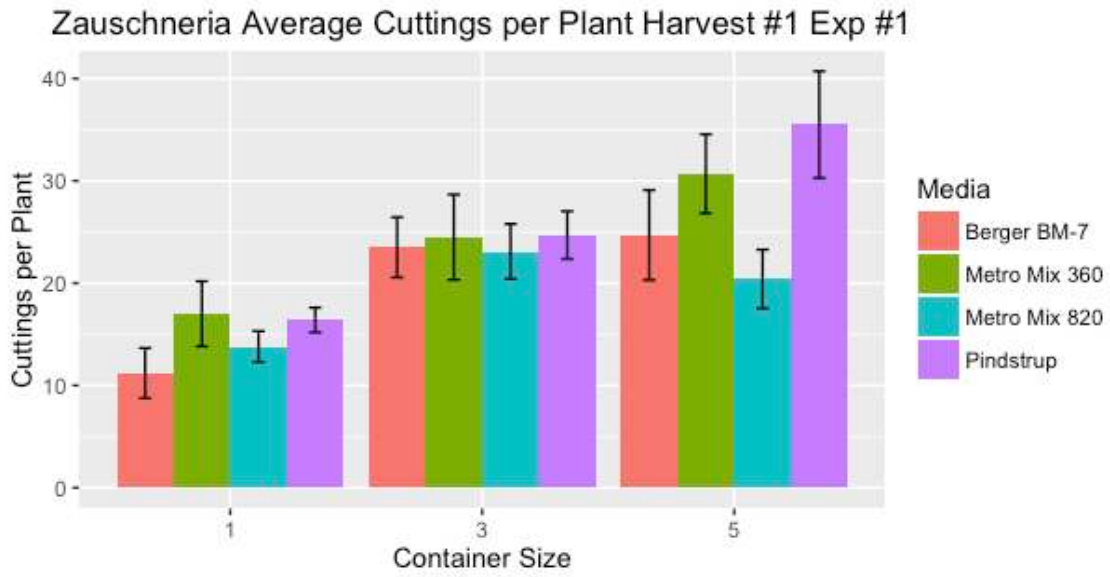

Figure 3.2.28 Experiment #1 bar plot of mean cuttings per plant during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: Cuttings2
             Sum Sq  Df  F value    Pr(>F)
(Intercept)  49573   1 336.2400 < 2.2e-16 ***
Size          4412   2  14.9643 1.835e-06 ***
Media         2990   3   6.7611 0.0003195 ***
Size:Media    1111   6   1.2557 0.2840744
Residuals    15923 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.29 Experiment #1 two-way ANOVA table of mean cuttings per plant during harvest #2.

Table 3.2.15 Experiment #1 mean cuttings per plant during harvest #2 for each media averaged over container size and each size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	17.67	13.27-22.06	1
Metro Mix 360	17.20	12.81-21.59	1
Metro Mix 820	17.47	13.07-21.86	1
Pindstrup	28.97	24.57-33.36	2
#1 Container	11.75	7.94-15.56	1
#3 Container	24.53	20.72-28.33	2
#5 Container	24.70	20.89-28.51	2

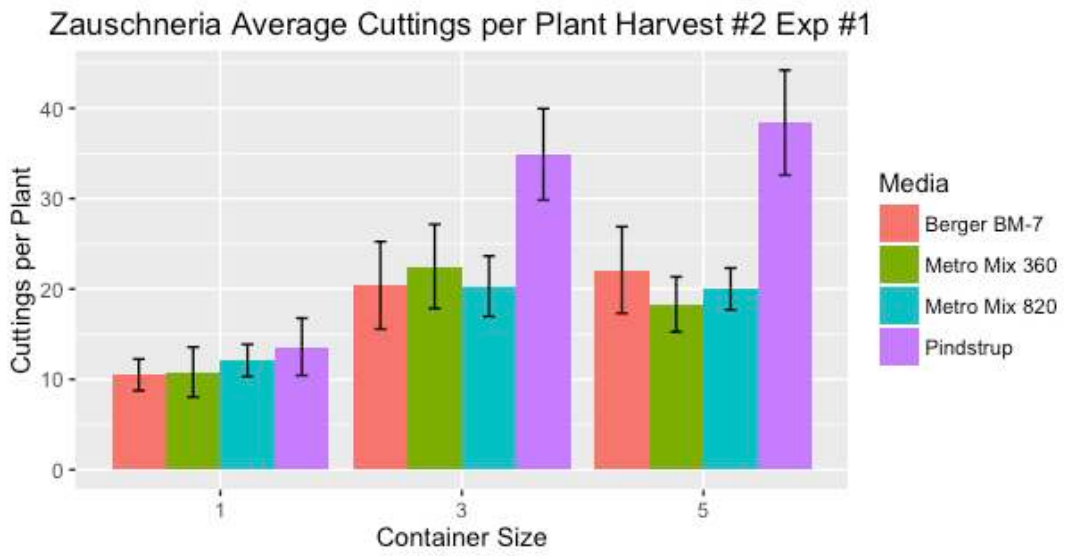

Figure 3.2.30 Experiment #1 bar plot of mean cuttings per plant during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: Cuttings3
             Sum Sq  Df  F value    Pr(>F)
(Intercept) 276384   1 441.8119 < 2.2e-16 ***
Size         24811   2  19.8306 4.619e-08 ***
Media         9901   3   5.2760  0.001961 **
Size:Media    1219   6   0.3248  0.922705
Residuals    67562 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.31 Experiment #1 two-way ANOVA table of mean cuttings per plant during harvest #3.

Table 3.2.16 Experiment #1 mean cuttings per plant during harvest #3 for each media averaged over container size and each size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	39.47	30.42-48.52	1
Metro Mix 360	51.77	42.72-60.82	1, 2
Metro Mix 820	39.60	30.55-48.65	1
Pindstrup	61.13	52.08-70.18	2
#1 Container	27.80	19.96-35.64	1
#3 Container	56.00	48.16-63.84	2
#5 Container	60.18	52.34-68.01	2

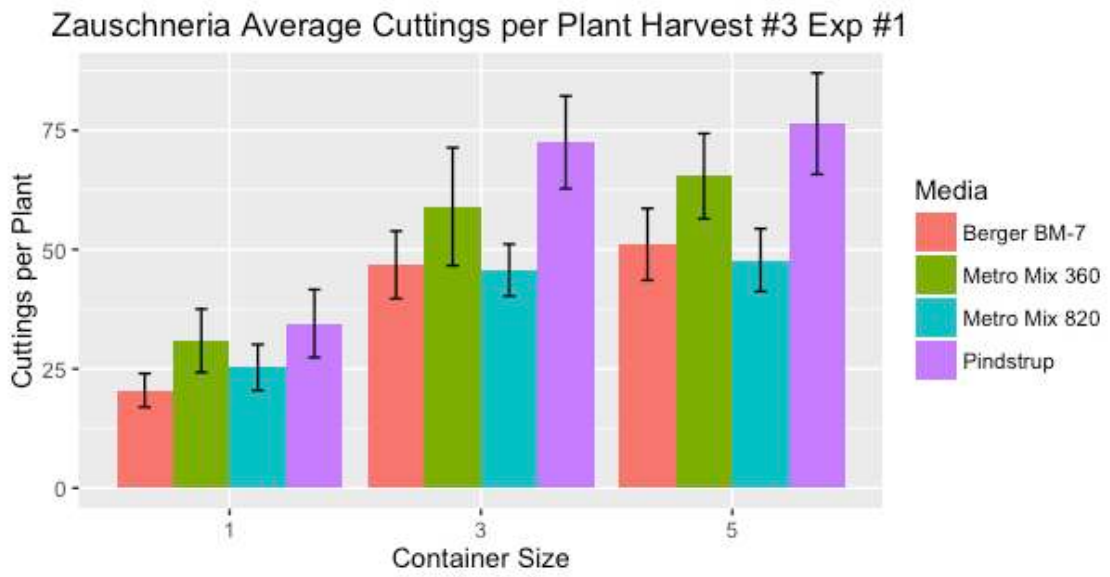

Figure 3.2.32 Experiment #1 bar plot of mean cuttings per plant during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

The results of the second experiment showed slightly different trends. For data that was averaged over harvest date, only the main effect of container size was significant, while media and size*media interaction were not (Figures 3.2.33 and 3.2.34). The highest average number of cuttings per plant was achieved in #5 (14.55L) containers, while the lowest was from stock plants grown in #1 (2.84L) containers (Table 3.2.17). Stock plants grown in #1 (2.84L) containers produced significantly fewer cuttings per plant than either of the larger container size treatments.

When data were analyzed for each harvest separately, ANOVA testing showed results of the first harvest followed the same trends as the averaged data, so these figures are presented in Appendix III (Figures A3.2.1-A3.2.2, Table A3.2.1). The second harvest of cuttings produced a significant main effect of container size, just as the averaged data, but all pairwise comparisons were significantly different by this time point (Figures 3.2.35 and 3.2.36) with #1 (2.84L) containers producing the fewest cuttings and #5 (14.55L) containers producing the most cuttings

per plant (Table 3.2.18). Results of the third harvest follow the same trends as the second harvest and are presented in Appendix III (Figures A3.2.3 and A3.2.4, Table A3.2.2).

Based on previous studies of container size and root restriction, the results of the present study are likely typical for most plant species. Although few studies have been done that examine number of cuttings produced by herbaceous perennial stock plants, Van Iersel (1997) noted more lateral branching on *Salvia splendens* grown in larger container sizes which would likely contribute to more acceptable cuttings. Tonutti and Giulivo (1990) also reported less vegetative shoot growth of kiwi plants grown under root restricted conditions which could also contribute to the production of more vegetative cuttings. As was seen in the size index measurements for Experiment #2, the effect of container size was initially subtle and became more pronounced with time. Unlike the first experiment, *Zauschneria* plants in the second experiment developed a more dramatic difference between the two larger container sizes, indicating that plants in the #3 (11.35L) containers had begun to suffer from root restriction by the second harvest.

```
Anova Table (Type III tests)

Response: AVGCut
            Sum Sq  Df   F value    Pr(>F)
(Intercept) 219080   1 1366.9472 < 2.2e-16 ***
Size          9473   2   29.5522  6.31e-11 ***
Media          622   3    1.2931    0.2807
Size:Media     983   6    1.0228    0.4146
Residuals    16989 106
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.33 Experiment #2 two-way ANOVA table for mean cuttings per plant averaged over harvest date.

Table 3.2.17 Experiment #2 mean cuttings per plant averaged over harvest date for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Cuttings per Plant	95% Confidence Interval	Significance Group
#1 (2.84L)	30.95	26.87-35.02	1
#3 (11.35L)	45.86	41.89-49.83	2
#5 (14.55L)	52.56	48.59-56.53	2

Figure 3.2.34 Experiment #2 mean cuttings per plant averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: Cuttings2
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 328677   1 1219.8494 < 2.2e-16 ***
Size         13919   2   25.8297 7.279e-10 ***
Media          995   3    1.2312    0.3021
Size:Media    1801   6    1.1139    0.3592
Residuals    28561 106
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.37 Experiment #2 two-way ANOVA table for mean cuttings per plant during harvest #2.

Table 3.2.18 Experiment #2 mean number of cuttings per plant during harvest #2 for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Cuttings per Plant	95% Confidence Interval	Significance Group
#1 (2.84L)	38.30	33.02-43.59	1
#3 (11.35L)	55.43	50.28-60.57	2
#5 (14.55L)	64.73	59.58-69.87	3

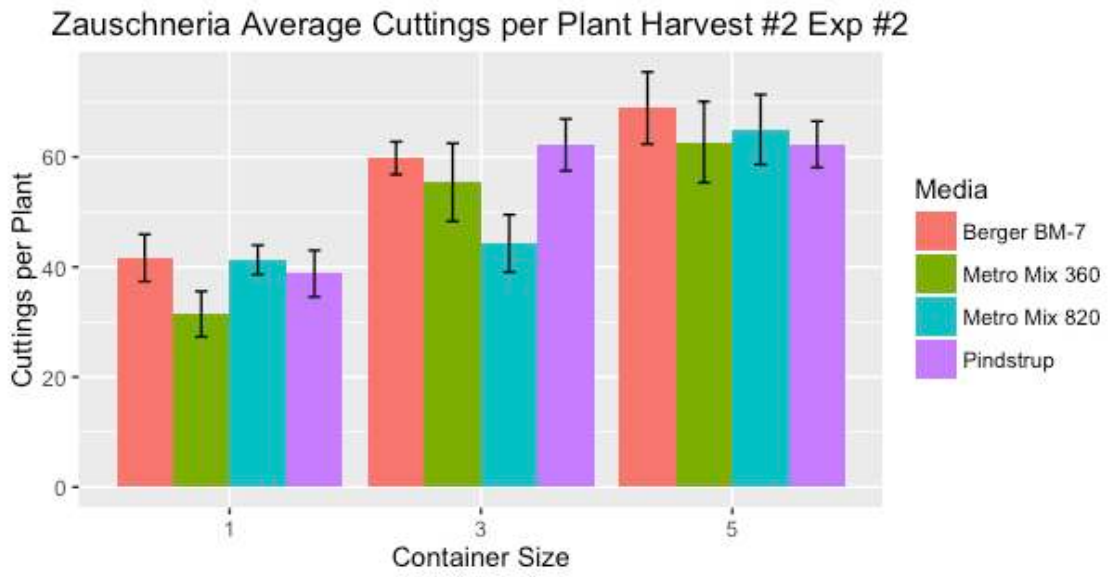

Figure 3.2.38 Experiment #2 mean number of cuttings per plant during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.2.3 Average Number of Cuttings per Square Foot

Cuttings per square foot were calculated by dividing the average number of cuttings per plant by the area occupied by each container size allowing adequate space for growth. For this experiment, each plant was given six inches (15.24cm) of space between containers to allow for air circulation and canopy expansion. Based on this measurement, #1 (2.84L) containers occupied 1.0 ft^2 while #3 (11.35L) and #5 (14.55L) containers occupied 2.25 ft^2 because the containers were the same width. Analysis of cuttings per square foot was based on this spacing with the intention of discerning the value of using larger containers for stock plants.

Results of the first experiment showed a significant main effect of media, although no significant effect of size or interaction between size and media (Figures 3.2.39 and 3.2.40). Under the conditions of the first experiment, the larger containers produced enough more cuttings per plant to account for the bench space they occupied. The media treatment that resulted in the highest number of cuttings per square foot was Pindstrup, while the lowest response was from Berger BM7 (Table 3.2.19). Pairwise comparisons showed that Pindstrup resulted in significantly more cuttings per square foot than both BM7 and Metro Mix 820.

Stock plants grown in Pindstrup produced more cuttings per square foot likely for the same reasons those plants produced the most cuttings per plant. As suggested previously, the pH and water retention capabilities of Pindstrup may have been more ideal for this taxon based on its relatives in the *Epilobium* genus that are native to wet sites or peaty grasslands (Raven 1974).

```
Anova Table (Type III tests)

Response: CPSF
            Sum Sq  Df  F value  Pr(>F)
(Intercept)  33635   1 580.4960 < 2e-16 ***
Size           132   2   1.1425 0.32284
Media          970   3   5.5785 0.00135 **
Size:Media      93   6   0.2671 0.95114
Residuals     6258 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.39 Experiment #1 two-way ANOVA table for averaged cuttings per square foot averaged over harvest date.

Table 3.2.19 Experiment #1 mean cuttings per square foot averaged over harvest date for each media treatment averaged over container size and each size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Cuttings Per Square Foot	95% Confidence Interval	Significance Group
Berger BM-7	14.00	11.25-16.76	1
Metro Mix 360	17.41	14.65-20.16	1, 2
Metro Mix 820	14.44	11.69-17.20	1
Pindstrup	21.11	18.36-23.87	2
#1 Container	18.05	15.66-20.44	1
#3 Container	15.48	13.09-17.86	1
#5 Container	16.70	14.31-19.08	1

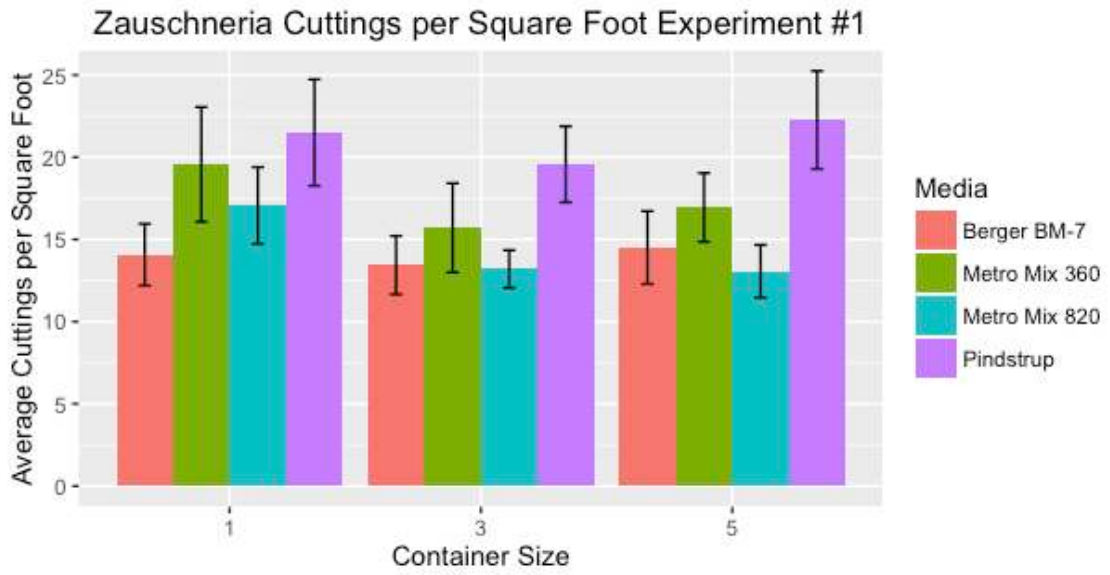

Figure 3.2.40 Experiment #1 bar plot of mean cuttings per square foot averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

In contrast to Experiment #1, the second experiment showed a significant main effect of size, but not media or the interaction of size*media (Figures 3.2.41 and 3.2.42). Pairwise comparisons averaged over media treatment revealed that cuttings per square foot differed significantly between #1 (2.84L) and #3 (11.35L) containers as well as #1 (2.84L) and #5 (14.55L) containers with plants grown in #1 (2.84L) containers producing the most cuttings per

square foot and plants grown in #3 (11.35L) containers producing the fewest (Table 3.2.20). Cuttings per square foot were not significantly different between #3 (11.35L) and #5 (14.55L) containers.

Although the larger containers did not produce enough cuttings per square foot to justify the bench space they occupied, it can be noted that when compared to Experiment #1, all treatments resulted in more cuttings. During Experiment #2, stock plants grown in the #1 (2.84L) containers produced on average 12.9 more cuttings per square foot than Experiment #1, while the larger container sizes saw a much smaller increase which is what caused a more dramatic effect of container size for this parameter. Based on research of *Epilobium angustifolium* by Myerscough and Whitehead (1966), it seems likely that lower greenhouse temperatures may have influenced productivity of stock plants grown in the smaller container sizes more than those in the larger containers.

```
Anova Table (Type III tests)

Response: CPSF
            Sum Sq  Df   F value    Pr(>F)
(Intercept)  73024   1 1334.5740 < 2.2e-16 ***
Size          2296   2   20.9820 2.104e-08 ***
Media          176   3    1.0736    0.3636
Size:Media     252   6    0.7662    0.5981
Residuals     5800 106
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.41 Experiment #2 two-way ANOVA table for mean cuttings per square foot averaged over harvest date.

Table 3.2.20 Experiment #2 mean number of cuttings per square foot averaged over harvest date for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Cuttings per Square Foot	95% Confidence Interval	Significance Group
#1 (2.84L)	30.95	28.57-33.33	1
#3 (11.35L)	20.38	18.06-22.70	2
#5 (14.55L)	23.36	21.04-25.68	2

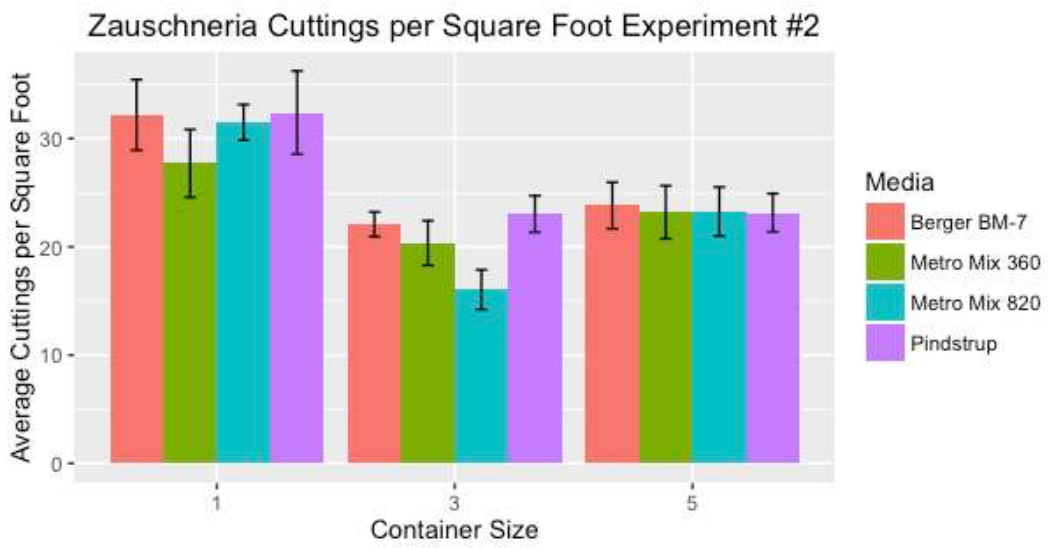

Figure 3.2.42 Experiment #2 bar plot of mean number of cuttings per square foot averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.2.4 Average Fresh Weight per Cutting

Average fresh weights per cutting were calculated by dividing the total fresh weight of cuttings by the total number of cuttings harvested for each plant averaged over the three harvest dates as well as separately for each harvest date. *Zauschneria* cuttings are quite small, and while all the mean responses from Experiment #1 averaged over harvest date were between 0.125 and 0.153 grams/cutting, even very small differences can be practically significant when it comes to the quality of a cutting and how well it will root. Results from Experiment #1 revealed that main effects of media were not significant when averaging over harvest date, nor was the interaction

of size*media. As can be seen from looking at Figure 3.2.44, larger containers resulted in higher average fresh weights per cutting and the effect of container size was statistically significant (Figure 3.2.43). When averaging over media type, stock plants grown in #1 (2.84L) containers produced the smallest cuttings and pairwise comparisons revealed they were significantly smaller than those produced from #3 (11.35L) and #5 (14.55L) containers (Table 3.2.21). There was no significant difference between #3 (11.35L) and #5 (14.55L) containers.

Because the first and second harvests showed no significant effect of treatment on average fresh weight per cutting, these analyses are presented in Appendix III (Figures A3.2.5-A3.2.8, Tables A3.2.3-A3.2.4). By the third harvest, a significant effect of container size developed (Figures 3.2.45 and 3.2.46), with #1 (2.84L) containers producing significantly smaller cuttings than the larger container sizes (Table 3.2.22). While #5 (14.55L) containers produced larger cuttings than #3 (11.35L) containers, these means were not significantly different. It can also be noted that all fresh weights increased over the course of the experiment regardless of treatment.

These results generally agree with root restriction research by Xie et al (2013) who found that grapes grown under root restricted conditions experienced a decrease in leaf expansion and shoot growth. Similar results were found by Bouzo and Favaro (2015), who reported tomato plants grown in larger containers produced more and larger leaves. While leaf area measurements were not taken during the present study, it was observed that larger cuttings often had thicker stems as well as larger and thicker leaves which would all contribute to larger fresh weights.

```
Anova Table (Type III tests)

Response: AVGFresh
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 2.35732   1 5805.4332 < 2.2e-16 ***
Size        0.00489   2    6.0201  0.003321 **
Media       0.00220   3    1.8043  0.150717
Size:Media  0.00043   6    0.1770  0.982568
Residuals   0.04385 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.43 Experiment #1 two-way ANOVA table for mean fresh weight per cutting averaged over harvest date.

Table 3.2.21 Experiment #1 mean fresh weight per cutting averaged over harvest date for each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Fresh Weight per Cutting	95% Confidence Interval	Significance Group
#1 (2.84L)	0.131	0.125-0.138	1
#3 (11.35L)	0.143	0.137-0.150	2
#5 (14.55)	0.146	0.140-0.152	2

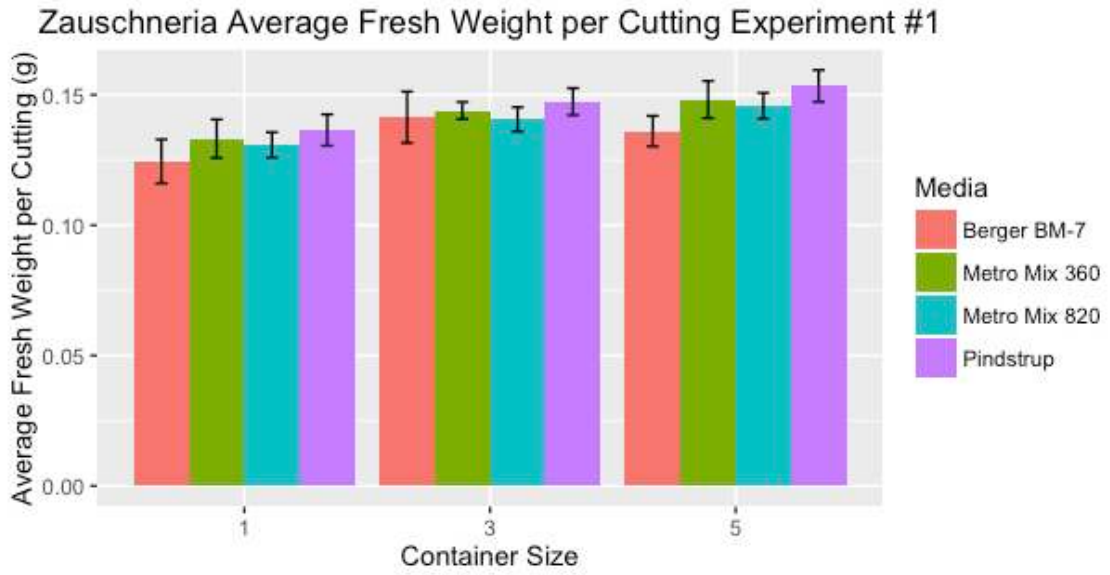

Figure 3.2.44 Experiment #1 bar plot of mean fresh weight per cutting averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh3
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 3.08385   1 4553.5340 < 2.2e-16 ***
Size        0.01321   2    9.7540 0.0001276 ***
Media       0.00479   3    2.3563 0.0758732 .
Size:Media  0.00319   6    0.7841 0.5841882
Residuals   0.07314 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.45 Experiment #1 two-way ANOVA table for mean fresh weight per cutting during harvest #3.

Table 3.2.22 Experiment #1 mean fresh weight per cutting during harvest #3 for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Fresh Weight per Cutting	95% Confidence Interval	Significance Group
#1 (2.84L)	0.146	0.138-0.154	1
#3 (11.35L)	0.165	0.157-0.173	2
#5 (14.55L)	0.170	0.162-0.178	2

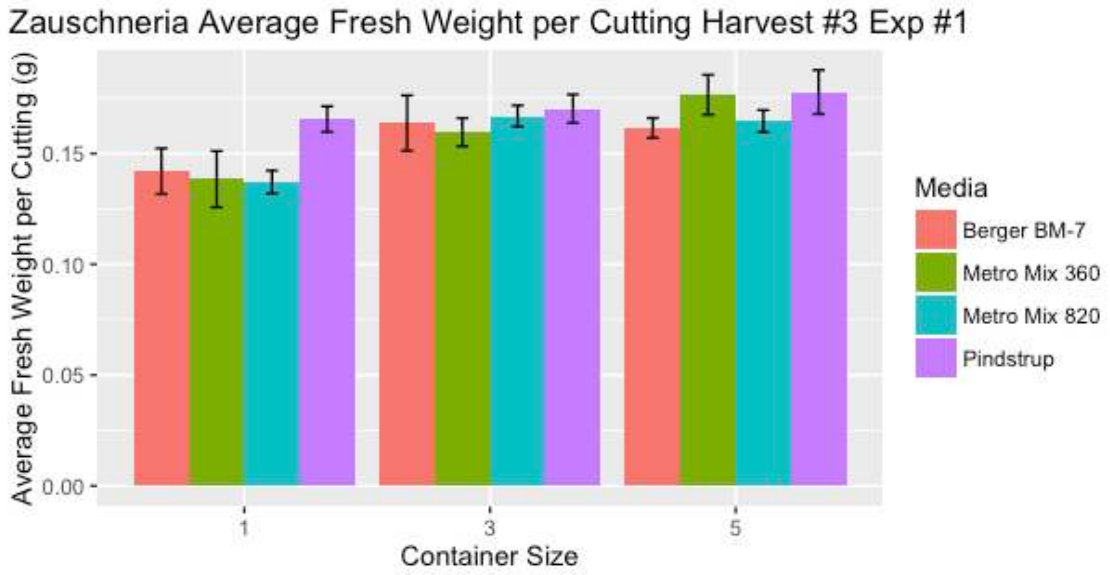

Figure 3.2.46 Experiment #1 bar plot of mean fresh weight per cutting during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

When data were averaged over harvest date, results of Experiment #2 showed no significant main effect of container size, nor was there a significant interaction between size and media. However, when averaging over container size, the main effect of media type was significant (Figures 3.2.47 and 3.2.48). Average fresh weights per cutting produced by stock plants grown in Pindstrup were the highest and significantly different than those from Metro mix 360 which were the lowest (Table 3.2.23).

When data were analyzed separately for each harvest date, the only significant differences were during harvest #2. Data for the first and third harvest dates are presented in Appendix III (Figures A3.2.9-A3.2.12, Tables A3.2.5-A3.2.6). During harvest #2, there was a significant main effect of both media and container size, though not the interaction of size and media (Figures 3.2.49 and 3.2.50). When averaging over container size, Pindstrup produced significantly larger cuttings than the other three treatment substrates (Table 3.2.24), though no other pairwise comparisons were significant. When averaging over media, #5 (14.55L) containers produced significantly larger cuttings than #1 (2.84L) containers, and there were no other significant pairwise comparisons.

Although there was very little difference in average fresh weight per cutting by the final harvest date, it is worth mentioning that all cuttings had increased in size over the course of the experiment. During the first harvest, all average fresh weights were between 0.100g and 0.150g regardless of treatment, but by the third harvest all average fresh weights were between 0.150g and 0.200g which indicates a marked increase in cutting quality across all treatments.

Based on these results, it seems that while the Pindstrup substrate may have encouraged the formation of larger stem and leaf tissues by the second harvest, stock plants grown in the other treatments "caught up" by the third harvest. This may be partially due to seasonality as the

sunlight became less intense and the greenhouse stayed on the cooler side of the programmed range, which was lower during the second experiment. Because *Epilobium angustifolium* is influenced by temperature and light intensity more than photoperiod (Myerscough and Whitehead 1966), it seems likely that the lower temperatures encouraged the production of larger cuttings on all plants regardless of treatment.

```
Anova Table (Type III tests)

Response: AVGFresh
             Sum Sq  Df    F value    Pr(>F)
(Intercept) 3.04228   1 18871.7423 < 2.2e-16 ***
Size        0.00072   2     2.2300  0.112601
Media       0.00208   3     4.2953  0.006692 **
Size:Media  0.00138   6     1.4288  0.210530
Residuals   0.01693 105
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.47 Experiment #2 two-way ANOVA for mean fresh weight per cutting averaged over harvest date.

Table 3.2.23 Experiment #2 mean fresh weight per cutting averaged over harvest date for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of $P<0.05$.

Media	Mean Fresh Weight per Cutting	95% Confidence Interval	Significance Group
Berger BM-7	0.164	0.159-0.168	1, 2
Metro Mix 360	0.156	0.151-0.161	1
Metro Mix 820	0.162	0.157-0.167	1, 2
Pindstrup	0.168	0.163-0.173	2

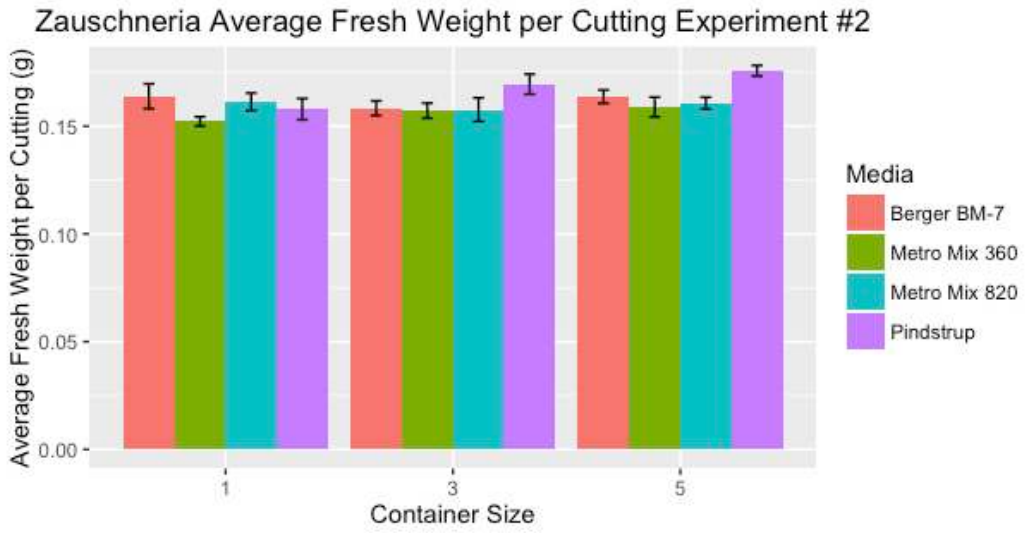

Figure 3.2.48 Experiment #2 bar plot of mean fresh weight per cutting averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh2
             Sum Sq  Df    F value    Pr(>F)
(Intercept) 3.9793   1 12860.5889 < 2.2e-16 ***
Size        0.0034   2     5.4527  0.005572 **
Media       0.0074   3     7.9232  8.11e-05 ***
Size:Media  0.0035   6     1.8936  0.088564 .
Residuals   0.0328 106
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.49 Experiment #2 two-way ANOVA table for mean fresh weight per cutting during harvest #2.

Table 3.2.24 Experiment #2 mean fresh weight per cutting during harvest #2 for each media averaged over container size and each size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Fresh Weight per Cutting	95% Confidence Interval	Significance Group
Berger BM-7	0.183	0.177-0.190	1
Metro Mix 360	0.176	0.169-0.182	1
Metro Mix 820	0.180	0.173-0.186	1
Pindstrup	0.197	0.190-0.203	2
#1 Container	0.177	0.172-0.183	1
#3 Container	0.184	0.178-0.189	1, 2
#5 Container	0.190	0.185-0.196	2

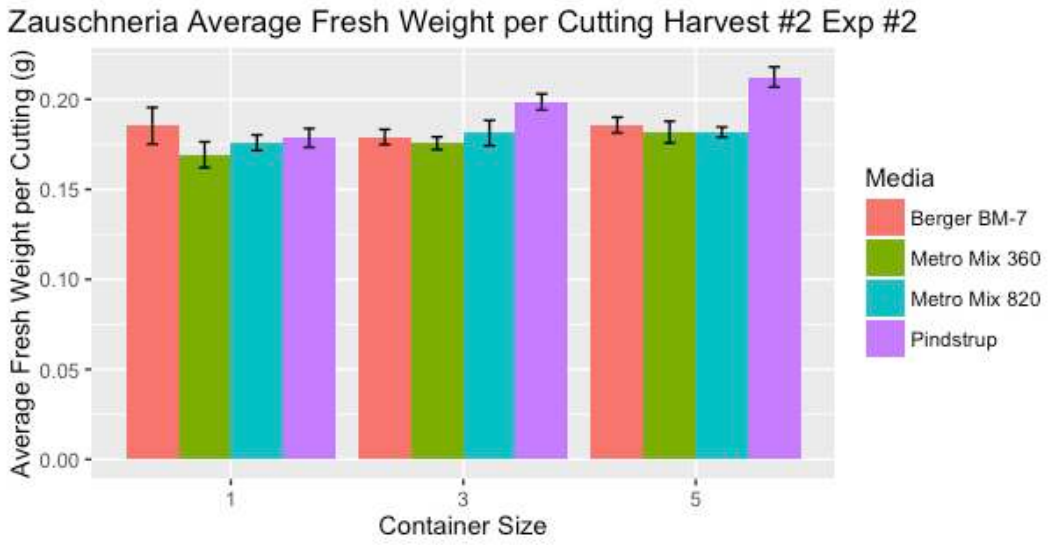

Figure 3.2.50 Experiment #2 bar plot of mean fresh weight per cutting during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.2.5 Average Dry Weight per Cutting

Average dry weights per cutting were calculated by dividing the total dry weight of cuttings by the total number of cuttings harvested for each plant during each harvest date and averaged over the three harvest dates. Results of Experiment #1 showed no significant interaction between size and media, although main effects of both size and media were statistically significant when data were averaged over harvest date (Figures 3.2.51 and 3.2.52). When averaged over container size, Pindstrup produced the largest cuttings which were significantly higher than those produced by Berger BM7, which were the smallest (Table 3.2.25). No other pairwise comparisons of media were significant at the level of $P<0.05$. When averaging over media type, larger container sizes resulted in larger cuttings with #1 (2.84L) containers producing significantly smaller cuttings than either #3 (11.35L) or #5 (14.55L) containers.

When examining data for each harvest date separately, effect of media treatment was only significant during harvest #1 (Figures 3.2.53 and 3.2.54). For the first harvest date, and when averaging over container size, Pindstrup produced significantly larger dry weights per cutting than Metro Mix 360, and no other pairwise comparisons were significant (Table 3.2.26). When averaging over media treatment, #1 (2.84L) containers produced significantly smaller cuttings than both #3 (11.35L) and #5 (14.55L) containers. Cuttings from #3 (11.35L) and #5 (14.55L) containers were not significantly different from one another. At this time point, the largest difference between means was only 0.005g and it is difficult to determine without further research if these small differences in dry weights are of practical importance when rooting cuttings.

The second harvest showed only a significant main effect of container size (Figures 3.2.55 and 3.2.56), with #1 (2.84L) containers producing significantly smaller cuttings than both #3 (11.35L) and #5 (14.55L) containers (Table 3.2.27). The pairwise comparison of #3 (11.35L) and #5 (14.55L) containers was not significant. Just as with the first and second harvests, effect of container size and significant differences continued during harvest #3 (Figures 3.2.57 and 3.2.58), but the average dry weight per cutting increased across all treatment combinations compared to earlier harvests (Table 3.2.28).

Since the results align fairly closely with analyses of fresh weights, it is probable that it can be explained by the same research done on grapes by Xie et al (2013) and on tomato plants by Bouzo and Favaro (2015).

```
Anova Table (Type III tests)

Response: AVGDry
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 0.136620   1 6806.7357 < 2.2e-16 ***
Size        0.001017   2   25.3226  9.59e-10 ***
Media       0.000163   3    2.6997   0.04931 *
Size:Media  0.000052   6    0.4336   0.85504
Residuals   0.002168 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.51 Experiment #1 two-way ANOVA table for mean dry weight per cutting averaged over harvest date.

Table 3.2.25 Experiment #1 mean dry weight per cutting averaged over harvest date for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.033	0.031-0.034	1
Metro Mix 360	0.033	0.031-0.035	1, 2
Metro Mix 820	0.034	0.032-0.035	1, 2
Pindstrup	0.036	0.034-0.037	2
#1 Container	0.030	0.028-0.031	1
#3 Container	0.035	0.034-0.037	2
#5 Container	0.036	0.035-0.038	2

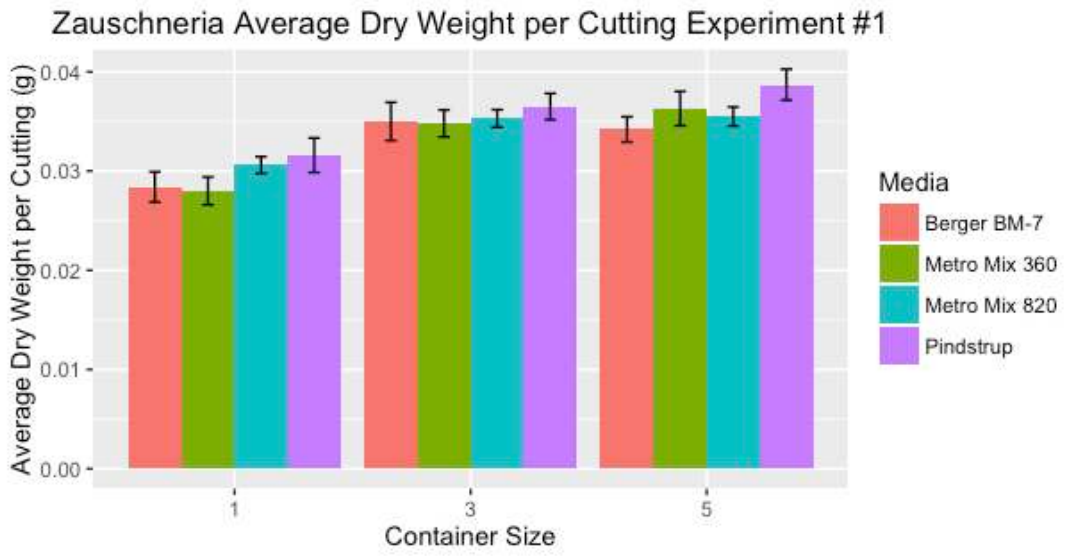

Figure 3.2.52 Experiment #1 bar plot of mean dry weight per cutting averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry1
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 0.072767   1 2737.9795 < 2.2e-16 ***
Size        0.000537   2   10.0943 9.572e-05 ***
Media       0.000273   3    3.4294   0.01969 *
Size:Media  0.000068   6    0.4255   0.86060
Residuals   0.002870 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.53 Experiment #1 two-way ANOVA table for mean dry weight per cutting during harvest #1.

Table 3.2.26 Experiment #1 mean dry weight per cutting during harvest #1 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.024	0.022-0.026	1, 2
Metro Mix 360	0.023	0.021-0.025	1
Metro Mix 820	0.024	0.022-0.026	1, 2
Pindstrup	0.027	0.025-0.029	2
#1 Container	0.022	0.020-0.023	1
#3 Container	0.025	0.024-0.027	2
#5 Container	0.027	0.025-0.028	2

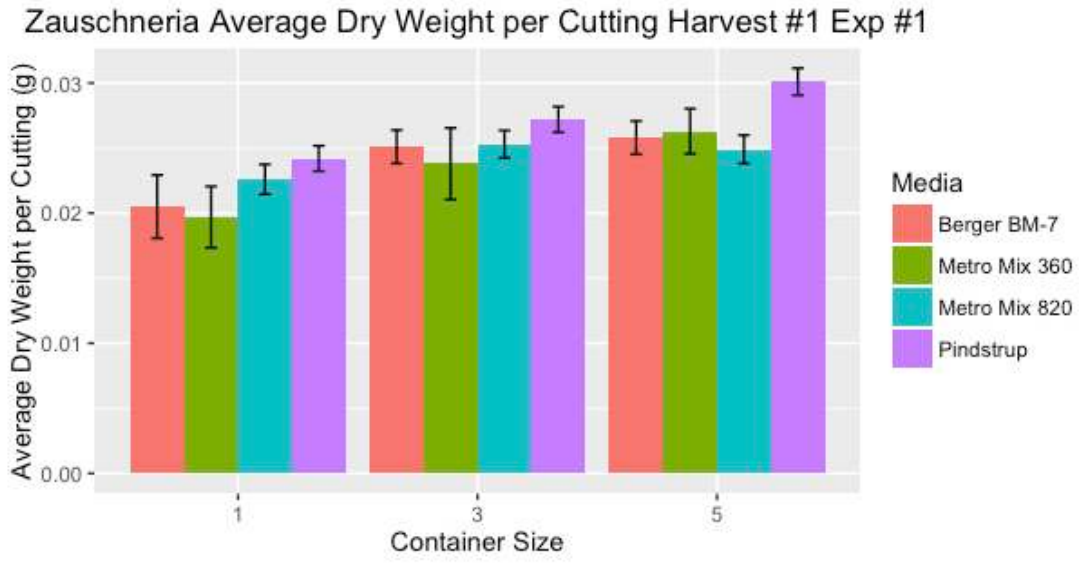

Figure 3.2.54 Experiment #1 mean dry weight per cutting during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry2
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 0.142141   1 3699.4433 < 2.2e-16 ***
Size        0.000868   2   11.2971 3.508e-05 ***
Media       0.000133   3    1.1570    0.3297
Size:Media  0.000094   6    0.4081    0.8723
Residuals   0.004150 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.55 Experiment #1 two-way ANOVA table for mean dry weight per cutting during harvest #2.

Table 3.2.27 Experiment #1 mean dry weight per cutting during harvest #2 for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Dry Weight per Cutting	95% Confidence Interval	Significance Group
#1 (2.84L)	0.031	0.029-0.033	1
#3 (11.35L)	0.037	0.035-0.039	2
#5 (14.55L)	0.036	0.034-0.038	2

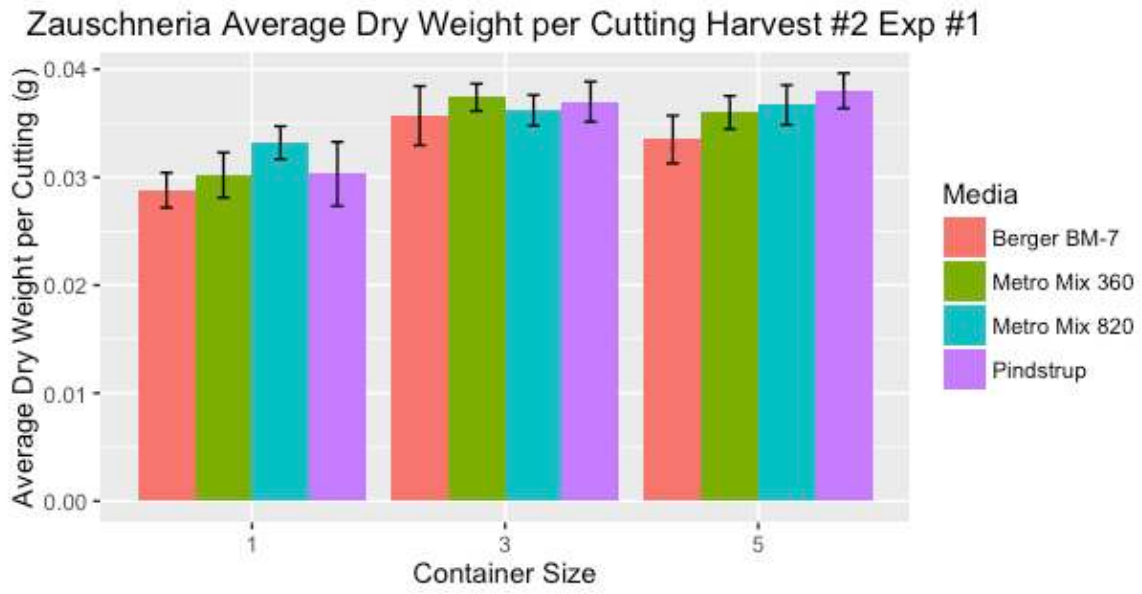

Figure 3.2.56 Experiment #1 bar plot of mean dry weight per cutting during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry3
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 0.214208   1 5497.4597 < 2.2e-16 ***
Size        0.001915   2   24.5786 1.595e-09 ***
Media       0.000214   3    1.8264    0.1467
Size:Media  0.000111   6    0.4765    0.8245
Residuals   0.004208 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.57 Experiment #1 two-way ANOVA for mean dry weight per cutting during harvest #3.

Table 3.2.28 Experiment #1 mean dry weight per cutting during harvest #3 for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Dry Weight per Cutting	95% Confidence Interval	Significance Group
#1 (2.84L)	0.037	0.035-0.039	1
#3 (11.35L)	0.044	0.042-0.046	2
#5 (14.55L)	0.046	0.044-0.048	2

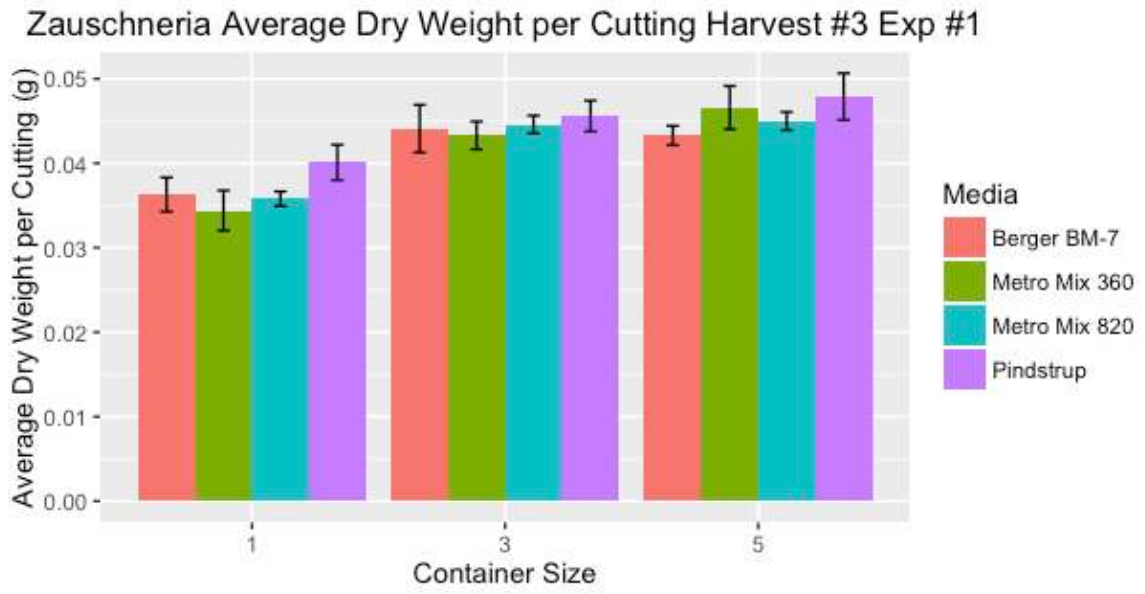

Figure 3.2.58 Experiment #1 bar plot of mean dry weight per cutting during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

The second experiment showed less of a trend when examining average dry weights per cutting. ANOVA testing revealed no significant effect of treatments when data were averaged over harvest date, so these figures are presented in Appendix III (Figures A3.2.13-A3.2.14, Table A3.2.7). When data were analyzed separately for each harvest date, there were no significant differences during harvest #1, so these figures are also presented in Appendix III (Figures A3.2.15-A3.2.16, Table A3.2.8). During the second harvest of cuttings, ANOVA testing showed a significant main effect of media (Figures 3.2.59 and 3.2.60) with Pindstrup resulting in significantly larger dry weights per cutting than Metro Mix 360. No other pairwise comparisons were significant and the largest difference between treatment means was only 0.005g (Table 3.2.29). Analysis of the third harvest demonstrated only a significant main effect of container size (Figures 3.2.61 and 3.2.62) with #5 (14.55L) containers producing significantly larger dry weights per cutting than #1 (2.84L) containers, although the difference was only 0.003g. Dry weights of cuttings from #3 (11.35L) containers were not significantly different from either #1 (2.84L) or #5 (14.55L) containers (Table 3.2.30). Although trends followed those of fresh weights from Experiment #1, such small differences in dry weights make it difficult to determine whether they are practically significant in terms of rooting without more in-depth investigation.

Despite small differences between treatment means during the second experiment, there was a notable difference between Experiment #1 and #2. The mean dry weight per cutting during Experiment #2 ranged from 0.04g to 0.05g when averaged over harvest date, as compared to 0.03g to 0.04g during Experiment #1. When data were analyzed separately, dry weights were also significantly larger during Experiment #2 regardless of harvest date, which demonstrates that changes in the environmental conditions may have improved the quality of cuttings from plants in all treatments.

```
Anova Table (Type III tests)

Response: AVGDry2
             Sum Sq  Df   F value  Pr(>F)
(Intercept) 0.308195   1 8493.0287 < 2e-16 ***
Size        0.000158   2    2.1754 0.11861
Media       0.000378   3    3.4713 0.01874 *
Size:Media  0.000374   6    1.7159 0.12429
Residuals   0.003847 106
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.59 Experiment #2 two-way ANOVA table for mean dry weight per cutting during harvest #2.

Table 3.2.29 Experiment #2 mean dry weight per cutting during harvest #2 for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Dry Weight per Cutting	95% Confidence Interval	Significance Group
Berger BM-7	0.051	0.048-0.052	1, 2
Metro Mix 360	0.049	0.047-0.051	1
Metro Mix 820	0.050	0.048-0.052	1, 2
Pindstrup	0.054	0.052-0.056	2

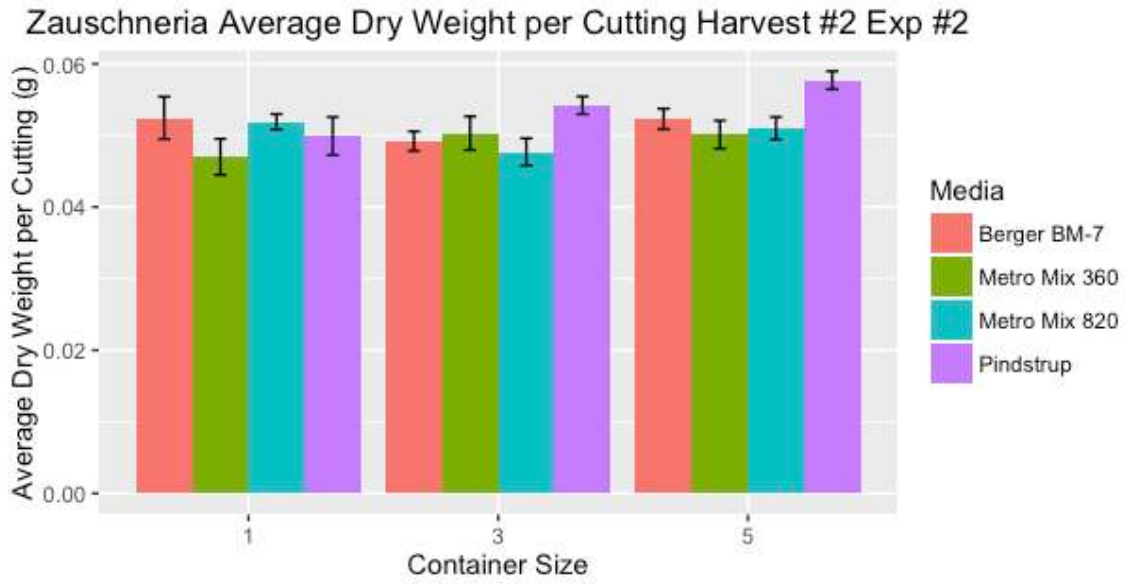

Figure 3.2.60 Experiment #2 bar plot of mean dry weight per cutting during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry3
             Sum Sq  Df    F value    Pr(>F)
(Intercept) 0.243725   1 17169.9083 < 2.2e-16 ***
Size        0.000195   2     6.8539  0.001588 **
Media       0.000011   3     0.2663  0.849573
Size:Media  0.000105   6     1.2356  0.294036
Residuals   0.001505 106
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 3.2.61 Experiment #2 two-way ANOVA table for mean dry weight per cutting during harvest #3.

Table 3.2.30 Experiment #2 mean dry weight per cutting during harvest #3 for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Dry Weight per Cutting	95% Confidence Interval	Significance Group
#1 (2.84L)	0.044	0.043-0.045	1
#3 (11.35L)	0.046	0.044-0.047	1, 2
#5 (14.55L)	0.047	0.046-0.048	2

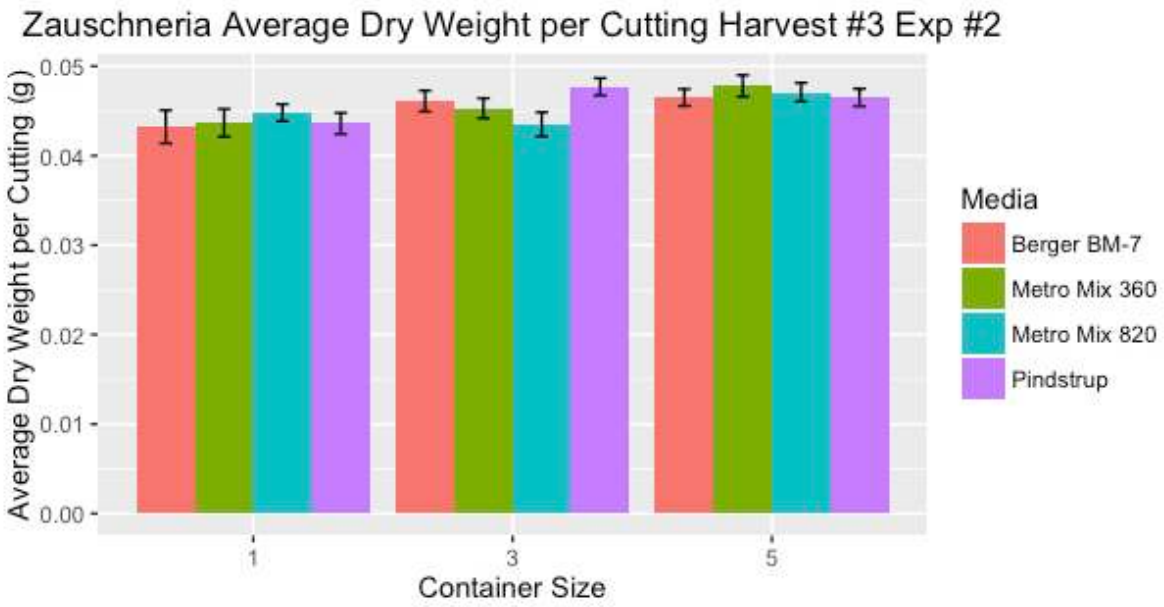

Figure 3.2.62 Experiment #2 bar plot of mean dry weight per cutting during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.2.6 Root Ratings

Root ratings from Experiment #1 showed a significant main effect of both media and container size, although not a significant interaction between the two (Figures 3.2.63 and 3.2.64). When averaged over container size, Pindstrup resulted in significantly higher root ratings than Metro Mix 820, but no other pairwise comparisons of media were significant (Table 3.2.31). When averaged over media treatment, #1 (2.84L) containers resulted in significantly lower root ratings than both larger container sizes, although #3 (11.35L) and #5 (14.55L) containers were very similar.

As has been suggested previously, based on research of its relatives in the *Epilobium* genus (Myerscough and Whitehead 1966) *Zauschneria* may be genetically predisposed to prefer a high peat content substrate with higher water retention capabilities. This could explain why stock plants had a more developed root system after being grown in Pindstrup, a substrate made entirely of sphagnum peat. Although stock plants seemed to excel in a medium that provides more moisture, lower root ratings in the #1 (2.84L) containers could be due to too much moisture because of poorer drainage. Bilderback and Fonteno (1987) reported that water drains progressively slower as it approaches the perched water table at the bottom of a container, making shallower containers more susceptible to saturated conditions which can inhibit root growth.

A second possible explanation for the lower root ratings in #1 (2.84L) containers would be their lower container capacity. Smaller containers will have a lower water holding capacity due to a lower substrate volume that results in less available water and nutrients, especially when plants are watered with the same amount of water regardless of container size as they were in this experiment (van Iersel 1997). Smaller containers will retain less water initially, dry out

faster and can indirectly predispose plants to drought (Poorter et al 2012b), which may explain why the #1 (2.84L) containers had much lower root ratings. What makes this explanation plausible is that stock plants grown in #1 (2.84L) containers with Pindstrup had much higher root ratings than the other media at that level of container size (Figure 3.2.64). This suggests that maybe the ability of Pindstrup to provide more water and nutrients to the stock plants allowed for the development of a more extensive root system.

```
Anova Table (Type III tests)

Response: RootRate
             Sum Sq Df  F value    Pr(>F)
(Intercept) 403.31  1 489.6849 < 2.2e-16 ***
Size         20.83  2  12.6428  2.01e-05 ***
Media         7.58  3   3.0672   0.03337 *
Size:Media    4.45  6   0.9002   0.49975
Residuals    58.48 71
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.63 Experiment #1 two-way ANOVA table for mean root rating after termination of the experiment.

Table 3.2.31 Experiment #1 mean root rating after termination of the experiment for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Root Rating	95% Confidence Interval	Significance Group
Berger BM-7	2.14	1.75-2.54	1, 2
Metro Mix 360	2.12	1.61-2.42	1, 2
Metro Mix 820	1.95	1.56-2.35	1
Pindstrup	2.71	2.32-3.11	2
#1 Container	1.50	1.16-1.84	1
#3 Container	2.58	2.23-2.93	2
#5 Container	2.54	2.19-2.88	2

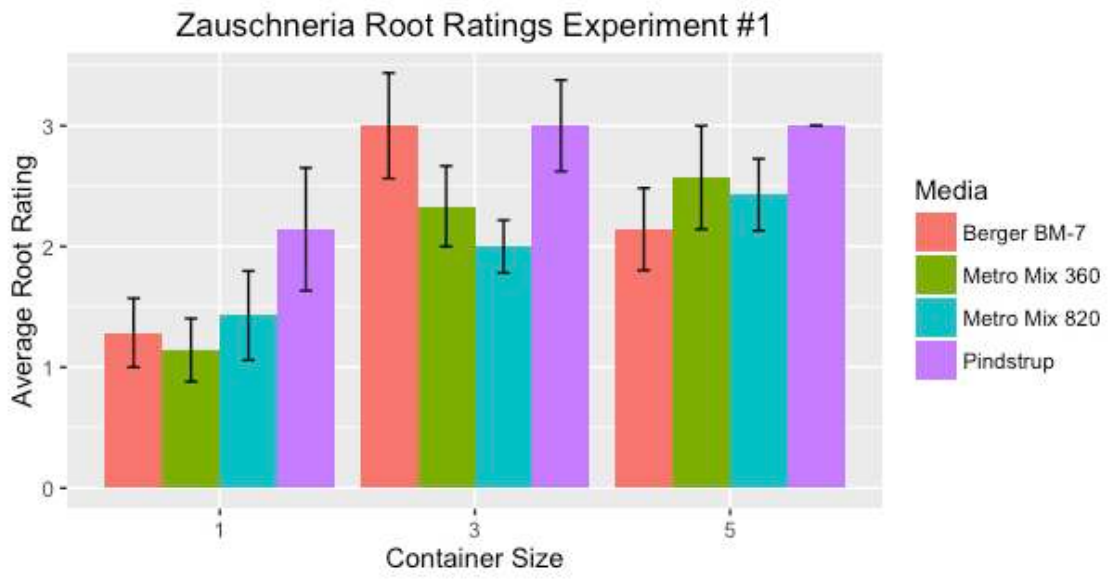

Figure 3.2.64 Experiment #1 bar plot of mean root rating after termination of the experiment for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Results of Experiment #2 showed a significant interaction between media and container size (Figures 3.2.65 and 3.2.66), although the only significant pairwise comparisons were within the #1 (2.84L) containers (Table 3.2.32). Within the #1 (2.84L) containers, Metro Mix 820 resulted in significantly higher root ratings than either Metro Mix 360 or Pindstrup, though no other pairwise comparisons were significant. It is difficult to identify a probable cause for the higher response to Metro Mix 820 in the #1 (2.84L) containers because it does not align with measurements of plant size index or final dry weight of top growth. This indicates a higher root:shoot ratio than the other treatment combinations which may be due to the lower water holding capacity of Metro Mix 820. Since this substrate holds dramatically less water (Appendix I Figure A1.2) than other substrates in this experiment, it is possible these plants were reacting to drought conditions caused by a smaller substrate volume paired with low water holding capacity of the media. Plants often increase their root:shoot ratio under drought stress by increasing the root metabolism and decreasing shoot metabolism as was found by Gargallo-Garriga et al

(2014). It is possible that the larger container sizes provided a large enough substrate volume to avoid drought even with Metro Mix 820 having a low water holding capacity.

```
Anova Table (Type III tests)

Response: RootRate
            Sum Sq Df  F value  Pr(>F)
(Intercept) 698.10  1 972.3161 < 2e-16 ***
Size          2.44  2   1.7025 0.18959
Media         4.67  3   2.1666 0.09952 .
Size:Media    9.90  6   2.2988 0.04382 *
Residuals    50.98 71
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.65 Experiment #2 two-way ANOVA table for mean root rating after termination of the experiment.

Table 3.2.32 Experiment #2 mean root rating for each media treatment within #1 (2.84L) containers. No significant differences were found in other container sizes. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Media	Mean Root Rating	95% Confidence Interval	Significance Group
#1 (2.84L) Container	Berger BM-7	2.93	2.29-3.57	1, 2
	Metro Mix 360	2.07	1.43-2.71	1
	Metro Mix 820	3.43	2.79-4.07	2
	Pindstrup	2.21	1.58-2.85	1

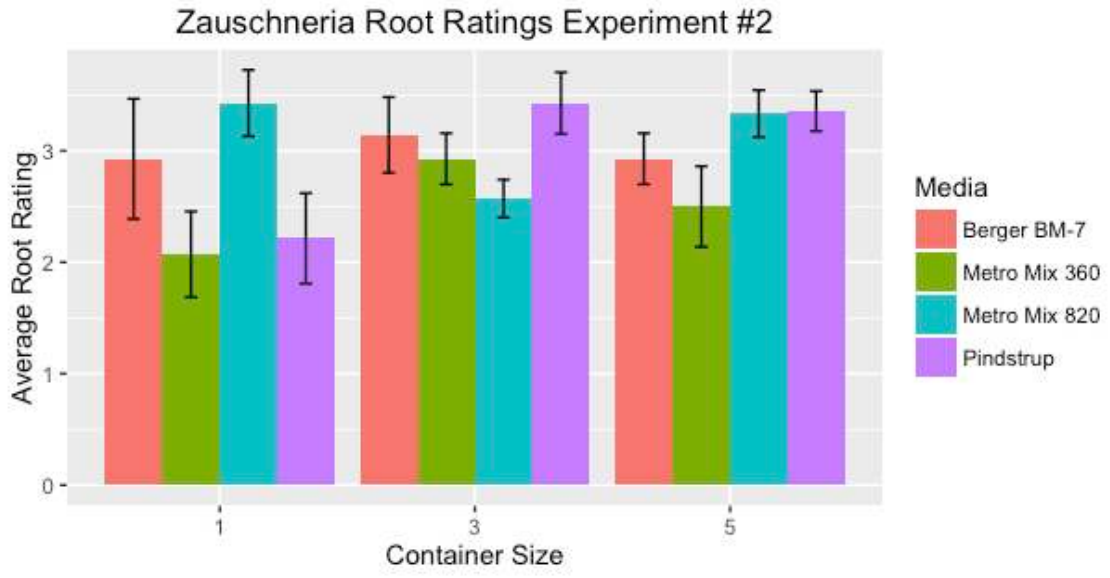

Figure 3.2.66 Experiment #2 bar plot of mean root rating after termination of the experiment for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

3.2.7 Differences Between Experiments 1 and 2

The results of the two experiments showed some differences between mean responses. The second experiment resulted in higher numbers of cuttings per plant and per square foot, as well as average fresh and dry weights per cutting, which may be due to cultural changes in the greenhouse such as lowering the temperature and the time of year the experiment was performed. Based on research on *Epilobium angustifolium* performed by Myerscough and Whitehead (1966), it is likely that *Zauschneria* is not under direct control of photoperiod, but is more sensitive to temperature and light intensity. Fewer cuttings may have been produced during the first experiment due to higher greenhouse temperatures and the higher light intensity during the summer months that encouraged the production of reproductive tissues that quickly become woody and don't root as well. Since the second experiment was performed in the fall and winter months, the sunlight would have been less intense and the temperature in the greenhouse was kept cooler. *Zauschneria garrettii* naturally flowers in mid to late summer when being grown in the field, so it is possible that lower temperatures and lower light intensity may help encourage more vegetative growth.

3.2.8 Rooting Experiment

During the first experiment, plug trays tended to dry out quickly because of ventilation in the propagation house. Numerous cuttings died during rooting due to desiccation, possibly skewing the data. Although there were significant losses during this experiment, some trends are detectable and statistically significant. Data and analysis is presented here, but should be interpreted with caution.

Rooting proportions were averaged over 3 harvests but analyzed after 1, 2, 3, and 4 weeks on the mist bench to examine the speed of rooting. Data was subjected to a Chi-Square

test to determine if there was an association between rooting status and treatment. Analysis showed a significant association with treatment at each of the four time points with Chi-Square test p values less than 0.05.

After one week on the mist bench, rooting status varied wildly (Figure 3.2.67), with the highest rooting percentage found in cuttings taken from stock plants grown in #1 (2.84L) containers in Metro Mix 360 as well as #5 (14.55L) containers with Metro Mix 820 or Pindstrup, and the lowest rooting percentage was from both Metro Mixes in #3 (11.35L) containers (Table 3.2.33). After 2 weeks under mist, the highest percentage of rooted cuttings was from stock plants grown in #5 (14.55L) containers with Berger BM-7 (Table 3.2.34 and Figure 3.2.68). The lowest percentage of rooted cuttings was from stock plants grown in #3 (11.35L) containers with Berger BM-7 or Metro Mix 360. After the third week, the highest percentage of rooted cuttings was from stock plants grown in #5 (14.55L) containers with Pindstrup (Table 3.2.35 and Figure 3.2.69). After 4 weeks on the mist bench, all rooting percentages dropped (Table 3.2.36) with the highest percentages being from the #5 (14.55L) Berger BM-7 treatment combination (Figure 3.2.70).

The decrease in percent of rooted cuttings across all treatment combinations was likely due to the flats drying out and cuttings dying from desiccation. Despite losses due to environmental conditions, it can be seen that #5 (14.55L) containers resulted in higher rooting percentages and fewer losses after 4 weeks under mist. A rooting experiment of poinsettias by Zerche and Druege (2009) demonstrated increased levels of sucrose and total sugar content in the leaves of cuttings as well as increased tissue nitrogen levels were correlated with an increase in

total root length. In the present study, higher success rates found in *Zauschneria* cuttings may be due to the cuttings having larger fresh weights which allows for more carbohydrate, nitrogen, and moisture reserves.

Table 3.2.33 Experiment #1 mean rooting percentage for each treatment combination after 1 week under mist. Chi Square test p-value = 0.04042.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	5.6%
	Metro Mix 360	16.7%
	Metro Mix 820	5.6%
	Pindstrup	11.1%
#3 (11.35L)	Berger BM-7	2.8%
	Metro Mix 360	0.0%
	Metro Mix 820	0.0%
	Pindstrup	13.9%
#5 (14.55L)	Berger BM-7	13.9%
	Metro Mix 360	5.6%
	Metro Mix 820	16.7%
	Pindstrup	16.7%

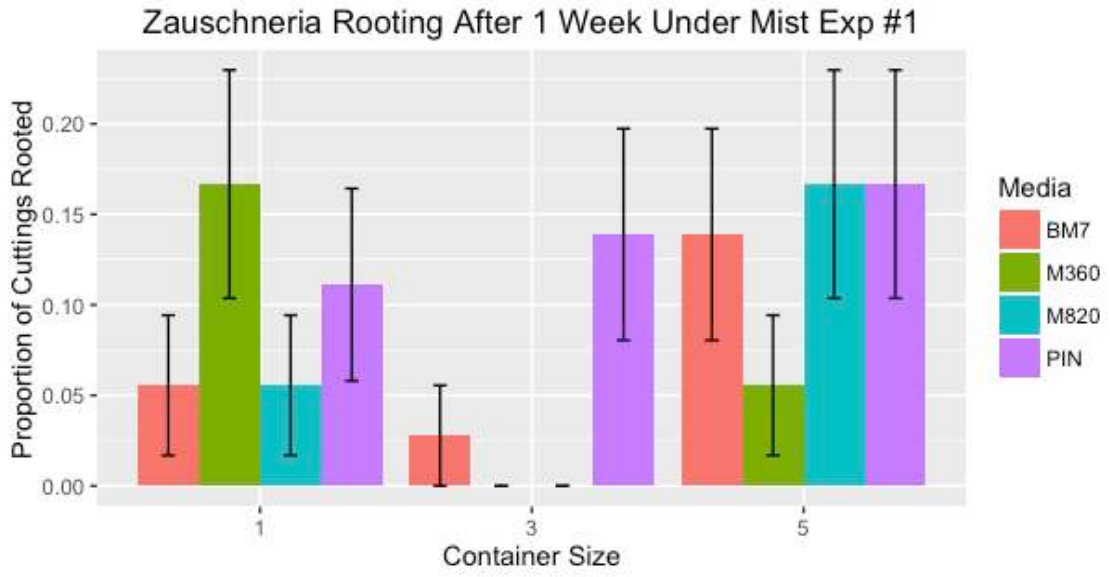

Figure 3.2.67 Experiment #1 bar plot of percent cuttings rooted after 1 week under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Table 3.2.34 Experiment #1 mean rooting percentage for each treatment combination after 2 weeks under mist. Chi Square p-value = 0.0004984.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	41.7%
	Metro Mix 360	55.6%
	Metro Mix 820	41.7%
	Pindstrup	41.7%
#3 (11.35L)	Berger BM-7	27.8%
	Metro Mix 360	27.8%
	Metro Mix 820	47.2%
	Pindstrup	55.6%
#5 (14.55L)	Berger BM-7	77.8%
	Metro Mix 360	63.9%
	Metro Mix 820	52.8%
	Pindstrup	58.3%

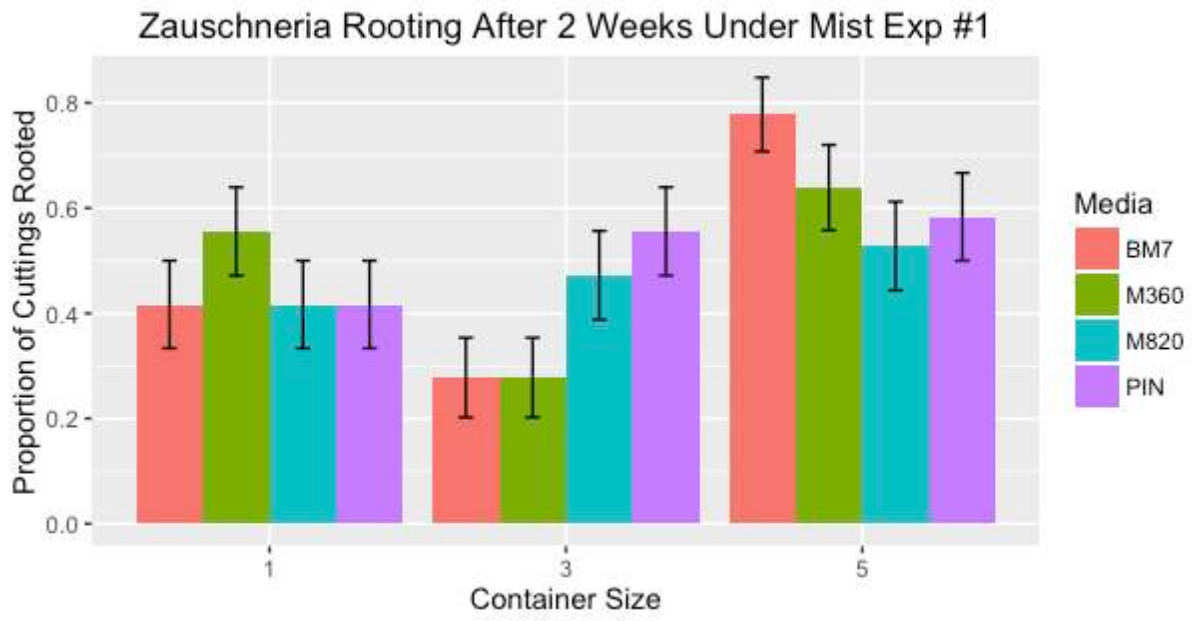

Figure 3.2.68 Experiment #1 bar plot of percent cuttings rooted after 2 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Table 3.2.35 Experiment #1 mean rooting percentage for each treatment combination after 3 weeks under mist. Chi Square p-value = 0.0003197.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	62.5%
	Metro Mix 360	83.3%
	Metro Mix 820	58.3%
	Pindstrup	70.8%
#3 (11.35L)	Berger BM-7	41.7%
	Metro Mix 360	45.8%
	Metro Mix 820	50.0%
	Pindstrup	91.7%
#5 (14.55L)	Berger BM-7	83.3%
	Metro Mix 360	79.2%
	Metro Mix 820	75.0%
	Pindstrup	83.3%

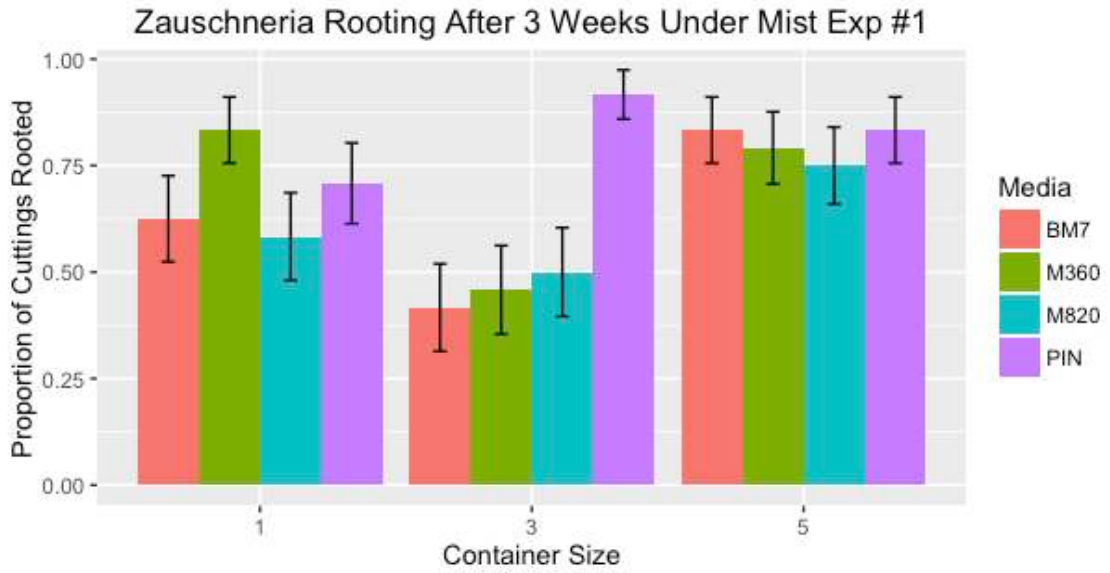

Figure 3.2.69 Experiment #1 bar plot of percent cuttings rooted after 3 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Table 3.2.36 Experiment #1 mean rooting percentage for each treatment combination after 4 weeks under mist. Chi Square p-value = 0.0001319.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	36.1%
	Metro Mix 360	47.2%
	Metro Mix 820	41.7%
	Pindstrup	55.6%
#3 (11.35L)	Berger BM-7	27.8%
	Metro Mix 360	19.4%
	Metro Mix 820	33.3%
	Pindstrup	55.6%
#5 (14.55L)	Berger BM-7	69.4%
	Metro Mix 360	50.0%
	Metro Mix 820	58.3%
	Pindstrup	63.9%

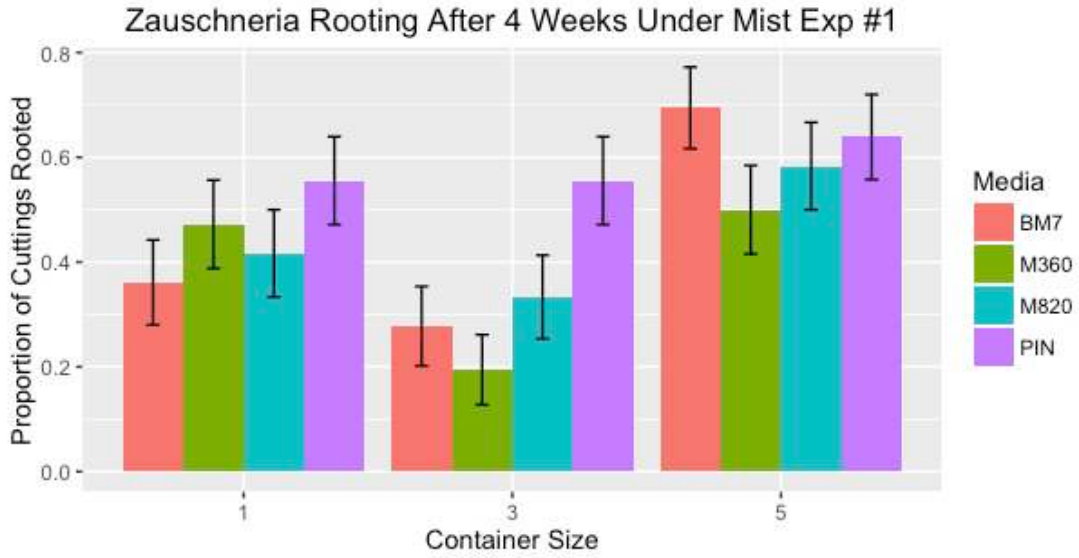

Figure 3.2.70 Experiment #1 bar plot of percent cuttings rooted after 4 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

When analyzing the number of visible roots during Experiment #1, the data suggest an even more dramatic trend of container size. Although some cuttings had rooted by the first week, there were no visible roots from any treatment, so this data is not presented. After the

second week on the mist bench, ANOVA testing showed a significant main effect of container size (Figures 3.2.71 and 3.2.72) with #5 (14.55L) containers resulting in cuttings with significantly more visible roots than the smaller container sizes (Table 3.2.37). There was no significant effect of media or the interaction of size *media. Although the number of roots increased after 3 and 4 weeks on the mist bench, the trends were the same, so this data is presented in Appendix III (Figures A3.2.17-A3.2.20, Tables A3.2.9-A3.2.10).

The trend of container size in relation to number of visible roots produced agrees with the rooting percentage data, which indicates a positive correlation between container size and cutting quality. Higher success rates found in *Zauschneria* cuttings produced by #5 (14.55L) containers may be due to the cuttings having larger fresh weights which provides more carbohydrate, nitrogen, and moisture reserves and could increase total root length as suggested by Zerche and Druege (2009).

```
Anova Table (Type III tests)

Response: RootNum
            Sum Sq  Df F value    Pr(>F)
(Intercept)  322.1   1 15.2092  0.000112 ***
Size         458.9   2 10.8363 2.578e-05 ***
Media         49.6   3  0.7811  0.505000
Size:Media   138.8   6  1.0926  0.365893
Residuals   8893.6 420
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.71 Experiment #1 two-way ANOVA table for mean number of visible roots after 2 weeks under mist averaged over harvest date.

Table 3.2.37 Experiment #1 mean number of visible roots after 2 weeks under mist averaged over harvest date for each container size averaged over media treatment. Means with different significance groups are statistically different at the level of P<0.05.

Container Size	Mean Visible Roots	95% Confidence Interval	Significance Group
#1 (2.84L)	0.08	0.00-0.83	1
#3 (11.35L)	0.19	0.00-0.95	1
#5 (14.55L)	2.13	1.57-3.07	2

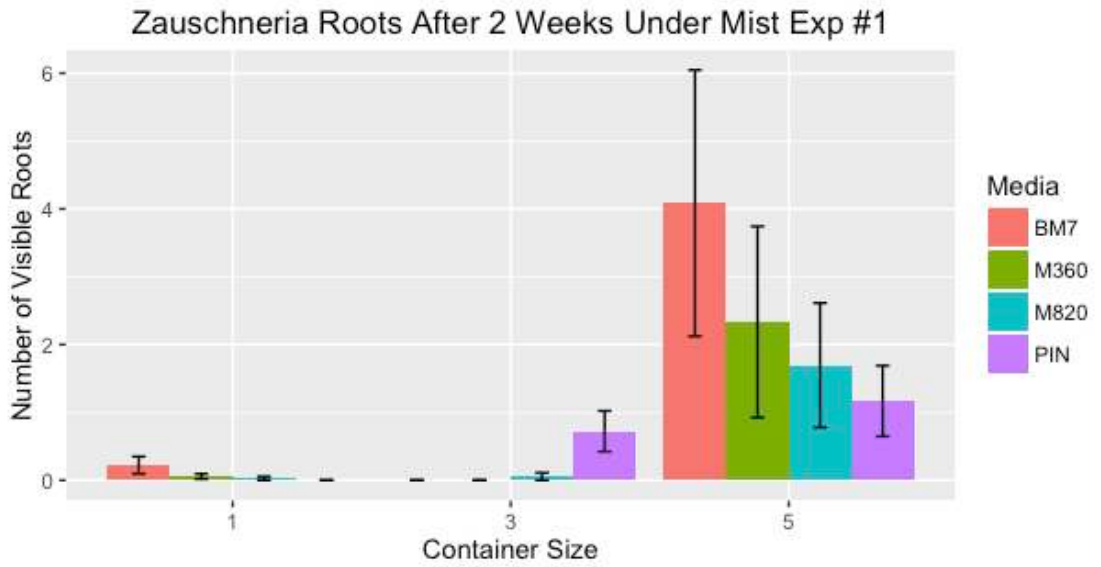

Figure 3.2.72 Experiment #1 bar plot of mean visible roots after 2 weeks under mist averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Problems with watering and drainage were encountered during Experiment #2 and resulted in data with very few clear trends. Due to issues with flats drying out as well as poor drainage of the heat mats, numerous cuttings were lost to both root rot and desiccation, so the data should be interpreted with caution. After one week under mist, no significant association was found between treatment and rooting status (Appendix III, Table A3.2.11 and Figure A3.2.21). After 2 weeks under mist, there was a significant association (Table 3.2.38 and Figure 3.2.73) although it did not continue to be significant through the remaining time points (Appendix III, Tables A3.2.12 and A3.2.13, Figures A3.2.22 and A3.2.23). After two weeks

under mist, the most successful cuttings were from #3 (11.35L) containers with Metro Mix 820, with 94% of the cuttings being rooted at that time. When averaged over media treatment, it appears that cuttings taken from the larger container sizes had higher rooting percentages after 2 weeks under mist Table 3.2.39). After 3 and 4 weeks under mist, the percentage of rooted cuttings dropped dramatically for all treatments because of losses due to drought and root rot, making it difficult to identify any trends.

Table 3.2.38 Experiment #2 mean percentage of cuttings rooted after 2 weeks under mist for each treatment combination. Significant association was found between treatment and rooting status with Chi Square p-value = 0.0155.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	75.0
	Metro Mix 360	66.7
	Metro Mix 820	63.9
	Pindstrup	66.7
#3 (11.35L)	Berger BM-7	77.8
	Metro Mix 360	77.8
	Metro Mix 820	94.4
	Pindstrup	80.6
#5 (14.55L)	Berger BM-7	83.3
	Metro Mix 360	86.1
	Metro Mix 820	86.1
	Pindstrup	61.1

Table 3.2.39 Experiment #2 mean percentage of cuttings rooted after 2 weeks under mist for each media treatment averaged over size and each container size averaged over media.

Treatment	Percent Rooted
Berger BM-7	78.7
Metro Mix 360	76.9
Metro Mix 820	81.5
Pindstrup	69.4
#1 Container	68.1
#3 Container	82.6
#5 Container	79.2

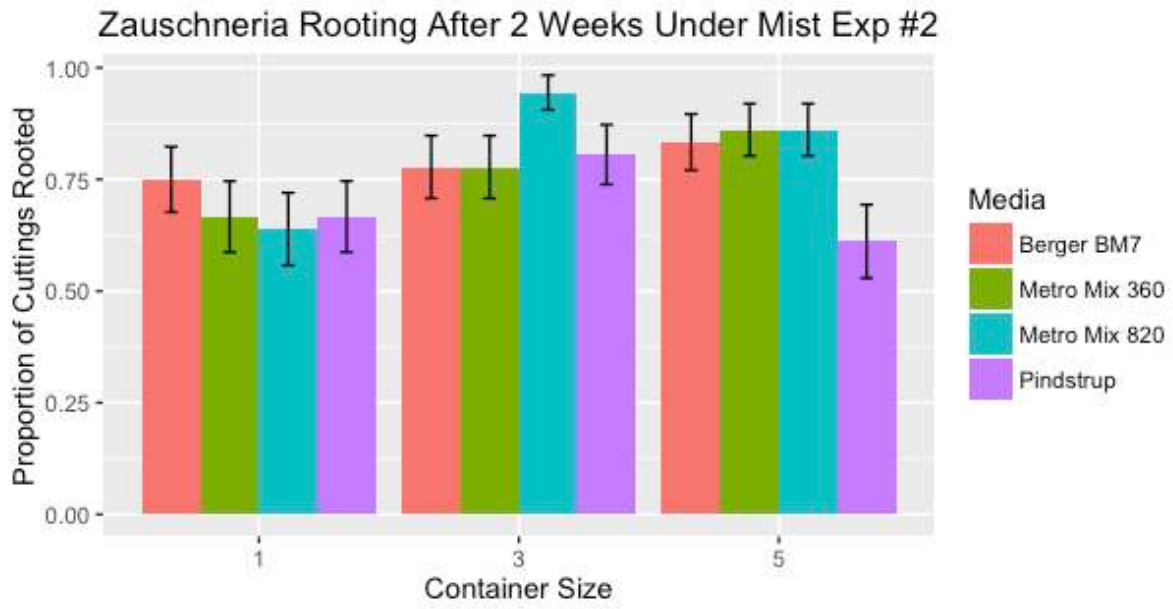

Figure 3.2.73 Experiment #2 bar plot of mean proportion of cuttings rooted after 2 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

The number of visible roots were counted after each week on the mist bench and analyzed to determine if stock plant treatments had any effect on root production of cuttings. After one week on the mist bench, there were no visible roots regardless of treatment, so the data are not presented. Although some visible roots were present after two weeks, there was no significant differences between treatments and data are presented in Appendix III (Figures A3.2.24 and A3.2.25, Table A3.2.14). After 3 weeks under mist, there was a significant interaction between media and container size, although the only significant pairwise comparisons were found within the #1 (2.84L) containers (Figures 3.2.74 and 3.2.75). Within the #1 (2.84L) containers, Pindstrup produced significantly more visible roots than either Metro Mix 360 or Metro Mix 820 (Table 3.2.40). No other pairwise comparisons were significant at this time point. After 4 weeks under mist, differences between treatments were no longer detectable (Appendix III Figures A3.2.26 an A3.2.27, Table A3.2.15).

It has been previously suggested that *Zauschneria* grows well in the Pindstrup media due to a possible genetic predisposition to peat substrates with higher water holding capacity. And while stock plants grown in Pindstrup produced significantly larger cuttings during the second stock plant experiment, it is surprising that the increased number of roots wasn't observed in cuttings from the larger container sizes with Pindstrup, but only in the #1 (2.84L) containers. It is likely that the data are skewed due to environmental issues that affected different parts of the propagation flats. Low areas in the heat mats gathered standing water which may have caused root rot in some parts of the flat more than others, thus affecting some treatments more than others. The same phenomenon could be true of uneven misting when the heaters and fans were on in the propagation house.

In order to determine if the stock plant treatments affect the rooting of *Zauschneria* cuttings, the experiment would need to be repeated with a more rigorously controlled propagation environment.

```
Anova Table (Type III tests)

Response: RootNum
             Sum Sq  Df F value    Pr(>F)
(Intercept)  1912.7   1 48.3722 1.358e-11 ***
Size           49.3   2  0.6233   0.53667
Media          75.2   3  0.6339   0.59351
Size:Media    528.6   6  2.2280   0.03964 *
Residuals   16607.3 420
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 3.2.74 Experiment #2 two-way ANOVA table for mean number of visible roots after 3 weeks under mist.

Table 3.2.40 Experiment #2 mean number of visible roots after 3 weeks under mist for each level of media at each level of container size. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Media	Mean Visible Roots	95% Confidence Interval	Significance Group
#1 (2.84L)	Berger BM-7	1.69	0.00-3.75	1, 2
	Metro Mix 360	0.39	0.00-2.45	1
	Metro Mix 820	0.39	0.00-2.45	1
	Pindstrup	4.50	2.44-6.56	2
#3 (11.35L)	Berger BM-7	2.53	0.47-4.59	1
	Metro Mix 360	3.67	1.61-5.73	1
	Metro Mix 820	2.50	0.44-4.56	1
	Pindstrup	1.53	0.00-3.59	1
#5 (14.55L)	Berger BM-7	3.53	1.47-5.59	1
	Metro Mix 360	1.64	0.00-3.70	1
	Metro Mix 820	1.69	0.00-3.75	1
	Pindstrup	1.19	0.00-3.25	1

Figure 3.2.75 Experiment #2 bar plot of mean number of visible roots after 3 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

CHAPTER 4. CONCLUSION

4.1. Conclusions Regarding *Heuchera* 'Snow Angel'

4.1.1 Response to Media Treatment

Stock plants of *Heuchera* 'Snow Angel' responded to media treatments differently depending on the batch of media being grown in and more in-depth research will need to be performed in order to determine the mechanisms involved in that response. During the first experiment, Metro Mix 820 resulted in initially larger plants, more cuttings per plant and per square foot, as well as larger fresh and dry weights of cuttings. The increased success of stock plants grown in the first batch of Metro Mix 820 was mostly attributed to pH (which started at 5.6 and ended at 5.3). Since the differences became less dramatic by the end of the experiment, the response may also be related to temporary nutrition levels provided by a pre-plant starter charge. Although Metro Mix 820 had the lowest initial total nitrogen concentration, it also had the highest concentration of NO_s and the lowest NH_4: NO_3 ratio (0.01), which may have been a quality of the pre-plant charge since all NH_4: NO_3 ratios were similar by the end of the first experiment varying between 1.143 and 1.931.

Unfortunately, there were dramatic differences between chemical properties of the two batches of media used for the first and second experiments, so there was very little correlation between results of the two experiments. During Experiment #2, the most successful stock plants were those grown in Metro Mix 360 and Pindstrup. These two substrates resulted in larger plants, more cuttings per plant and per square foot, as well as higher fresh and dry weights of the cuttings. The increased response was mostly attributed to pH levels. Initial pH levels of the second batch of media were between 3.8 and 4.7 which varied dramatically from the first batch

of media used in Experiment #1. By the end of Experiment #2, Pindstrup had a pH of 5.8 (starting pH of 4.7) and Metro Mix 360 had a pH of 5.1 (starting pH of 3.8) which could partially explain why Pindstrup initially produced the largest plants, while by the end of the experiment, Metro Mix 360 had produced the largest.

4.1.2 Response to Container Size Treatment

Stock plant responses to container size were fairly similar between the two experiments with #3 (11.35L) and #5 (14.55L) containers resulting in slightly larger plants by the end of the study, though fewer cuttings per square foot, indicating that stock plants of *Heuchera* 'Snow Angel' would be more efficiently grown in #1 (2.84L) containers. Although stock plants remained in their treatments for 24 weeks during the first experiment and only 18 weeks in the second experiment, there was very little difference in productivity between those grown in #3 (11.35L) and #5 (14.55L) containers, which indicates the experiments were not long enough for the #3 (11.35L) containers to start suffering from root restriction. It is possible that plants in the larger containers would become more efficient after those in the smaller containers started to decline due to root restriction, though more research would need to be conducted over a longer time period to determine whether the larger containers would warrant the space they occupy on the bench.

When cuttings from each stock plant treatment combination were rooted, the results showed that *Heuchera* 'Snow Angel' cuttings can be rooted with almost 100% success regardless of stock plant media or container size treatment. Rooting status was not statistically affected by treatment after 4 weeks on the mist bench and reached 100% for most treatments after 3 weeks. During the first experiment, cuttings taken from #5 (14.55L) containers rooted

slightly faster than those from the smaller container sizes, although by the 4th week, there was no statistical difference between treatments.

Although rooting status was relatively unaffected by treatment, effects of both media and container size influenced the number of visible roots produced during Experiment #1 after 4 weeks on the mist bench. The number of visible roots produced by cuttings increased significantly with increasing container size, which was partially attributed to stock plant health during the hotter months. During the second experiment, the opposite trend was observed, and increasing numbers of roots corresponded to a decrease in container size of the stock plant. It is possible this phenomenon is related to the time of year, but because the results of the two experiments did not agree, more research would need to be performed in order to identify the primary cause of the response.

4.1.3 Propagator Recommendations

Despite some discrepancies between the first and second experiment, it is possible to make some recommendations to perennial propagators for stock plant care and rooting of *Heuchera* 'Snow Angel'. Based on the research conducted, stock plants would likely perform best in a well-drained media with physical properties similar to that of Metro Mix 820 with a fairly low pH (possibly between 4.7 and 5.6). For the initial 6 months after starting a new stock plant from a cutting, it is much more efficient to grow them in #1 (2.84L) containers, as the larger containers do not provide enough advantage to justify the space they occupy. Since our experiment did not last as long as most growers keep their stock plants, no claims can be made about the longevity of a stock plant in relation to the container size or media it is grown in. Since more cuttings were produced during the first experiment, it may be advantageous to

maintain daytime greenhouse temperatures between 18.3 and 22.8 °C and nighttime temperatures between 16.1 and 22.8 °C, although higher cutting production could also be due to seasonality of the plants.

After completing the rooting study, it is recommended that growers follow the propagation protocols described in Chapter 2 which resulted in very successful rooting during both experiments.

4.2. Conclusions Regarding *Zauschneria garrettii* 'PWWG01S'

4.2.1 Response to Media Treatment

The response to media found in *Zauschneria garrettii* 'PWWG01S' stock plants was fairly consistent across both experiments with the best results observed in Pindstrup treatments, although differences were more dramatic during Experiment #1. Stock plants grown in Pindstrup were larger, produced more cuttings per plant and per square foot with higher dry weights per cutting during the first experiment. While the second experiment showed no significant correlation between media treatment and plant size or number of cuttings produced, stock plants grown in Pindstrup resulted in cuttings with slightly higher fresh and dry weights. The increased response to Pindstrup was mostly attributed to a higher CEC, higher starting levels of phosphorus and a higher water holding capacity. It is possible that being part of the *Epilobium* genus, these plants tend to prefer a substrate with a higher peat content with more available water, since this mimic the natural habitats of many closely related species.

Results from Experiment #2 showed a dramatic increase in number of cuttings and size of the cuttings regardless of treatment, and this response was mostly attributed to greenhouse temperature differences between the two experiments. During Experiment #1, daytime greenhouse temperatures were between 18.3 and 22.8 °C and nighttime temperatures between

16.1 and 22.8 °C. For the second experiment, these set points were lowered to 16.7-20.0 °C (day) and 12.8-16.1 °C (night) in an attempt to discourage flowering on the *Zauschneria* plants which seemed to help some. It is also possible that differences between treatments were smaller during the second experiment because all plants were experiencing less temperature stress than Experiment #1.

In order to determine if media or container size treatments had any effect on the rooting of cuttings, a propagation experiment followed the stock plant experiment. Many difficulties were encountered in creating a conducive propagation environment for these cuttings and numerous losses were observed due to greenhouse fans, improper drainage, and irregular mist application. While attempts were made to correct these issues between the two experiments, dramatic losses were encountered during the second experiment as well, making it difficult to identify which treatments may offer an advantage during the rooting process. Very few trends were identifiable and the only media that showed an increased rooting response was Pindstrup during Experiment #2, which resulted in slightly more visible roots after 3 weeks under mist. Since the difference was only found after the 3rd week and no other time point, more research will need to be conducted to determine the true effects of media treatment on rooting capability in this taxon.

4.2.2 Response to Container Size Treatment

In contrast to the *Heuchera* stock plants, *Zauschneria* showed a much more dramatic response to container size with the larger containers producing larger stock plants, more cuttings per plant. During Experiment #1, the larger containers also resulted in cuttings with larger fresh and dry weights and very similar numbers of cuttings per square foot when compared to #1 (2.84L) containers. During the second experiment, there was no significant effect of size on the

fresh weights of cuttings, but dry weights increased with the larger container sizes by the end of the experiment. Stock plants grown in #1 (2.84L) containers during the second experiment produced significantly more cuttings per square foot, which is likely because they were not experiencing the same level of heat stress as the first experiment, allowing them to be more healthy and productive. Overall, the response to container size was mostly attributed to root restriction and higher root zone temperatures within the smaller containers.

During Experiment #1, higher rooting percentages and number of visible roots were found in cuttings from stock plants grown in #5 (14.55L) containers. This response was mostly attributed to #5 (14.55L) containers producing larger cuttings that would have more water and carbohydrate reserves, making them more resistant to desiccation. During Experiment #2, larger containers appeared to increase the rate of rooting slightly, although dramatic losses due to desiccation during week 3 convoluted the data. More research will need to be conducted to determine if container size has any effect on the rooting ability of *Zauschneria* cuttings.

4.2.3 Propagator Recommendations

Although very little can be claimed about the effect of media and container size treatments on rooting of *Zauschneria* cuttings, recommendations can be made in terms of stock plant care. Based on the research conducted over the last two years, perennial propagators should grow *Zauschneria garrettii* 'PWWG01S' in a relatively cool greenhouse, maintaining temperatures below 20.0 °C if possible, as it seems to induce more production of higher quality cuttings. Plants of this taxon seem to prefer a high peat content media similar to the moist sites where many *Epilobium* species thrive natively, although if the greenhouse environment is kept cool, the media type is not very influential and plants will grow well in any of the four substrates used in this study. It is recommended that for the best use of space, propagators grow stock

plants in #1 (2.84L) containers, although further research may be able to show an advantage of using larger containers to increase rooting percentages and number of roots produced. If stock plants must be held in a warmer greenhouse above 20 °C, it would be recommended that they be grown in larger containers, as this will result in more higher quality cuttings.

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Table A1.1 Results of sieve tests for particle size distribution of four media samples from second batch of media.

	----------% Retained by Sieve Size----------				
Media	**0.5mm**	**2mm**	**4mm**	**6mm**	**8mm**
Berger BM-7	28.46	9.46	8.54	5.98	6.32
Metro Mix 360	14.40	5.62	5.30	1.88	0
Metro Mix 820	39.08	8.84	9.94	2.72	0.56
Pindstrup	31.22	4.92	0.88	0	29.56

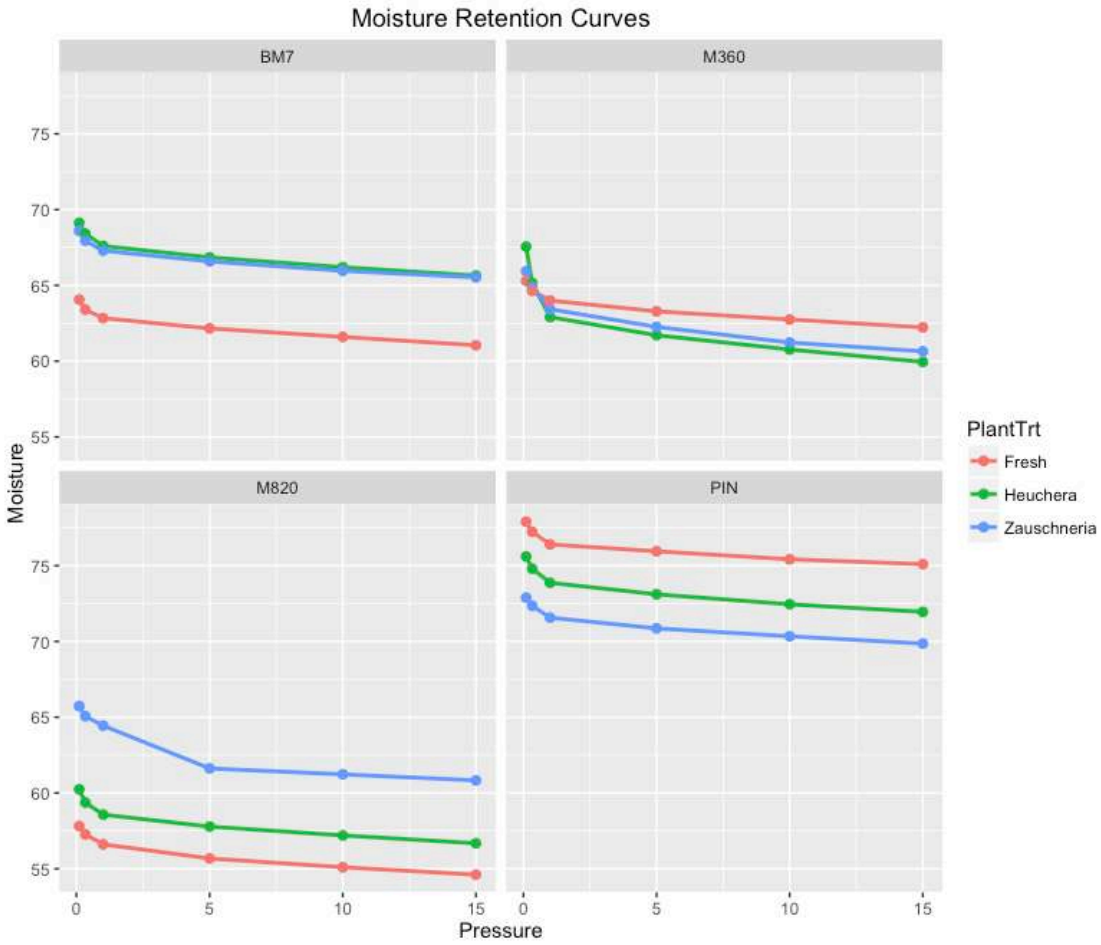


Figure A1.1 Moisture retention curves for Berger BM-7 (BM-7), Metro Mix 360 (M360), Metro Mix 820 (M820), and Pindstrup (PIN) prior to plant growth ("Fresh" in red) and after plant growth for both taxa ("Heuchera" in green and "Zauschneria" in blue).

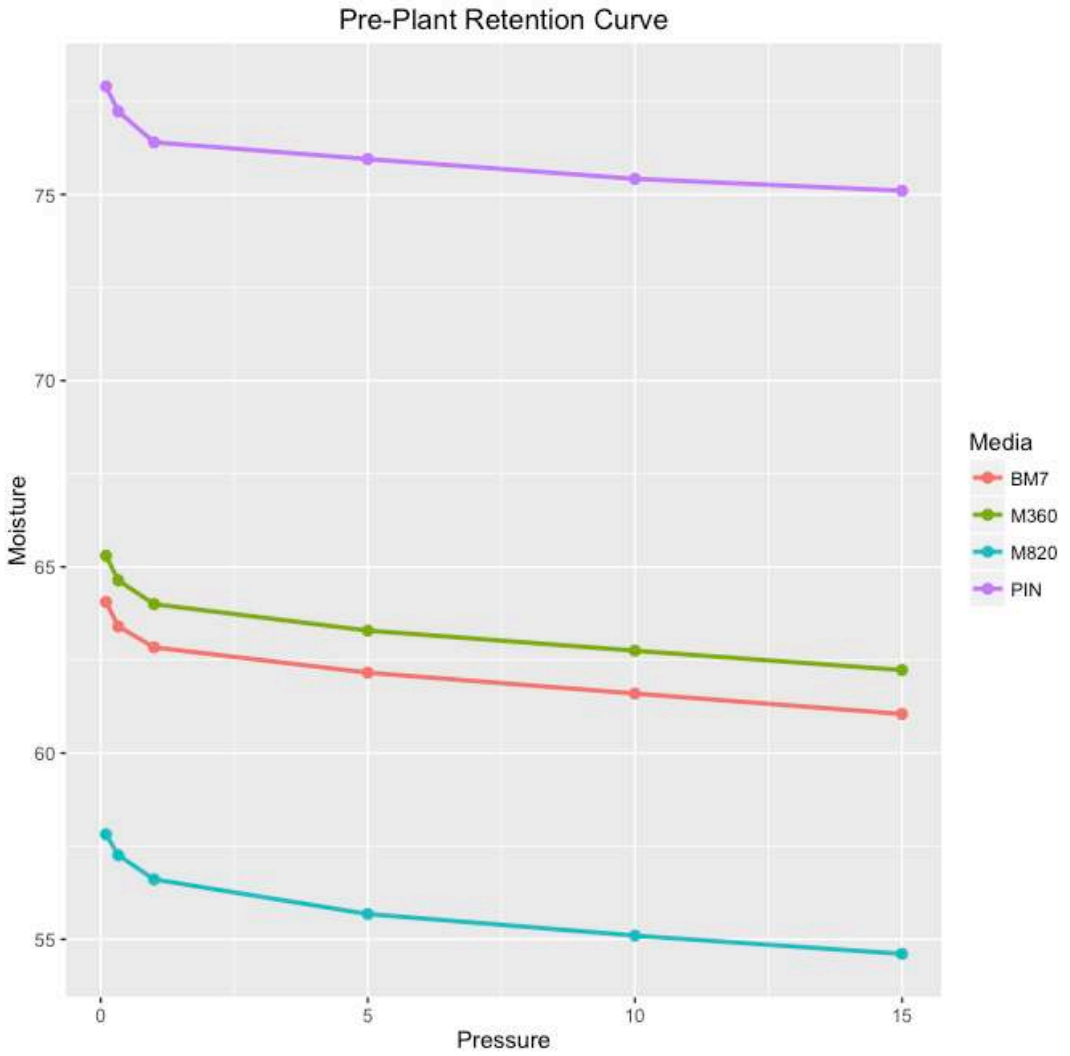


Figure A1.2 Moisture Retention curves for fresh Berger BM-7 (BM-7), Metro Mix 360 (M360), Metro Mix 820 (M820), and Pindstrup (PIN) from Experiment #2 prior to planting.

Soil Analyses

Soil analysis methods are from:

1. "Test Methods for The Examination of Composting and Compost.2001, W.H Thompson (ed)
2. Soil Survey Laboratory Methods Manual, Soil Survey Investigations Report, No. 42,Version 3, 1996.
3. EPA methods 3050 (digestion) and 6010 (analysis) from SW-846. Methods of Soil Analysis. A.L. Page (ed), ASA, 1982

AB-DTPA is ammonium bicarbonate-DTPA.

Table A1.2 Experiment #1 soil analyses of Berger BM-7 (BM-7), Metro Mix 360 (M360), Metro Mix 820 (M820), and Pindstrup (PIN) acquired for experiment #1 conducted on fresh media before planting.

	Soil Analysis Prior to Experiment #1			
	BM-7	M360	M820	PIN
Organic Matter	65.5	44.7	52.5	84.1
pH (paste)	6.1	6.3	5.6	6.1
EC (paste, mmhos/cm)	1.3	0.8	2.1	0.9
CEC (meq/100g)	77	59	69	97
% $CaCO_3$ (Lime)	0.5	0.9	0.45	1.4
% Total N	1.1290	2.2670	0.3971	0.7496
% Organic N	1.0807	2.2654	0.3435	0.7471
NH_4-N (mg/kg)	7.4	7.3	7.2	7.7
NO_3-N (mg/kg)	475.7	8.8	528.8	17.8
NH_4:NO_3 Ratio	0.02	0.83	0.01	0.43
% Total C	34.85	29.42	31.76	40.93
C:N Ratio	30.9	13.0	83.8	54.6
% P	0.0142	0.0403	0.334	0.456
% P_2O_5	0.0325	0.0923	0.0765	0.1044
% K	0.1135	1.1142	0.1920	0.1950
% K_2O	0.1362	1.3370	0.2304	0.2340

Table A1.3 Experiment #1 soil analyses of Berger BM-7 (BM-7), Metro Mix 360 (M360), Metro Mix 820 (M820), and Pindstrup (PIN) conducted on soil harvest from root balls of *Heuchera* after Experiment #1. Soil samples were taken from multiple root balls of each container size and homogenized before testing.

	Soil Analysis After *Heuchera* Experiment #1			
	BM-7	M360	M820	PIN
Organic Matter	55.7	33.0	45.3	59.7
pH (paste)	6.3	5.4	5.3	6.2
EC (paste, mmhos/cm)	1.0	1.9	0.5	0.9
CEC (meq/100g)	10.33	10.21	9.80	9.76
% $CaCO_3$ (Lime)	0.056	0.523	0.181	3.225
% Total N	0.2023	0.1327	0.1403	0.3292
% Organic N	0.18	0.06	0.07	0.33
NH_4-N (mg/kg)	111	405	401	25.1
NO_3-N (mg/kg)	89.0	307	351	12.0
NH_4:NO_3 Ratio	1.249	1.319	1.143	1.931
% Total C	14.59	10.11	17.36	14.33
C:N Ratio	72.12	76.19	123.7	43.53
% P	0.0097	0.0219	0.0151	0.0198
% P_2O_5	0.0221	0.0502	0.0345	0.0452
% K	0.0372	0.2277	0.0569	0.0364
% K_2O	0.0447	0.2733	0.0683	0.0437

Table A1.4 Experiment #1 soil analyses of Berger BM-7 (BM-7), Metro Mix 360 (M360), Metro Mix 820 (M820), and Pindstrup (PIN) conducted on soil harvest from root balls of *Zauschneria* after Experiment #1. Soil samples were taken from multiple root balls of each container size and homogenized before testing.

	Soil Analysis After *Zauschneria* Experiment #1			
	BM-7	M360	M820	PIN
Organic Matter	49.7	31.7	44.0	61.2
pH (paste)	4.3	4.2	3.9	3.8
EC (paste, mmhos/cm)	3.0	2.9	1.9	2.9
CEC (meq/100g)	6.11	6.06	4.41	8.01
% $CaCO_3$ (Lime)	0.398	0.740	0.295	0.170
% Total N	0.2268	0.1786	0.1597	0.2452
% Organic N	0.14	0.07	0.10	0.12
NH_4-N (mg/kg)	501	611	313	920
NO_3-N (mg/kg)	402	524	260	681
NH_4:NO_3 Ratio	1.246	1.167	1.205	1.351
% Total C	11.48	9.874	13.89	12.50
C:N Ratio	50.62	55.29	86.98	50.98
% P	0.0212	0.0350	0.0201	0.0247
% P_2O_5	0.0486	0.0800	0.0461	0.0566
% K	0.0525	0.2481	0.0802	0.0701
% K_2O	0.0630	0.2978	0.0962	0.0842

Table A1.5 Experiment #2 soil analyses of Berger BM-7 (BM-7), Metro Mix 360 (M360), Metro Mix 820 (M820), and Pindstrup (PIN) acquired for experiment #2 conducted on fresh media before planting.

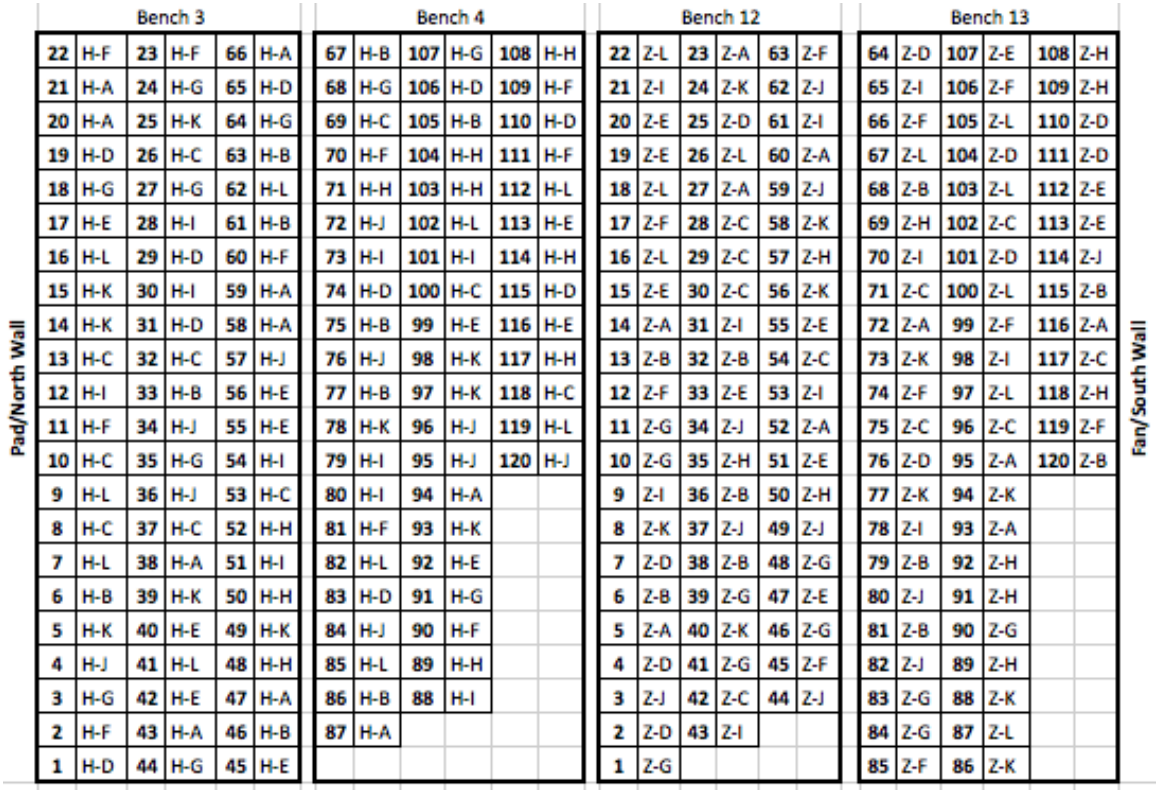
	Soil Analysis Prior to Experiment #2			
	BM-7	M360	M820	PIN
Organic Matter	52.1	32.4	43.7	59.7
pH (paste)	3.8	3.8	3.8	4.7
EC (paste, mmhos/cm)	1.2	1.7	1.9	2.4
CEC (meq/100g)	3.60	4.33	5.14	11.40
% $CaCO_3$ (Lime)	0.329	0.261	0.466	0.466
% Total N	0.1517	0.0973	0.1389	0.3028
% Organic N	0.10	0.02	0.07	0.25
NH_4-N (mg/kg)	293	452	401	601
NO_3-N (mg/kg)	193	321	305	493
NH_4:NO_3 Ratio	1.516	1.409	1.314	1.219
% Total C	12.43	5.374	10.21	12.49
C:N Ratio	81.94	55.23	73.51	41.25
% P	0.0082	0.0185	0.0152	0.0255
% P_2O_5	0.0187	0.0423	0.0349	0.0583
% K	0.0346	0.2642	0.0307	0.0454
% K_2O	0.0415	0.3170	0.0369	0.0545

Table A1.6 Experiment #2 soil analyses of Berger BM-7 (BM-7), Metro Mix 360 (M360), Metro Mix 820 (M820), and Pindstrup (PIN) conducted on soil harvest from root balls of *Heuchera* after Experiment #2. Soil samples were taken from multiple root balls of each container size and homogenized before testing.

	Soil Analysis After *Heuchera* Experiment #2			
	BM-7	M360	M820	PIN
Organic Matter	31.6	17.0	34.7	17.7
pH (paste)	5.1	4.7	5.3	5.8
EC (paste)	1.1	1.4	1.2	0.9
CEC (meq/100g)	2	2	2	3
% $CaCO_3$ (Lime)	0.52	0.6	0.22	0.31
% Total N	3.9100	3.7700	3.0100	2.7800
% Organic N	3.8194	3.6896	2.9248	2.6882
NH_4-N (mg/kg)	597.3	522.7	555.6	600.2
NO_3-N (mg/kg)	308.3	281.7	296.4	317.9
NH_4:NO_3 Ratio	1.94	1.9	1.87	1.89
% Total C	45.42	34.0	34.0	52.26
C:N Ratio	11.6	9.0	11.3	18.8
% P	0.0477	0.0490	0.0463	0.0322
% P_2O_5	0.1091	0.1123	0.1061	0.0738
% K	0.0907	0.0304	0.0852	0.0845
% K_2O	0.1089	0.0365	0.1023	0.1014

Table A1.7 Experiment #2 soil analyses of Berger BM-7 (BM-7), Metro Mix 360 (M360), Metro Mix 820 (M820), and Pindstrup (PIN) conducted on soil harvest from root balls of *Zauschneria* after Experiment #1. Soil samples were taken from multiple root balls of each container size and homogenized before testing.

	Soil Analysis After *Zauschneria* Experiment #2			
	BM-7	M360	M820	PIN
Organic Matter	22.8	13.5	20.7	15.5
pH (paste)	5.0	4.9	4.4	6.1
EC (paste)	1.4	1.6	1.3	1.3
CEC (meq/100g)	2	2	2	4
% $CaCO_3$ (Lime)	0.29	0.5	0.49	0.79
% Total N	3.6200	3.1400	3.5400	3.4700
% Organic N	3.5027	3.0349	3.4353	3.3381
NH_4-N (mg/kg)	802.5	711.1	721.3	900.2
NO_3-N (mg/kg)	370.4	339.7	326.2	419.3
NH_4:NO_3 Ratio	2.17	2.09	2.21	2.15
% Total C	46.4	28.46	36.87	50.62
C:N Ratio	12.8	9.1	10.4	14.6
% P	0.0396	0.1043	0.0637	0.0469
% P_2O_5	0.0908	0.2388	0.1458	0.1074
% K	0.0801	0.0291	0.0687	0.1024
% K_2O	0.0962	0.0349	0.0824	0.1228



Bench 3					
22	H-F	23	H-F	66	H-A
21	H-A	24	H-G	65	H-D
20	H-A	25	H-K	64	H-G
19	H-D	26	H-C	63	H-B
18	H-G	27	H-G	62	H-L
17	H-E	28	H-I	61	H-B
16	H-L	29	H-D	60	H-F
15	H-K	30	H-I	59	H-A
14	H-K	31	H-D	58	H-A
13	H-C	32	H-C	57	H-J
12	H-I	33	H-B	56	H-E
11	H-F	34	H-J	55	H-E
10	H-C	35	H-G	54	H-I
9	H-L	36	H-J	53	H-C
8	H-C	37	H-C	52	H-H
7	H-L	38	H-A	51	H-I
6	H-B	39	H-K	50	H-H
5	H-K	40	H-E	49	H-K
4	H-J	41	H-L	48	H-H
3	H-G	42	H-E	47	H-A
2	H-F	43	H-A	46	H-B
1	H-D	44	H-G	45	H-E

Bench 4					
67	H-B	107	H-G	108	H-H
68	H-G	106	H-D	109	H-F
69	H-C	105	H-B	110	H-D
70	H-F	104	H-H	111	H-F
71	H-H	103	H-H	112	H-L
72	H-J	102	H-L	113	H-E
73	H-I	101	H-I	114	H-H
74	H-D	100	H-C	115	H-D
75	H-B	99	H-E	116	H-E
76	H-J	98	H-K	117	H-H
77	H-B	97	H-K	118	H-C
78	H-K	96	H-J	119	H-L
79	H-I	95	H-J	120	H-J
80	H-I	94	H-A		
81	H-F	93	H-K		
82	H-L	92	H-E		
83	H-D	91	H-G		
84	H-J	90	H-F		
85	H-L	89	H-H		
86	H-B	88	H-I		
87	H-A				

Bench 12					
22	Z-L	23	Z-A	63	Z-F
21	Z-I	24	Z-K	62	Z-J
20	Z-E	25	Z-D	61	Z-I
19	Z-E	26	Z-L	60	Z-A
18	Z-L	27	Z-A	59	Z-J
17	Z-F	28	Z-C	58	Z-K
16	Z-L	29	Z-C	57	Z-H
15	Z-E	30	Z-C	56	Z-K
14	Z-A	31	Z-I	55	Z-E
13	Z-B	32	Z-B	54	Z-C
12	Z-F	33	Z-E	53	Z-I
11	Z-G	34	Z-J	52	Z-A
10	Z-G	35	Z-H	51	Z-E
9	Z-I	36	Z-B	50	Z-H
8	Z-K	37	Z-J	49	Z-J
7	Z-D	38	Z-B	48	Z-G
6	Z-B	39	Z-G	47	Z-E
5	Z-A	40	Z-K	46	Z-G
4	Z-D	41	Z-G	45	Z-F
3	Z-J	42	Z-C	44	Z-J
2	Z-D	43	Z-I		
1	Z-G				

Bench 13					
64	Z-D	107	Z-E	108	Z-H
65	Z-I	106	Z-F	109	Z-H
66	Z-F	105	Z-L	110	Z-D
67	Z-L	104	Z-D	111	Z-D
68	Z-B	103	Z-L	112	Z-E
69	Z-H	102	Z-C	113	Z-E
70	Z-I	101	Z-D	114	Z-J
71	Z-C	100	Z-L	115	Z-B
72	Z-A	99	Z-F	116	Z-A
73	Z-K	98	Z-I	117	Z-C
74	Z-F	97	Z-L	118	Z-H
75	Z-C	96	Z-C	119	Z-F
76	Z-D	95	Z-A	120	Z-B
77	Z-K	94	Z-K		
78	Z-I	93	Z-A		
79	Z-B	92	Z-H		
80	Z-J	91	Z-H		
81	Z-B	90	Z-G		
82	Z-J	89	Z-H		
83	Z-G	88	Z-K		
84	Z-G	87	Z-L		
85	Z-F	86	Z-K		

Figure A2.1 Experiment #1 plot plans with bench locations of each plant and treatment. See key below.

Key

Numbers 1-120 indicate plant ID/location code

First letter indicates plant taxa:

H- indicates *Heuchera*

Z- indicates *Zauschneria*

Second letter indicates treatment combination:

A - #1 (2.84L), Berger BM7

B - #1 (2.84L), Metro Mix 360

C - #1 (2.84L), Metro Mix 820

D - #1 (2.84L), Pindstrup

E - #3 (11.35L), Berger BM7

F - #3 (11.35L), Metro Mix 360

G - #3 (11.35L), Metro Mix 820

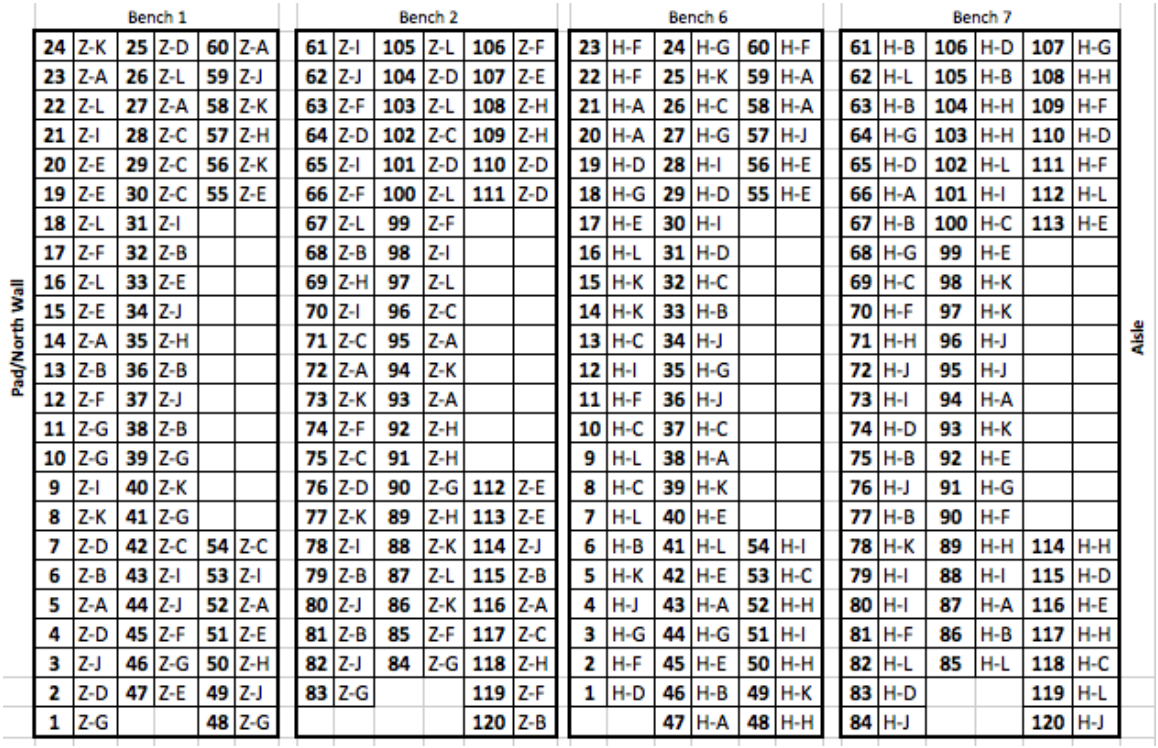
H - #3 (11.35L), Pindstrup

I - #5 (14.55L), Berger BM7

J - #5 (14.55L), Metro Mix 360

K - #5 (14.55L), Metro Mix 820

L - #5 (14.55L), Pindstrup



Bench 1					
24	Z-K	25	Z-D	60	Z-A
23	Z-A	26	Z-L	59	Z-J
22	Z-L	27	Z-A	58	Z-K
21	Z-I	28	Z-C	57	Z-H
20	Z-E	29	Z-C	56	Z-K
19	Z-E	30	Z-C	55	Z-E
18	Z-L	31	Z-I		
17	Z-F	32	Z-B		
16	Z-L	33	Z-E		
15	Z-E	34	Z-J		
14	Z-A	35	Z-H		
13	Z-B	36	Z-B		
12	Z-F	37	Z-J		
11	Z-G	38	Z-B		
10	Z-G	39	Z-G		
9	Z-I	40	Z-K		
8	Z-K	41	Z-G		
7	Z-D	42	Z-C	54	Z-C
6	Z-B	43	Z-I	53	Z-I
5	Z-A	44	Z-J	52	Z-A
4	Z-D	45	Z-F	51	Z-E
3	Z-J	46	Z-G	50	Z-H
2	Z-D	47	Z-E	49	Z-J
1	Z-G			48	Z-G

Bench 2					
61	Z-I	105	Z-L	106	Z-F
62	Z-J	104	Z-D	107	Z-E
63	Z-F	103	Z-L	108	Z-H
64	Z-D	102	Z-C	109	Z-H
65	Z-I	101	Z-D	110	Z-D
66	Z-F	100	Z-L	111	Z-D
67	Z-L	99	Z-F		
68	Z-B	98	Z-I		
69	Z-H	97	Z-L		
70	Z-I	96	Z-C		
71	Z-C	95	Z-A		
72	Z-A	94	Z-K		
73	Z-K	93	Z-A		
74	Z-F	92	Z-H		
75	Z-C	91	Z-H		
76	Z-D	90	Z-G	112	Z-E
77	Z-K	89	Z-H	113	Z-E
78	Z-I	88	Z-K	114	Z-J
79	Z-B	87	Z-L	115	Z-B
80	Z-J	86	Z-K	116	Z-A
81	Z-B	85	Z-F	117	Z-C
82	Z-J	84	Z-G	118	Z-H
83	Z-G			119	Z-F
				120	Z-B

Bench 6					
23	H-F	24	H-G	60	H-F
22	H-F	25	H-K	59	H-A
21	H-A	26	H-C	58	H-A
20	H-A	27	H-G	57	H-J
19	H-D	28	H-I	56	H-E
18	H-G	29	H-D	55	H-E
17	H-E	30	H-I		
16	H-L	31	H-D		
15	H-K	32	H-C		
14	H-K	33	H-B		
13	H-C	34	H-J		
12	H-I	35	H-G		
11	H-F	36	H-J		
10	H-C	37	H-C		
9	H-L	38	H-A		
8	H-C	39	H-K		
7	H-L	40	H-E		
6	H-B	41	H-L	54	H-I
5	H-K	42	H-E	53	H-C
4	H-J	43	H-A	52	H-H
3	H-G	44	H-G	51	H-I
2	H-F	45	H-E	50	H-H
1	H-D	46	H-B	49	H-K
		47	H-A	48	H-H

Bench 7					
61	H-B	106	H-D	107	H-G
62	H-L	105	H-B	108	H-H
63	H-B	104	H-H	109	H-F
64	H-G	103	H-H	110	H-D
65	H-D	102	H-L	111	H-F
66	H-A	101	H-I	112	H-L
67	H-B	100	H-C	113	H-E
68	H-G	99	H-E		
69	H-C	98	H-K		
70	H-F	97	H-K		
71	H-H	96	H-J		
72	H-J	95	H-J		
73	H-I	94	H-A		
74	H-D	93	H-K		
75	H-B	92	H-E		
76	H-J	91	H-G		
77	H-B	90	H-F		
78	H-K	89	H-H	114	H-H
79	H-I	88	H-I	115	H-D
80	H-I	87	H-A	116	H-E
81	H-F	86	H-B	117	H-H
82	H-L	85	H-L	118	H-C
83	H-D			119	H-L
84	H-J			120	H-J

Figure A2.2 Experiment 2 plot plans including location of each plant and treatment. See key below.

Key

Numbers 1-120 indicate plant ID/location code

First letter indicates plant taxa:

H- indicates *Heuchera*

Z- indicates *Zauschneria*

Second letter indicates treatment combination:

A - #1 (2.84L), Berger BM7

B - #1 (2.84L), Metro Mix 360

C - #1 (2.84L), Metro Mix 820

D - #1 (2.84L), Pindstrup

E - #3 (11.35L), Berger BM7

F - #3 (11.35L), Metro Mix 360

G - #3 (11.35L), Metro Mix 820

H - #3 (11.35L), Pindstrup

I - #5 (14.55L), Berger BM7

J - #5 (14.55L), Metro Mix 360

K - #5 (14.55L), Metro Mix 820

L - #5 (14.55L), Pindstrup

A3.1 Additional Analyses for *Heuchera* 'Snow Angel'

```
Anova Table (Type III tests)

Response: Cuttings1
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 5427.1   1 4971.3664 < 2.2e-16 ***
Size           7.5   2    3.4580   0.03502 *
Media         54.9   3   16.7608 5.205e-09 ***
Size:Media     7.6   6    1.1578   0.33441
Residuals    117.9 108
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.1.1 Experiment #1 two-way ANOVA table for mean cuttings per plant during harvest #1.

Table A3.1.1 Experiment #1 mean cuttings per plant during harvest #1 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of $P<0.05$.

Treatment	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	5.77	5.39-6.14	1
Metro Mix 360	7.20	6.82-7.58	2
Metro Mix 820	7.50	7.12-7.88	2
Pindstrup	6.43	6.06-6.81	1
#1 Container	7.08	6.75-7.40	2
#3 Container	6.50	6.17-6.83	1
#5 Container	6.60	6.27-6.93	1, 2

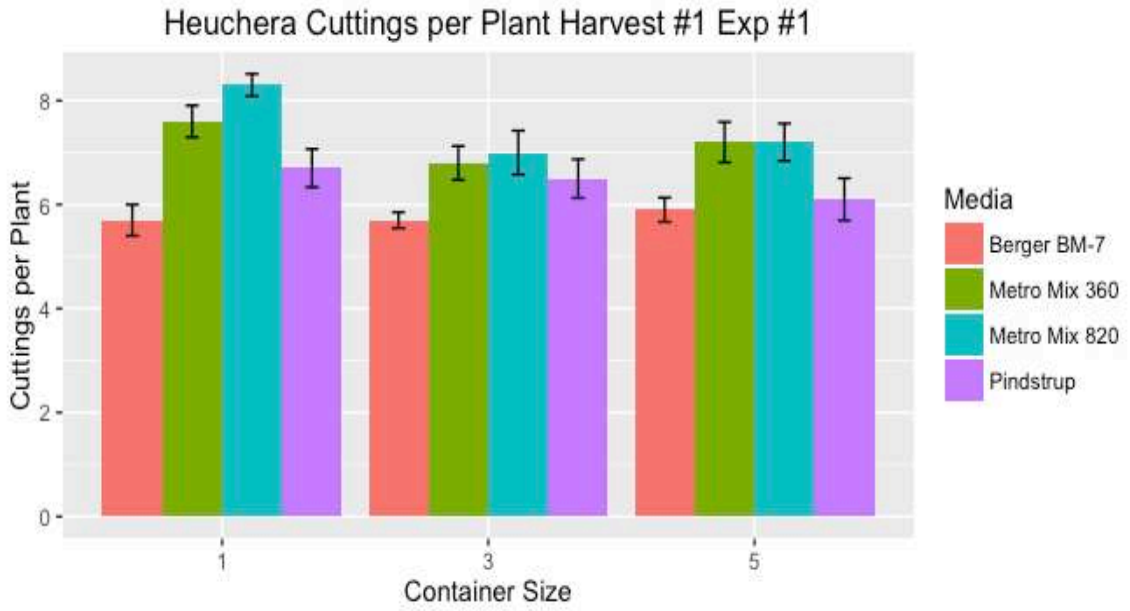


Figure A3.1.2 Experiment #1 bar plot of mean cuttings per plant during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: Cuttings2
            Sum Sq  Df   F value    Pr(>F)
(Intercept) 5187.7   1 2666.6773 < 2.2e-16 ***
Size           8.7   2    2.2489   0.11043
Media         97.7   3   16.7392 5.319e-09 ***
Size:Media    22.8   6    1.9519   0.07892 .
Residuals    210.1 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.1.3 Experiment #1 two-way ANOVA for mean cuttings per plant during harvest #2.

Table A3.1.2 Experiment #1 mean cuttings per plant during harvest #2 for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	5.40	4.90-5.90	1
Metro Mix 360	6.83	6.33-7.34	2
Metro Mix 820	7.87	7.36-8.37	3
Pindstrup	6.20	5.70-6.70	1, 2

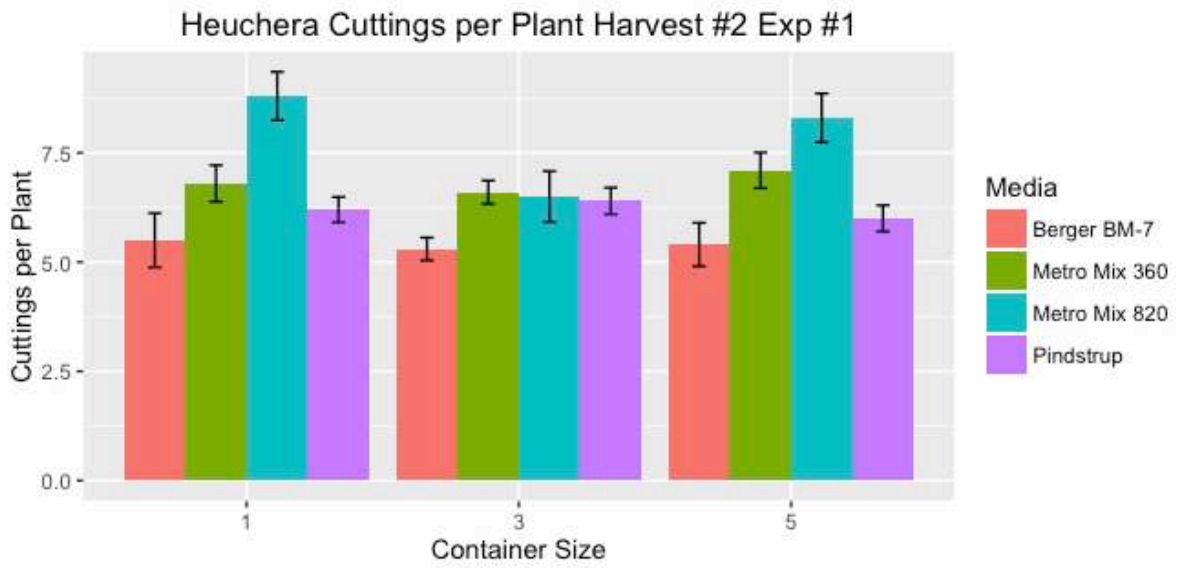


Figure A3.1.4 Experiment #1 bar plot of mean cuttings per plant during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: Cuttings3
            Sum Sq  Df   F value    Pr(>F)
(Intercept) 7053.3   1 2075.6403 < 2.2e-16 ***
Size           8.3   2    1.2237    0.2982
Media        154.8   3   15.1847 2.592e-08 ***
Size:Media     0.6   6    0.0270    0.9999
Residuals    367.0 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure A3.1.5 Experiment #1 two-way ANOVA table for mean cuttings per plant during harvest #3.

Table A3.1.3 Experiment #1 mean cuttings per plant during harvest #3 for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	6.17	5.50-6.83	1
Metro Mix 360	8.77	8.10-9.43	2
Metro Mix 820	8.77	8.10-9.43	2
Pindstrup	6.97	6.30-7.63	1

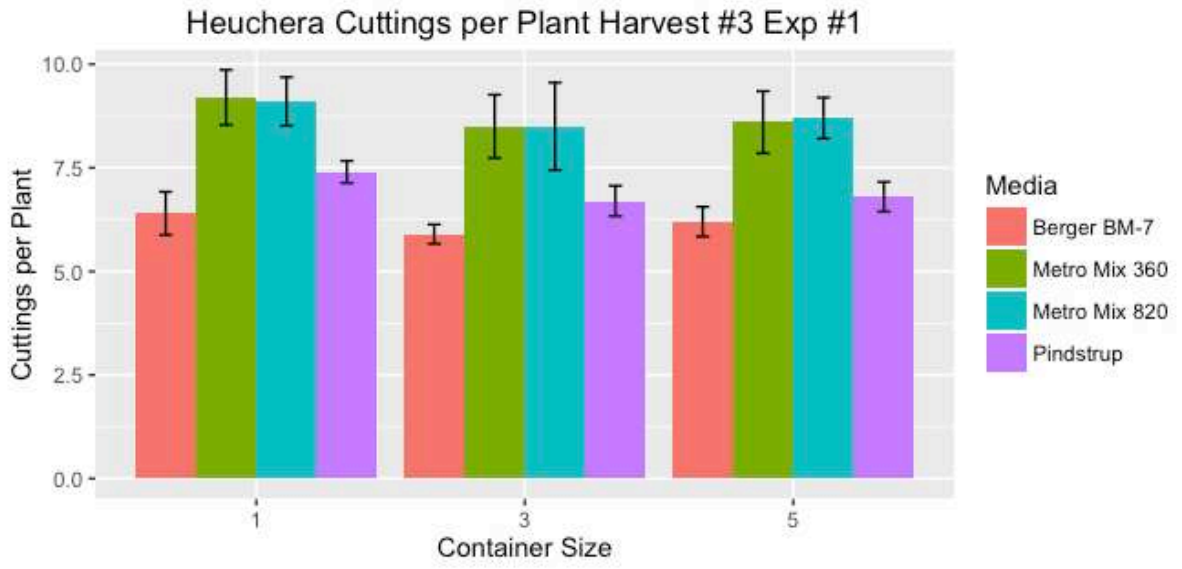


Figure A3.1.6 Experiment #1 bar plot of mean cuttings per plant during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: Cuttings2
             Sum Sq  Df   F value  Pr(>F)
(Intercept) 1778.70   1 2401.2450 < 2e-16 ***
Size           4.65   2    3.1388 0.04732 *
Media          2.50   3    1.1250 0.34230
Size:Media     6.15   6    1.3838 0.22766
Residuals     80.00 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.1.7 Experiment #2 two-way ANOVA for mean cuttings per plant during harvest #2.

Table A3.1.4 Experiment #2 mean cuttings per plant during harvest #2 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Cuttings Per Plant	95% Confidence Interval	Significance Group
Berger BM-7	3.60	3.29-3.91	1
Metro Mix 360	3.93	3.62-4.24	1
Metro Mix 820	3.93	3.62-4.24	1
Pindstrup	3.93	3.62-4.24	1
#1 Container	3.58	3.31-3.84	1
#3 Container	3.95	3.68-4.22	1
#5 Container	4.03	3.76-4.29	1

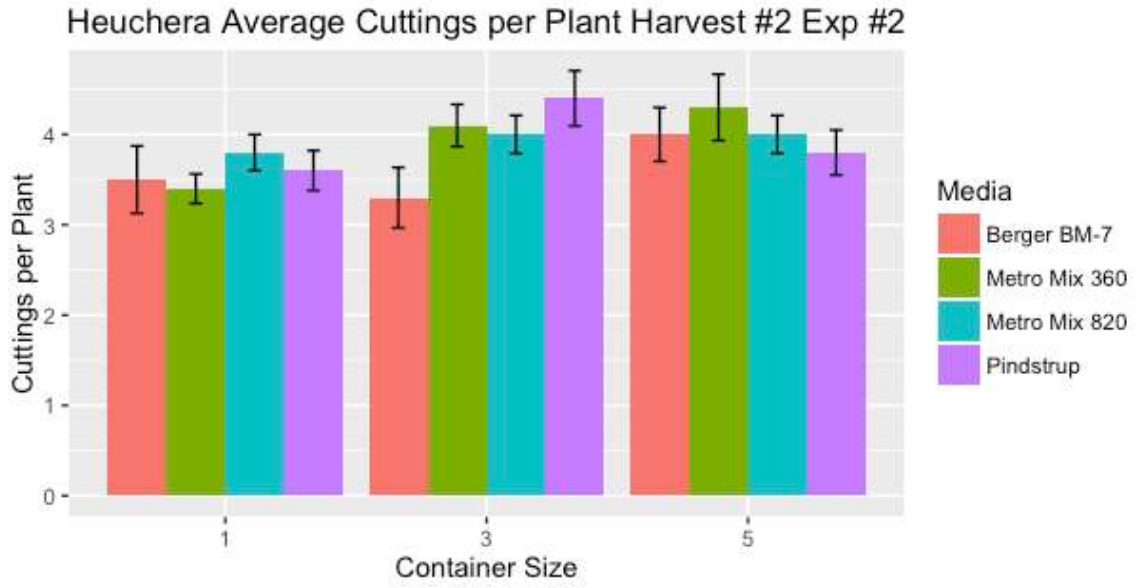


Figure A3.1.8 Experiment #2 bar plot of mean number of cuttings per plant during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh2
             Sum Sq  Df   F value Pr(>F)
(Intercept) 1771.93   1 5679.6115 <2e-16 ***
Size           0.37   2    0.5910 0.5555
Media          1.09   3    1.1695 0.3249
Size:Media     1.17   6    0.6250 0.7099
Residuals     33.69 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.1.9 Experiment #1 two-way ANOVA for mean fresh weight per cutting during harvest #2.

Table A3.1.5 Experiment #1 mean fresh weight per cutting during harvest #2 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	3.78	3.58-3.98	1
Metro Mix 360	3.97	3.76-4.17	1
Metro Mix 820	3.73	3.52-3.93	1
Pindstrup	3.90	3.70-4.10	1
#1 Container	3.87	3.70-4.05	1
#3 Container	3.77	3.59-3.94	1
#5 Container	3.89	3.72-4.07	1

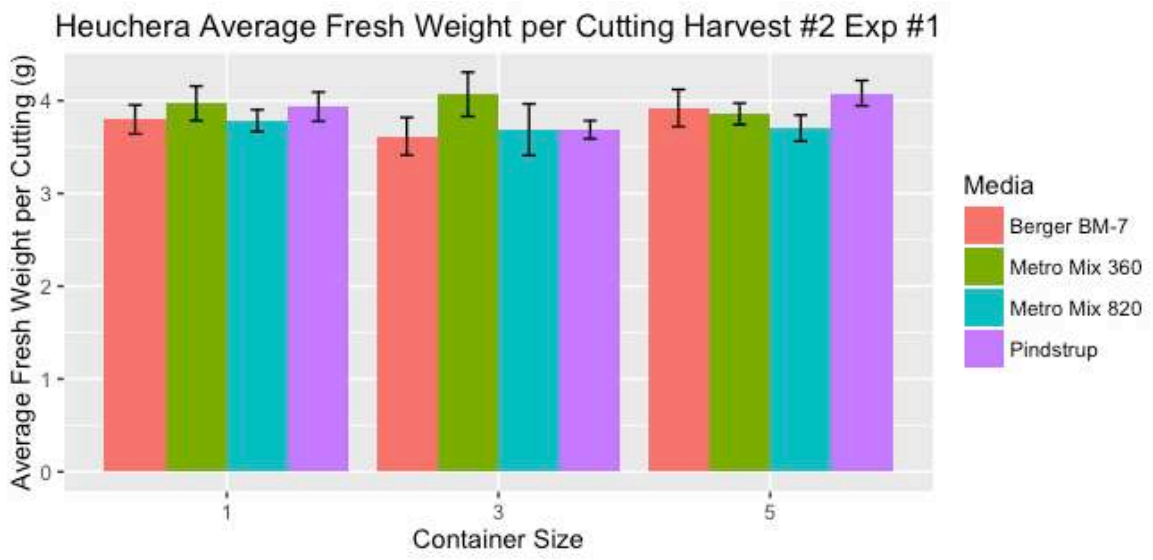


Figure A3.1.10 Experiment #1 bar plot of mean fresh weight per cutting during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh3
             Sum Sq  Df   F value Pr(>F)
(Intercept) 1772.16   1 3516.3172 <2e-16 ***
Size           2.28   2    2.2654 0.1087
Media          0.31   3    0.2042 0.8933
Size:Media     2.57   6    0.8513 0.5333
Residuals     54.43 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure A 3.1.11 Experiment #1 two-way ANOVA table for mean fresh weight per cutting during harvest #3.

Table A3.1.6 Experiment #1 mean fresh weight per cutting during harvest #3 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	3.87	3.61-4.12	1
Metro Mix 360	3.80	3.55-4.06	1
Metro Mix 820	3.79	3.53-4.04	1
Pindstrup	3.91	3.66-4.17	1
#1 Container	3.65	3.43-3.87	1
#3 Container	3.90	3.68-4.12	1
#5 Container	3.97	3.75-4.20	1

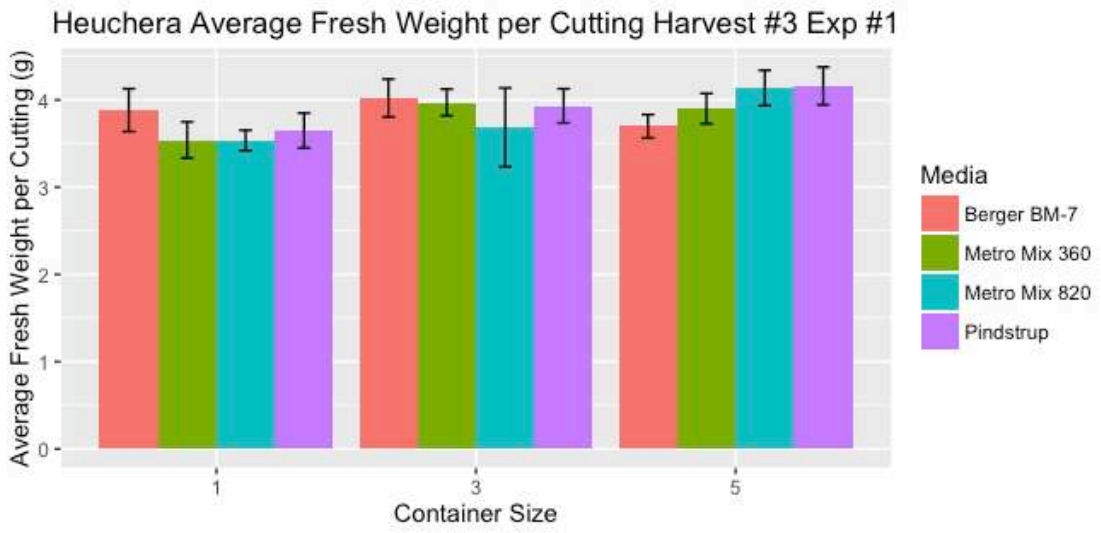


Figure A3.1.12 Experiment #1 bar plot of mean fresh weight per cutting during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh1
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 1121.17   1 1518.6296 < 2.2e-16 ***
Size           2.38   2    1.6130    0.2041
Media         47.76   3   21.5639 5.335e-11 ***
Size:Media     0.79   6    0.1775    0.9824
Residuals     79.00 107
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure A3.1.13 Experiment #2 two-way ANOVA table for mean fresh weight per cutting during harvest #1.

Table A3.1.7 Experiment #2 mean fresh weight per cutting during harvest #1 for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	2.68	2.37-2.99	1, 2
Metro Mix 360	3.19	2.88-3.50	2
Metro Mix 820	2.36	2.05-2.67	1
Pindstrup	4.05	3.73-4.36	3

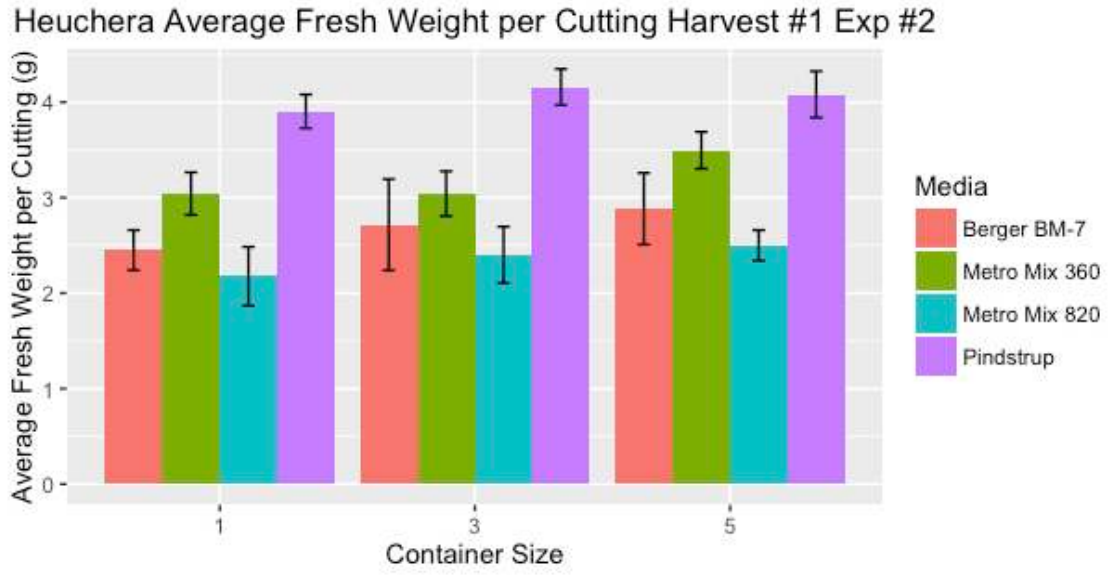


Figure A3.1.14 Experiment #2 bar plot of mean fresh weight per cutting during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh2
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 2607.08   1 6080.4793 < 2.2e-16 ***
Size           0.92   2    1.0764 0.3444594
Media          7.60   3    5.9074 0.0009019 ***
Size:Media     2.53   6    0.9838 0.4399084
Residuals     46.31 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.1.15 Experiment #2 two-way ANOVA table for mean fresh weight per cutting during harvest #2.

Table A 3.1.8 Experiment #2 mean fresh weight per cutting during harvest #2 for each media treatment averaged over container size. Means with different significance groups are significantly different at the level of P<0.05.

Media	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	4.44	4.20-4.68	1
Metro Mix 360	4.77	4.54-5.01	1, 2
Metro Mix 820	4.41	4.17-4.65	1
Pindstrup	5.02	4.78-5.26	2

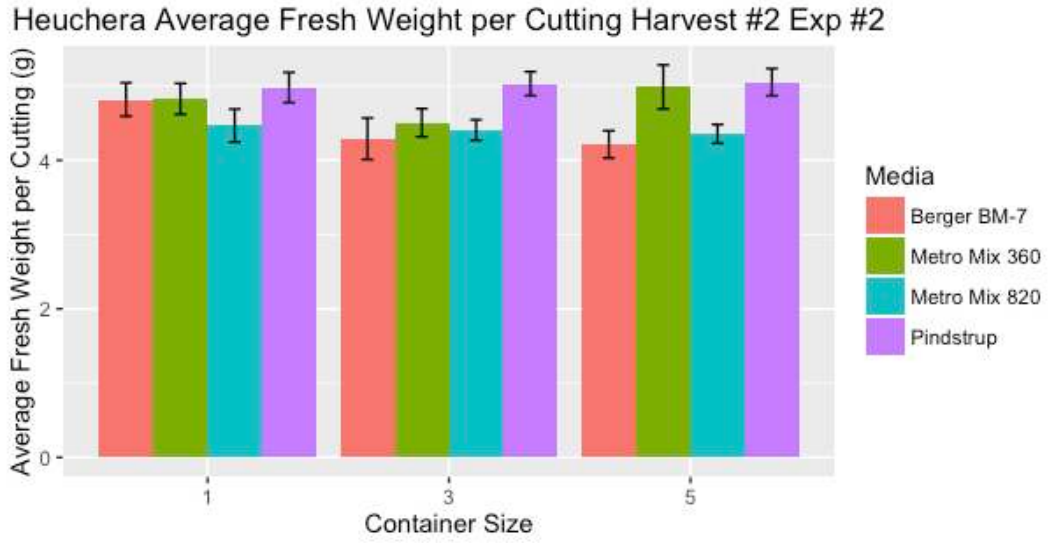


Figure A3.1.16 Experiment #2 bar plot of mean fresh weight per cutting during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh3
             Sum Sq  Df   F value Pr(>F)
(Intercept) 1993.33   1 2385.6662 <2e-16 ***
Size           0.88   2    0.5265 0.5922
Media          1.12   3    0.4478 0.7194
Size:Media     4.34   6    0.8661 0.5224
Residuals     90.24 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.1.17 Experiment #2 two-way ANOVA table for mean fresh weight per cutting during harvest #3.

Table A3.1.9 Experiment #2 mean fresh weight per cutting during harvest #3 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	3.95	3.62-4.28	1
Metro Mix 360	4.08	3.75-4.41	1
Metro Mix 820	4.22	3.89-4.55	1
Pindstrup	4.05	3.72-4.38	1
#1 Container	3.98	3.69-4.27	1
#3 Container	4.06	3.77-4.35	1
#5 Container	4.19	3.90-4.47	1

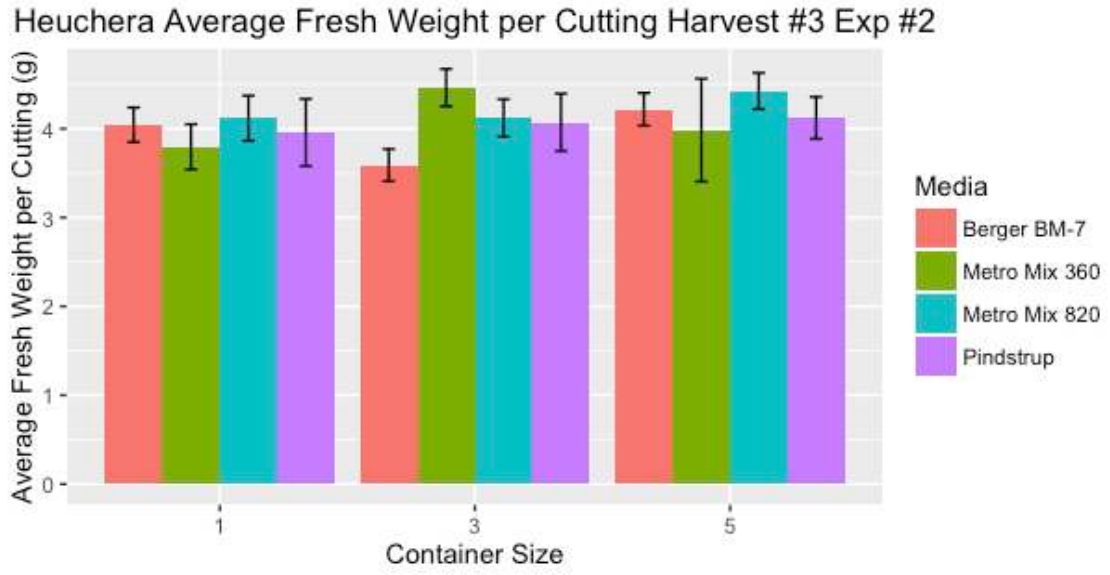


Figure A3.1.18 Experiment #2 bar plot of mean fresh weight per cutting during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry2
             Sum Sq  Df   F value Pr(>F)
(Intercept) 51.903   1 4736.8806 <2e-16 ***
Size         0.022   2    1.0243 0.3625
Media        0.061   3    1.8673 0.1395
Size:Media   0.084   6    1.2707 0.2769
Residuals    1.183 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.1.19 Experiment #1 two-way ANOVA table for mean dry weight per cutting during harvest #2.

Table A3.1.10 Experiment #1 mean dry weight per cutting during harvest #2 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.648	0.610-0.686	1
Metro Mix 360	0.687	0.649-0.725	1
Metro Mix 820	0.627	0.589-0.665	1
Pindstrup	0.670	0.632-0.708	1
#1 Container	0.677	0.644-0.710	1
#3 Container	0.648	0.615-0.680	1
#5 Container	0.649	0.616-0.681	1

Figure A3.1.20 Experiment #1 bar plot of mean dry weight per cutting during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry3
             Sum Sq  Df   F value Pr(>F)
(Intercept) 58.437   1 3355.6375 <2e-16 ***
Size         0.002   2    0.0537 0.9477
Media        0.005   3    0.1033 0.9580
Size:Media   0.106   6    1.0126 0.4210
Residuals    1.881 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure A3.1.21 Experiment #1 two-way ANOVA table for mean dry weight per cutting during harvest #3.

Table A3.1.11 Experiment #1 mean dry weight per cutting during harvest #3 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.699	0.651-0.747	1
Metro Mix 360	0.692	0.645-0.740	1
Metro Mix 820	0.692	0.644-0.739	1
Pindstrup	0.708	0.661-0.756	1
#1 Container	0.692	0.651-0.734	1
#3 Container	0.701	0.659-0.742	1
#5 Container	0.701	0.659-0.742	1

Figure A3.1.22 Experiment #1 bar plot of mean dry weight per cutting during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry3
             Sum Sq  Df   F value Pr(>F)
(Intercept) 91.863   1 1666.7240 <2e-16 ***
Size         0.026   2    0.2351 0.7909
Media        0.174   3    1.0504 0.3734
Size:Media   0.268   6    0.8099 0.5644
Residuals    5.953 108
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.1.23 Experiment #2 two-way ANOVA table for mean dry weight per cutting during harvest #3.

Table A3.1.12 Experiment #2 mean dry weight per cutting during harvest #3 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.846	0.751-0.921	1
Metro Mix 360	0.848	0.763-0.933	1
Metro Mix 820	0.934	0.849-1.019	1
Pindstrup	0.881	0.796-0.966	1
#1 Container	0.884	0.811-0.958	1
#3 Container	0.886	0.812-0.960	1
#5 Container	0.854	0.781-0.928	1

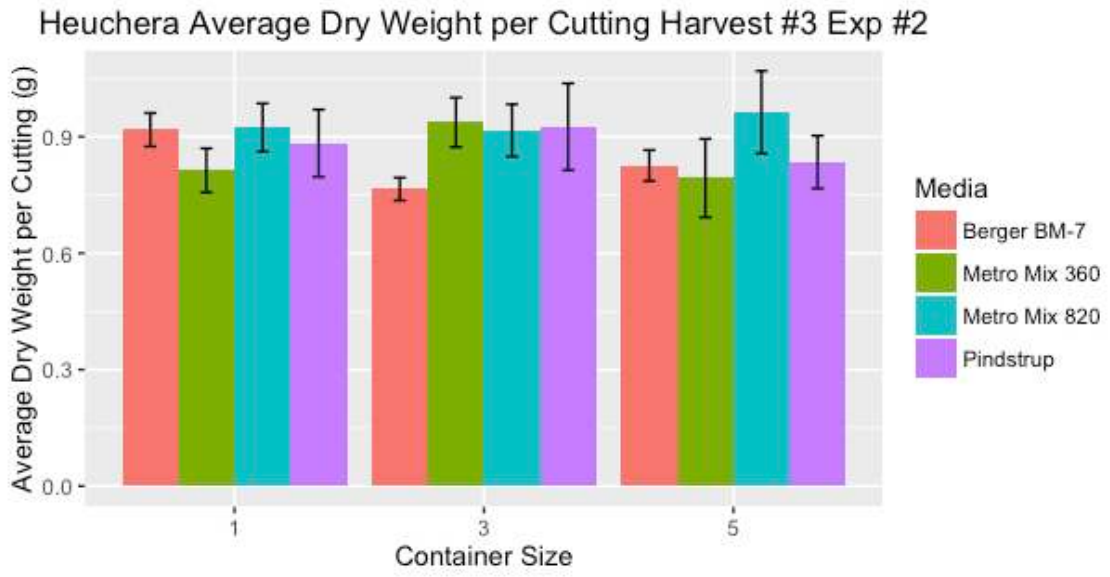


Figure A3.1.24 Experiment #2 bar plot of mean dry weight per cutting during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Table A3.1.13 Experiment #2 percent of cuttings rooted after 3 weeks under mist for each treatment combination. Chi Square p-value = 1.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	100.0
#1 (2.84L)	Metro Mix 360	100.0
#1 (2.84L)	Metro Mix 820	100.0
#1 (2.84L)	Pindstrup	100.0
#3 (11.35L)	Berger BM-7	100.0
#3 (11.35L)	Metro Mix 360	100.0
#3 (11.35L)	Metro Mix 820	100.0
#3 (11.35L)	Pindstrup	100.0
#5 (14.55L)	Berger BM-7	100.0
#5 (14.55L)	Metro Mix 360	100.0
#5 (14.55L)	Metro Mix 820	100.0
#5 (14.55L)	Pindstrup	100.0

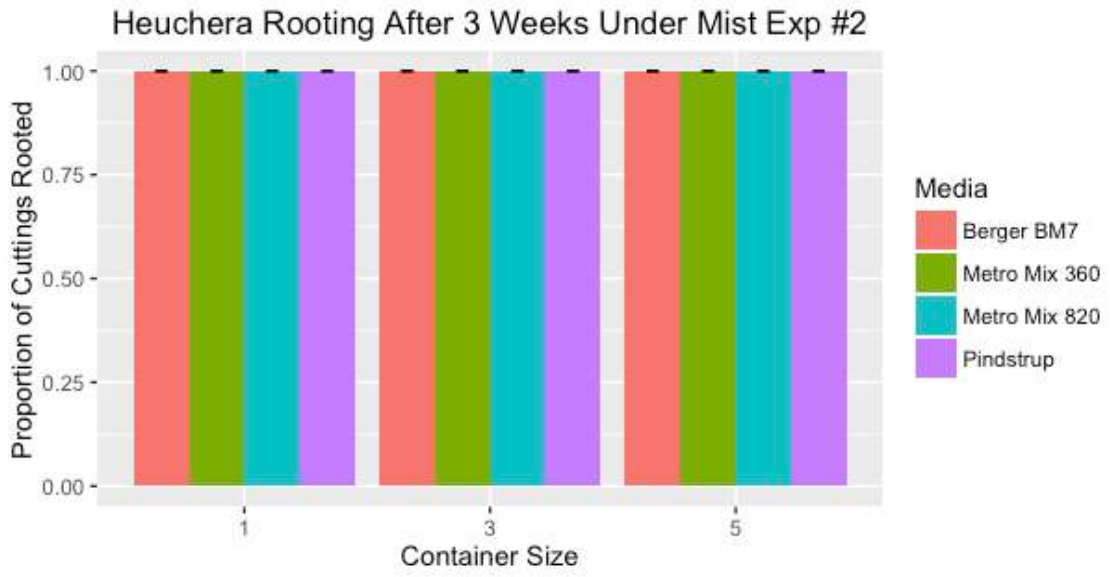


Figure A3.1.25 Experiment #2 bar plot of mean proportion of cuttings rooted after 3 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Table A3.1.14 Experiment #2 percent of cuttings rooted after 4 weeks under mist for each treatment combination. Chi Square p-value = 1.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	100.0
#1 (2.84L)	Metro Mix 360	100.0
#1 (2.84L)	Metro Mix 820	100.0
#1 (2.84L)	Pindstrup	100.0
#3 (11.35L)	Berger BM-7	100.0
#3 (11.35L)	Metro Mix 360	100.0
#3 (11.35L)	Metro Mix 820	100.0
#3 (11.35L)	Pindstrup	100.0
#5 (14.55L)	Berger BM-7	100.0
#5 (14.55L)	Metro Mix 360	100.0
#5 (14.55L)	Metro Mix 820	100.0
#5 (14.55L)	Pindstrup	100.0

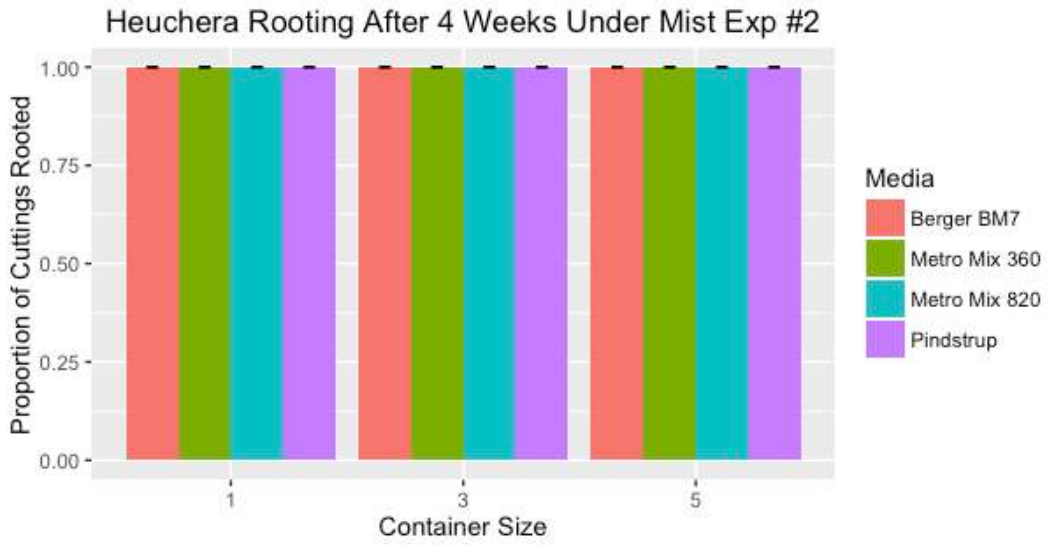


Figure A3.1.26 Experiment #2 bar plot of mean proportion of cuttings rooted after 4 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: RootNum
            Sum Sq  Df F value   Pr(>F)
(Intercept)  689.5   1 40.6035 4.92e-10 ***
Size          40.2   2  1.1828   0.3074
Media         18.6   3  0.3643   0.7788
Size:Media    64.2   6  0.6304   0.7060
Residuals   7114.7 419
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.1.27 Experiment #2 two-way ANOVA table for mean number of visible roots after 2 weeks under mist.

Table A3.1.15 Experiment #2 mean visible roots after 2 weeks under mist for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Visible Roots	95% Confidence Interval	Significance Group
Berger BM-7	1.33	0.55-2.11	1
Metro Mix 360	1.09	0.31-1.87	1
Metro Mix 820	1.06	0.28-1.84	1
Pindstrup	1.57	0.79-2.35	1
#1 Container	1.69	1.01-2.37	1
#3 Container	1.11	0.44-1.79	1
#5 Container	0.99	0.31-1.66	1

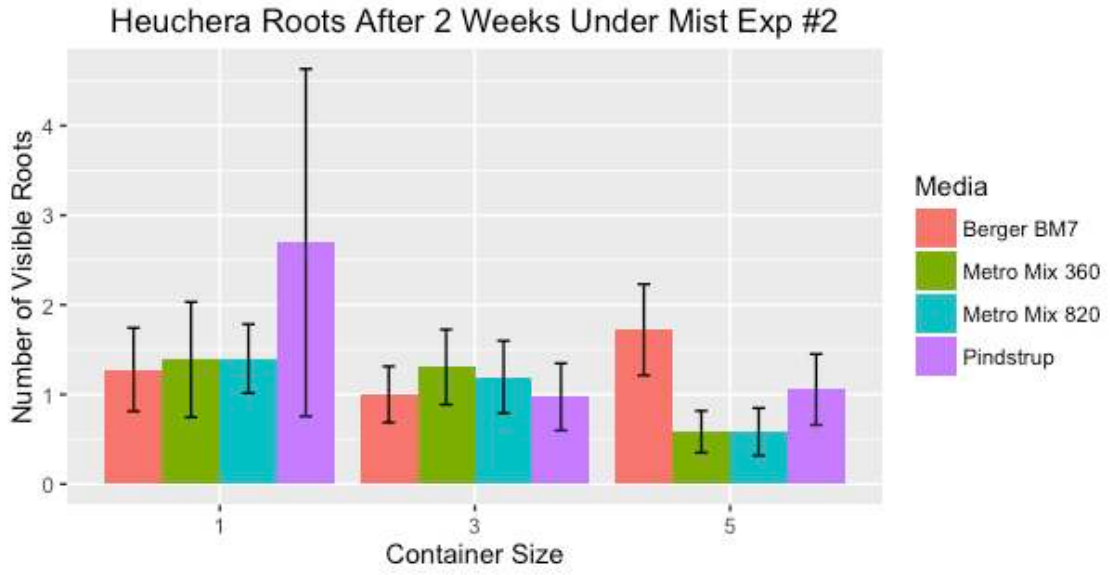


Figure A3.1.28 Experiment #2 bar plot of mean number of visible roots after 2 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

A3.2 *Zauschneria garrettii* 'PWWG01S' ORANGE CARPET®

```
Anova Table (Type III tests)

Response: Cuttings1
            Sum Sq  Df  F value    Pr(>F)
(Intercept)  88089   1 653.4728 < 2.2e-16 ***
Size          1900   2   7.0475  0.001338 **
Media          642   3   1.5878  0.196678
Size:Media     630   6   0.7792  0.588048
Residuals    14289 106
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.2.1 Experiment #2 two-way ANOVA table for mean number of cuttings per plant during harvest #1.

Table A3.2.1 Experiment #2 mean number of cuttings per plant during harvest #1 for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Cuttings per Plant	95% Confidence Interval	Significance Group
#1 (2.84L)	21.91	18.17-25.64	1
#3 (11.35L)	28.53	24.89-32.16	2
#5 (14.55L)	31.60	27.96-35.24	2

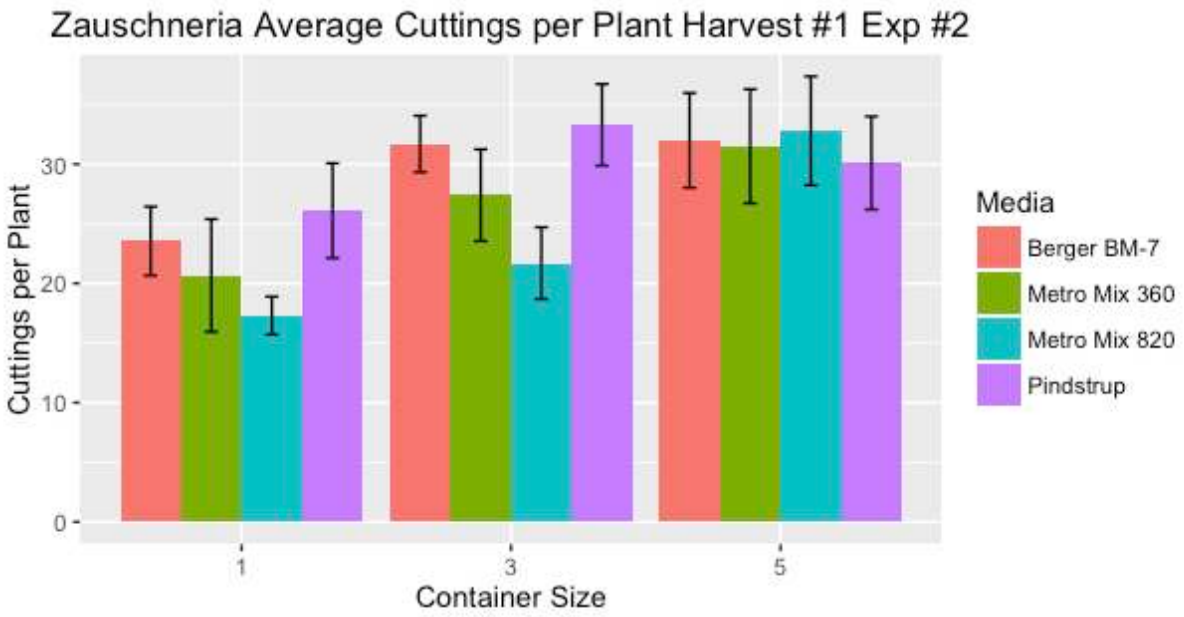


Figure A3.2.2 Experiment #2 mean number of cuttings per plant during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: Cuttings3
             Sum Sq  Df   F value    Pr(>F)
(Intercept) 285228   1 1564.4518 < 2.2e-16 ***
Size         17078   2   46.8357 2.657e-15 ***
Media          599   3    1.0947    0.3548
Size:Media    1546   6    1.4131    0.2164
Residuals    19326 106
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure A3.2.3 Experiment #2 two-way ANOVA table for mean cuttings per plant during harvest #3.

Container Size	Mean Cuttings per Plant	95% Confidence Interval	Significance Group
#1 (2.84L)	32.63	28.28-36.98	1
#3 (11.35L)	53.63	49.39-57.86	2
#5 (14.55L)	61.35	57.12-65.58	3

Table A3.2.2 Experiment #2 mean cuttings per plant during harvest #3 for each container size averaged over media. Means with different significance groups are significantly different at the level of $P<0.05$.

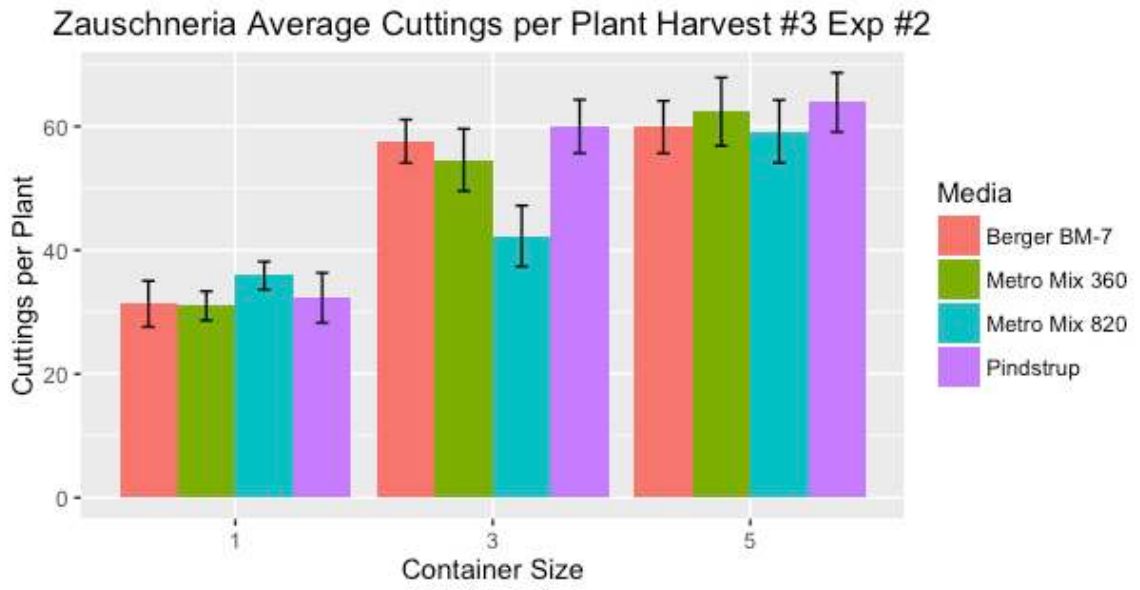


Figure A3.2.4 Experiment #2 bar plot of mean cuttings per plant during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh1
             Sum Sq  Df   F value Pr(>F)
(Intercept) 1.72157   1 1897.1846 <2e-16 ***
Size        0.00091   2    0.5037 0.6057
Media       0.00127   3    0.4667 0.7061
Size:Media  0.00275   6    0.5057 0.8029
Residuals   0.09710 107
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure A3.2.5 Experiment #1 two-way ANOVA table for mean fresh weight per cutting during harvest #1.

Table A3.2.3 Experiment #1 mean fresh weight per cutting during harvest #1 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of $P<0.05$.

Treatment	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.116	0.106-0.127	1
Metro Mix 360	0.120	0.110-0.131	1
Metro Mix 820	0.119	0.108-0.130	1
Pindstrup	0.125	0.114-0.137	1
#1 Container	0.117	0.107-0.127	1
#3 Container	0.121	0.111-0.131	1
#5 Container	0.123	0.114-0.133	1

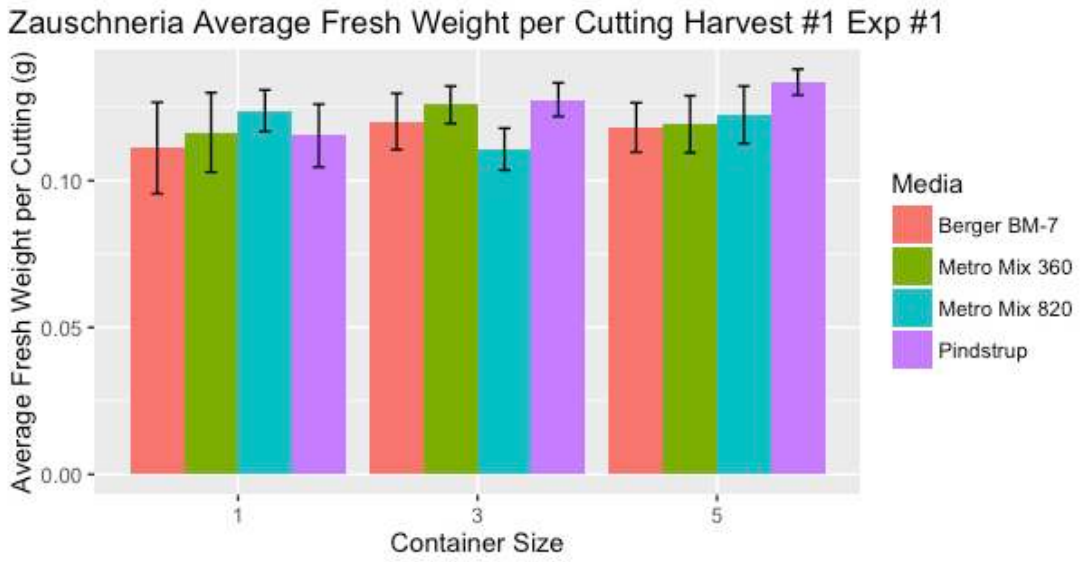


Figure A3.2.6 Experiment #1 bar plot of mean fresh weight per cutting during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh2
             Sum Sq  Df   F value  Pr(>F)
(Intercept) 2.33886   1 3161.9290 < 2e-16 ***
Size        0.00391   2    2.6440 0.07567 .
Media       0.00443   3    1.9980 0.11861
Size:Media  0.00195   6    0.4399 0.85065
Residuals   0.07989 108
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure A3.2.7 Experiment #1 two-way ANOVA for mean fresh weight per cutting during harvest #2.

Table A3.2.4 Experiment #1 mean fresh weight per cutting during harvest #2 for each media treatment average over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.130	0.120-0.140	1
Metro Mix 360	0.146	0.137-0.157	1
Metro Mix 820	0.142	0.132-0.152	1
Pindstrup	0.140	0.130-0.150	1
#1 Container	0.132	0.123-0.140	1
#3 Container	0.143	0.135-0.152	1
#5 Container	0.144	0.136-0.153	1

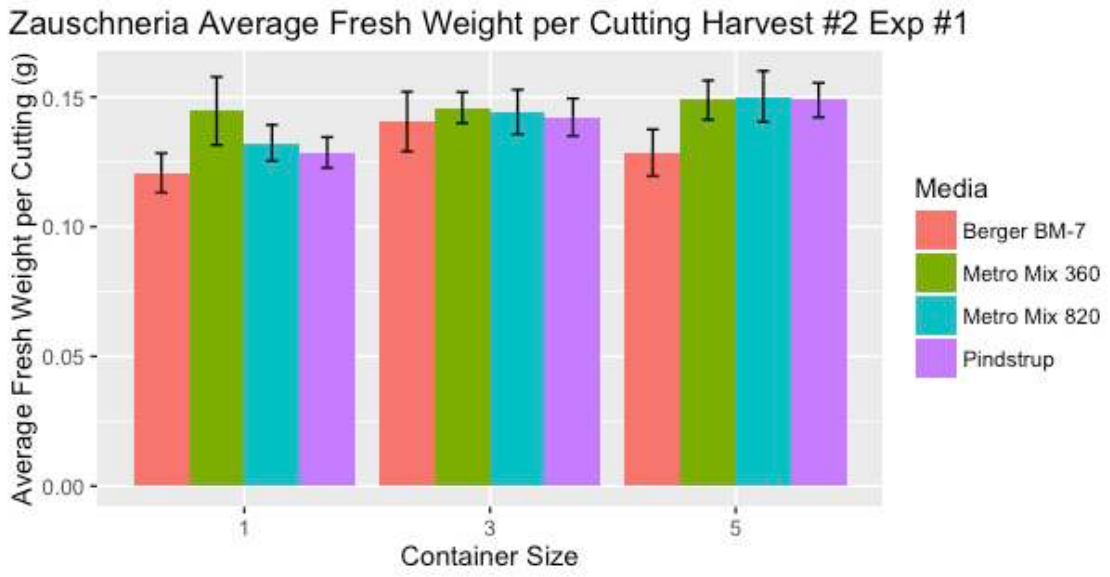


Figure A3.2.8 Experiment #1 bar plot of mean fresh weight per cutting during harvest #2 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh1
             Sum Sq  Df   F value  Pr(>F)
(Intercept) 1.83873   1 4719.4868 < 2e-16 ***
Size        0.00033   2    0.4281 0.65291
Media       0.00297   3    2.5371 0.06065 .
Size:Media  0.00313   6    1.3382 0.24683
Residuals   0.04091 105
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.2.9 Experiment #2 two-way ANOVA table for mean fresh weight per cutting during harvest #1.

Table A3.2.5 Experiment #2 mean fresh weight per cutting during harvest #1 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.127	0.120-0.134	1, 2
Metro Mix 360	0.118	0.111-0.126	1
Metro Mix 820	0.125	0.118-0.132	1, 2
Pindstrup	0.132	0.125-0.139	2
#1 Container	0.126	0.120-0.133	1
#3 Container	0.123	0.117-0.129	1
#5 Container	0.127	0.121-0.133	1

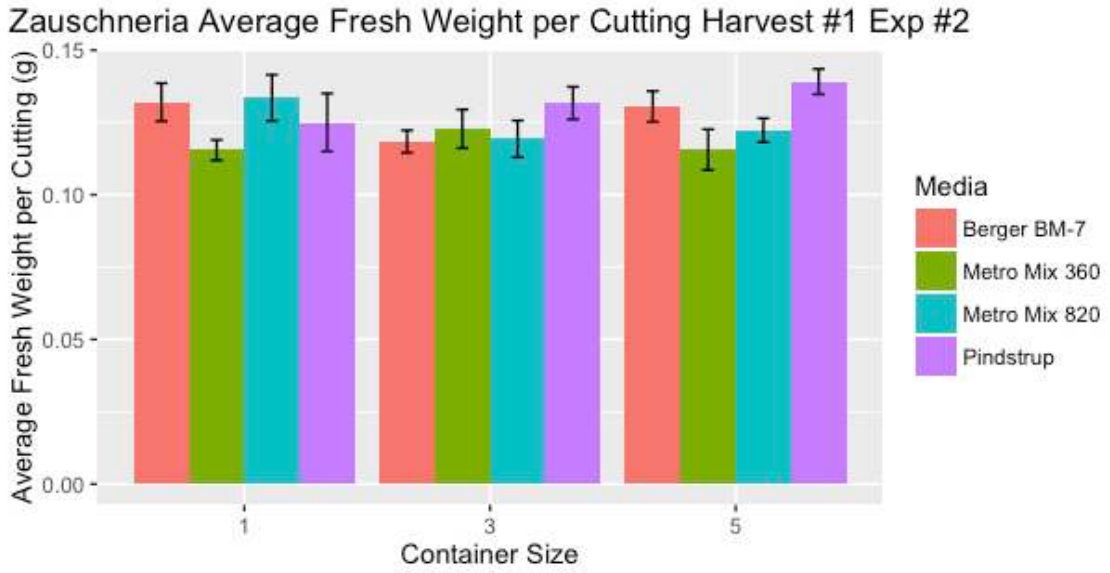


Figure A 3.2.10 Experiment #2 bar plot of mean fresh weight per cutting during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGFresh3
             Sum Sq  Df    F value Pr(>F)
(Intercept) 3.5712   1 22668.1529 <2e-16 ***
Size        0.0003   2     1.0901 0.3400
Media       0.0000   3     0.0028 0.9998
Size:Media  0.0004   6     0.4610 0.8357
Residuals   0.0165 105
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A 3.2.11 Experiment #2 two-way ANOVA table for mean fresh weight per cutting during harvest #3.

Table A3.2.6 Experiment #2 mean fresh weight per cutting during harvest #3 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Fresh Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.175	0.170-0.180	1
Metro Mix 360	0.175	0.170-0.180	1
Metro Mix 820	0.175	0.170-0.179	1
Pindstrup	0.175	0.170-0.179	1
#1 Container	0.173	0.169-0.177	1
#3 Container	0.175	0.171-0.179	1
#5 Container	0.177	0.173-0.181	1

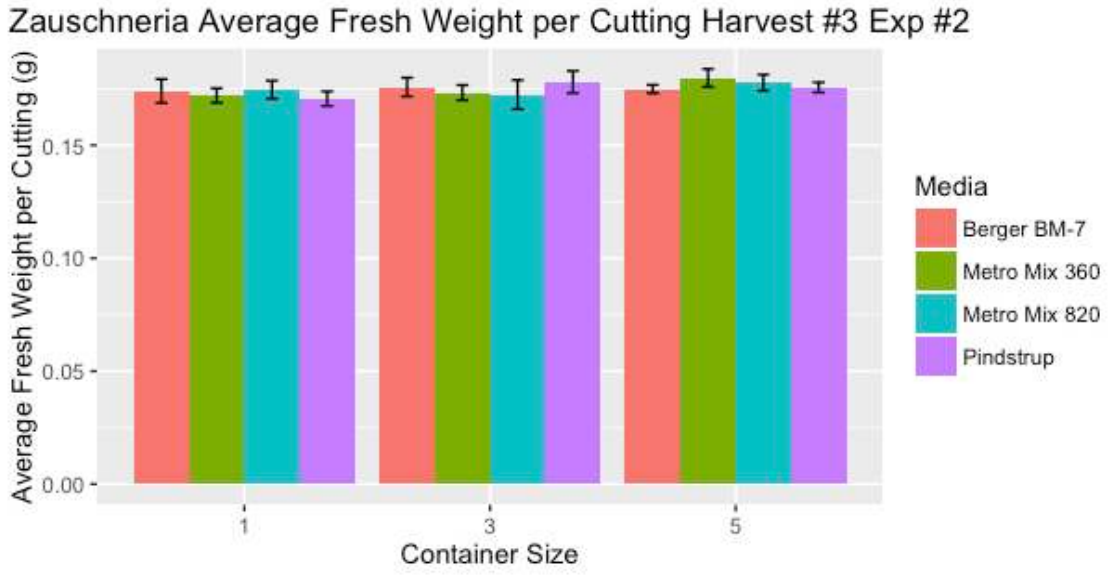


Figure A3.2.12 Experiment #2 bar plot of mean fresh weight per cutting during harvest #3 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry
              Sum Sq  Df    F value Pr(>F)
(Intercept) 0.219393   1 13359.8749 <2e-16 ***
Size        0.000046   2     1.3857 0.2547
Media       0.000102   3     2.0644 0.1094
Size:Media  0.000147   6     1.4937 0.1874
Residuals   0.001724 105
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.2.13 Experiment #2 two-way ANOVA table for mean dry weight per cutting averaged over harvest date.

Table A3.2.7 Experiment #2 mean dry weight per cutting averaged over harvest date for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of $P<0.05$.

Media	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.044	0.042-0.045	1
Metro Mix 360	0.042	0.041-0.044	1
Metro Mix 820	0.043	0.041-0.044	1
Pindstrup	0.045	0.043-0.046	1
#1 Container	0.043	0.042-0.044	1
#3 Container	0.043	0.042-0.044	1
#5 Container	0.044	0.043-0.045	1

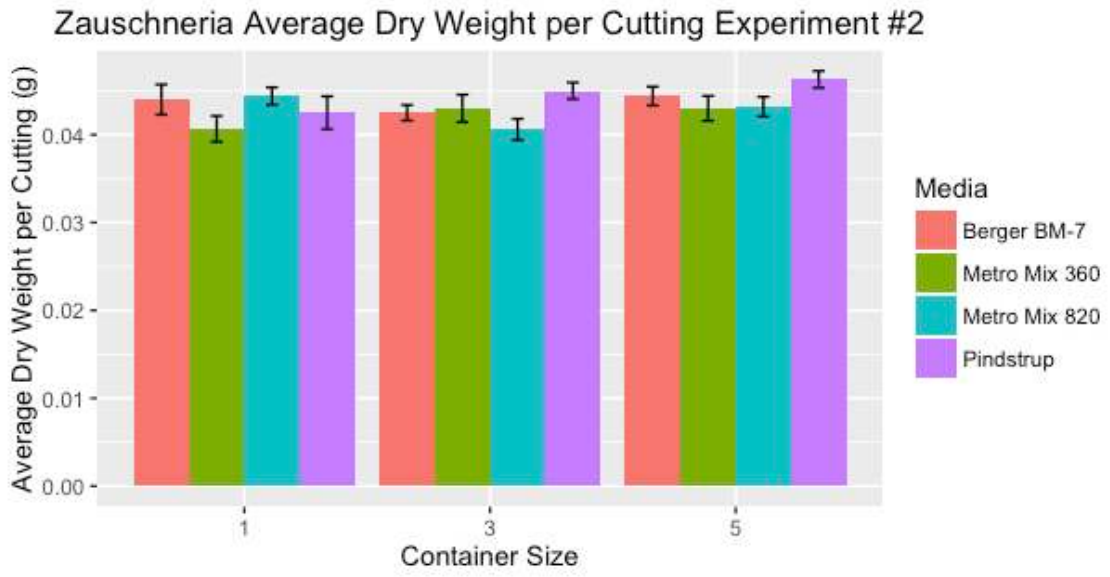


Figure A3.2.14 Experiment #2 bar plot of mean dry weight per cutting averaged over harvest date for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: AVGDry1
             Sum Sq  Df   F value Pr(>F)
(Intercept) 0.130105   1 4712.1345 <2e-16 ***
Size        0.000076   2    1.3720 0.2581
Media       0.000118   3    1.4232 0.2402
Size:Media  0.000281   6    1.6936 0.1297
Residuals   0.002899 105
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.2.15 Experiment #2 two-way ANOVA table for mean dry weight per cutting during harvest #1.

Table A3.2.8 Experiment #2 mean dry weight per cutting during harvest #1 for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Dry Weight per Cutting (g)	95% Confidence Interval	Significance Group
Berger BM-7	0.034	0.032-0.036	1
Metro Mix 360	0.032	0.030-0.034	1
Metro Mix 820	0.033	0.031-0.035	1
Pindstrup	0.034	0.032-0.036	1
#1 Container	0.034	0.033-0.036	1
#3 Container	0.033	0.031-0.034	1
#5 Container	0.033	0.031-0.035	1

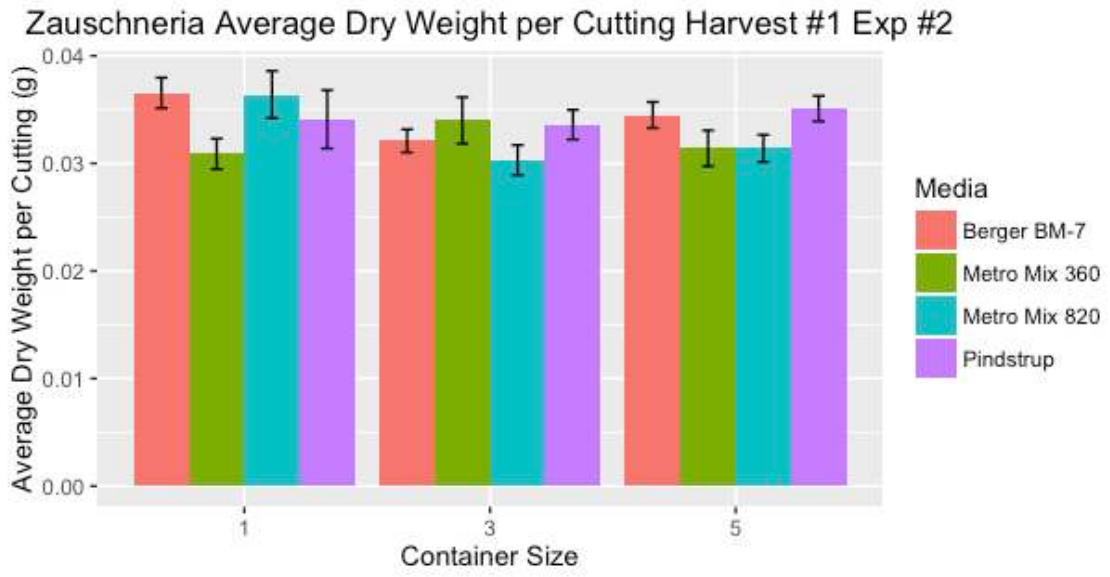


Figure A3.2.16 Experiment #2 bar plot of mean dry weight per cutting during harvest #1 for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: RootNum
             Sum Sq  Df F value    Pr(>F)
(Intercept)  13861   1 70.3878 2.553e-15 ***
Size          6138   2 15.5838 3.869e-07 ***
Media          323   3  0.5464   0.65097
Size:Media    2175   6  1.8409   0.09127 .
Residuals    54351 276
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.2.17 Experiment #1 two-way ANOVA table for mean number of visible roots after 3 weeks under mist.

Table A3.2.9 Experiment #1 mean number of visible roots after 3 weeks under mist for each container size averaged over media treatment. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Visible Roots	95% Confidence Interval	Significance Group
#1 (2.84L)	3.26	0.44-6.08	1
#3 (11.35L)	4.10	1.28-6.92	1
#5 (14.55L)	13.45	10.63-16.27	2

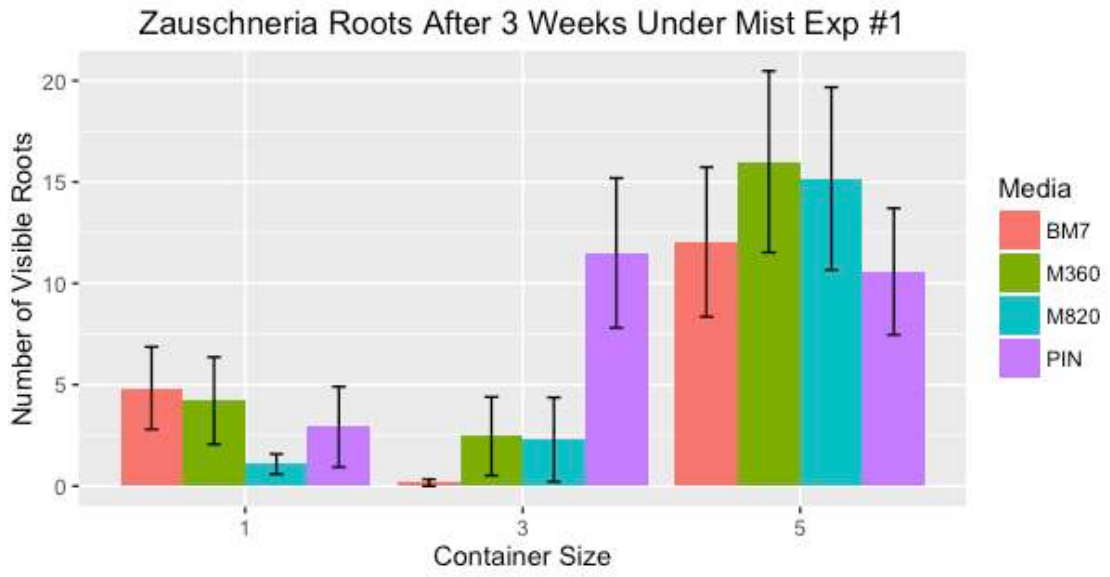


Figure A3.2.18 Experiment #1 bar plot of mean number of visible roots after 3 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: RootNum
             Sum Sq  Df F value    Pr(>F)
(Intercept)  24360   1 98.8150 < 2.2e-16 ***
Size         10171   2 20.6299 2.843e-09 ***
Media          545   3  0.7373   0.53024
Size:Media    2678   6  1.8106   0.09553 .
Residuals   103539 420
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.2.19 Experiment #1 two-way ANOVA table for mean number of visible roots after 4 weeks under mist.

Table A3.2.10 Experiment #1 mean number of visible roots after 4 weeks under mist for each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Container Size	Mean Visible Roots	95% Confidence Interval	Significance Group
#1 (2.84L)	3.53	0.96-6.10	1
#3 (11.35L)	4.66	2.09-7.23	1
#5 (14.55L)	14.34	11.77-16.91	2

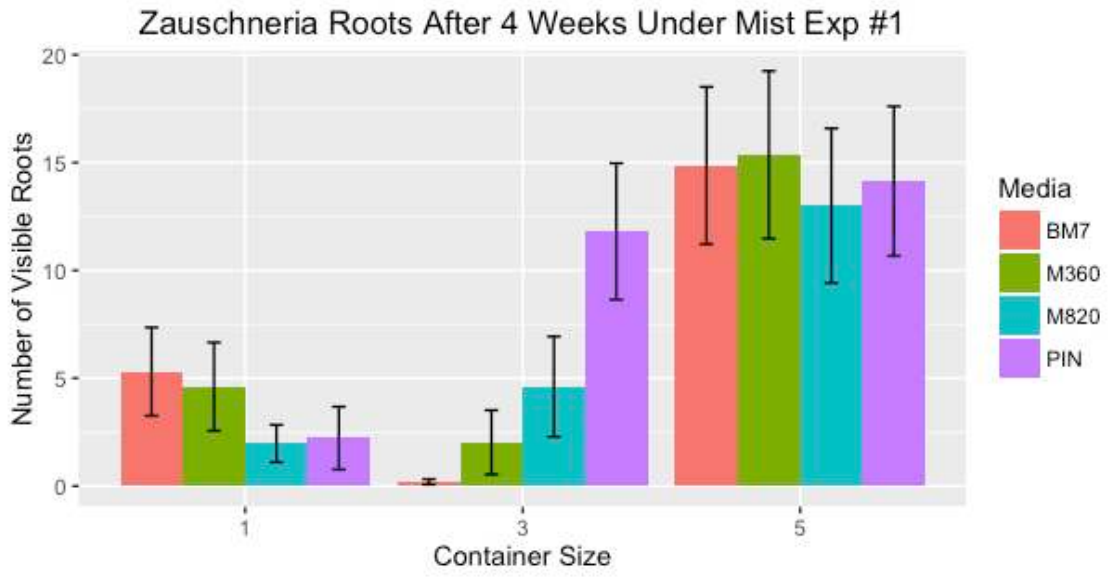


Figure A3.2.20 Experiment #1 bar plot of mean number of visible roots after 4 wees under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Table A3.2.11 Experiment #2 mean percentage of rooted cuttings after 1 week under mist. Chi Square p-value = 0.9241.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	13.9
	Metro Mix 360	19.4
	Metro Mix 820	25.0
	Pindstrup	27.8
#3 (11.35L)	Berger BM-7	19.4
	Metro Mix 360	19.4
	Metro Mix 820	30.6
	Pindstrup	27.8
#5 (14.55L)	Berger BM-7	19.4
	Metro Mix 360	22.2
	Metro Mix 820	22.9
	Pindstrup	19.4

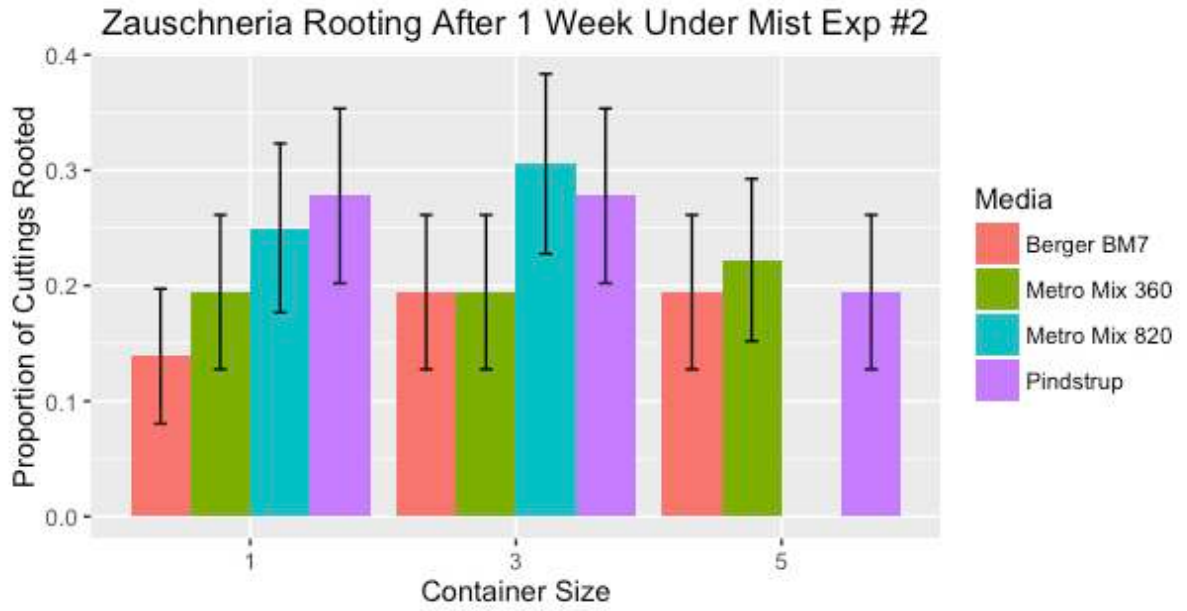


Figure A3.2.21 Experiment #2 bar plot of mean proportion of cuttings rooted after one week under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

Table A3.2.12 Experiment #2 mean percentage of cuttings rooted after 3 weeks under mist for each treatment combination.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	69.4
	Metro Mix 360	69.4
	Metro Mix 820	61.1
	Pindstrup	66.7
#3 (11.35L)	Berger BM-7	77.8
	Metro Mix 360	72.2
	Metro Mix 820	86.1
	Pindstrup	69.4
#5 (14.55L)	Berger BM-7	66.7
	Metro Mix 360	77.8
	Metro Mix 820	83.3
	Pindstrup	66.7

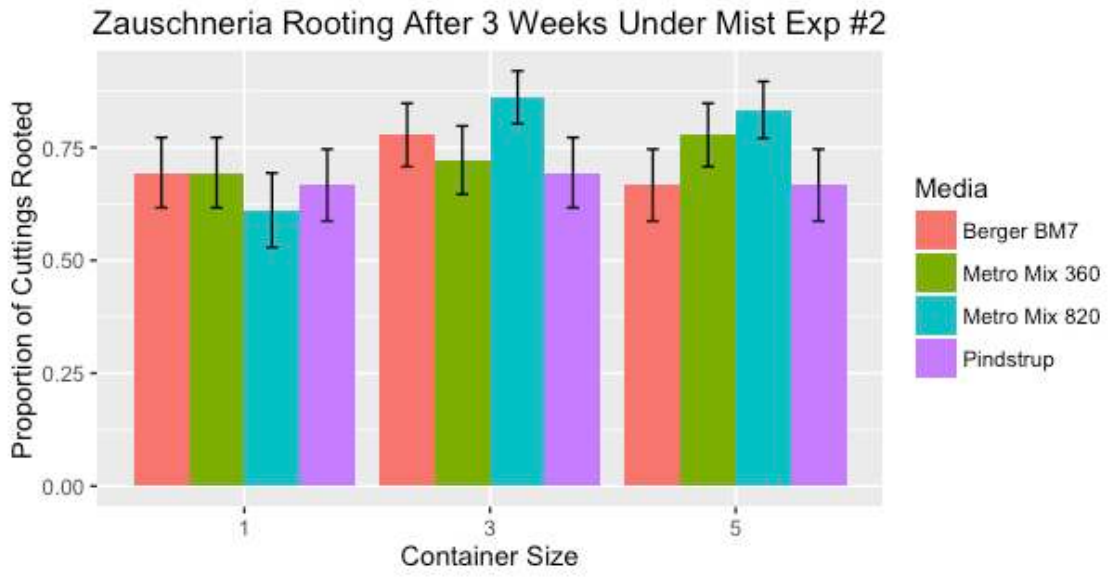


Figure A3.2.22 Experiment #2 bar plot of mean proportion of cuttings rooted after 3 weeks under mist. Standard error bars indicate a 95% confidence interval for the mean.

Table A3.2.13 Experiment #2 mean percentage of cuttings rooted after 4 weeks under mist for each treatment combination.

Container Size	Media	Percent Rooted
#1 (2.84L)	Berger BM-7	63.9
	Metro Mix 360	58.3
	Metro Mix 820	52.8
	Pindstrup	63.9
#3 (11.35L)	Berger BM-7	63.9
	Metro Mix 360	66.7
	Metro Mix 820	75.0
	Pindstrup	63.9
#5 (14.55L)	Berger BM-7	66.7
	Metro Mix 360	58.3
	Metro Mix 820	72.2
	Pindstrup	52.8

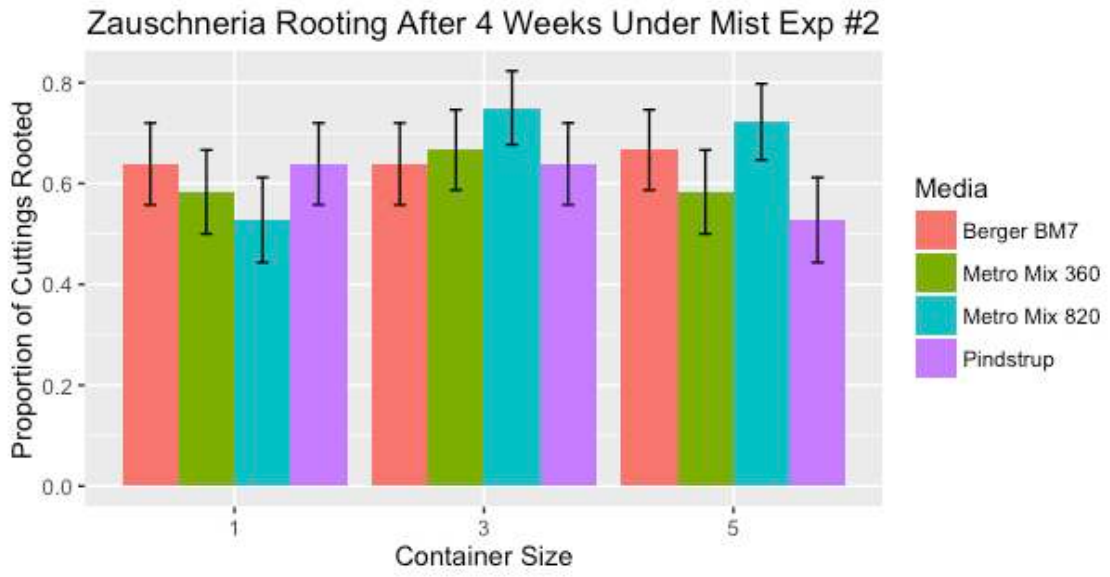


Figure A3.2.23 Experiment #2 bar plot of mean proportion of cuttings rooted after 4 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: RootNum
             Sum Sq  Df F value    Pr(>F)
(Intercept)   95.39   1 20.8816 6.433e-06 ***
Size          22.03   2  2.4115   0.09092 .
Media          9.19   3  0.6707   0.57038
Size:Media    21.75   6  0.7934   0.57548
Residuals   1918.64 420
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure A3.2.24 Experiment #2 two-way ANOVA table for mean number of visible roots after 2 weeks under mist.

Table A3.2.14 Experiment #2 mean number of visible roots after 2 weeks under mist for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Visible Roots	95% Confidence Interval	Significance Group
Berger BM-7	0.71	0.31-1.12	1
Metro Mix 360	0.32	0.00-0.73	1
Metro Mix 820	0.42	0.01-0.82	1
Pindstrup	0.43	0.02-0.83	1
#1 Container	0.17	0.00-0.52	1
#3 Container	0.53	0.18-0.88	1
#5 Container	0.71	0.36-1.06	1

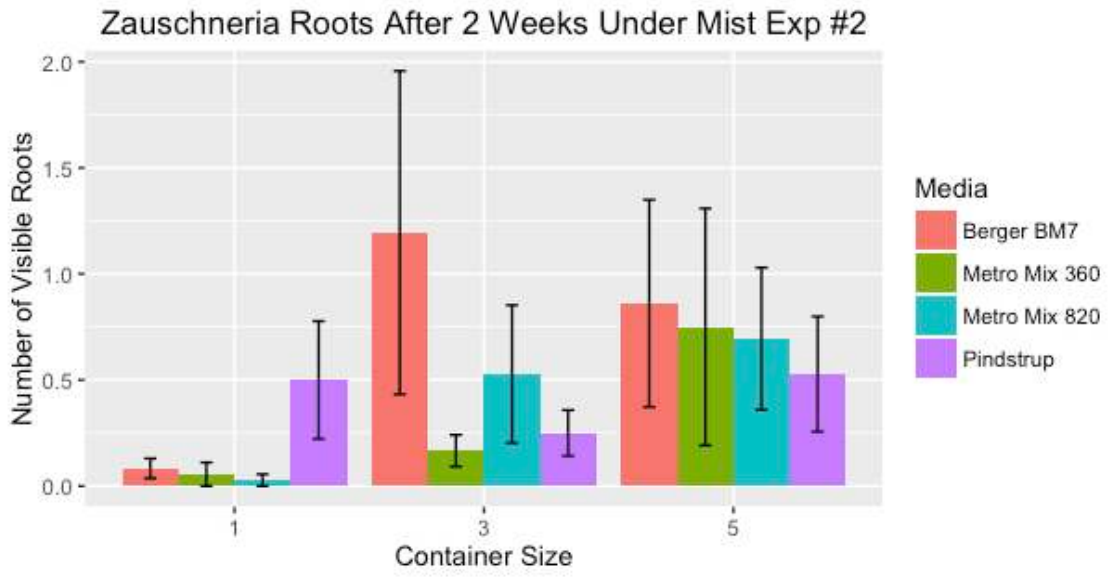


Figure A3.2.25 Experiment #2 bar plot of mean number of visible roots after 2 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.

```
Anova Table (Type III tests)

Response: RootNum
            Sum Sq  Df F value  Pr(>F)
(Intercept)  20063   1 94.3836 < 2e-16 ***
Size           737   2  1.7333 0.17797
Media         1044   3  1.6373 0.18010
Size:Media    2538   6  1.9901 0.06587 .
Residuals    89278 420
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure A3.2.26 Experiment #2 two-way ANOVA table for mean number of visible roots after 4 weeks under mist.

Table A3.2.15 Experiment #2 mean number of visible roots after 4 weeks under mist for each media treatment averaged over size and each container size averaged over media. Means with different significance groups are significantly different at the level of P<0.05.

Treatment	Mean Visible Roots	95% Confidence Interval	Significance Group
Berger BM-7	9.05	6.29-11.80	1
Metro Mix 360	5.17	2.41-7.92	1
Metro Mix 820	5.57	2.82-8.33	1
Pindstrup	7.47	4.71-10.23	1
#1 Container	6.48	4.09-8.87	1
#3 Container	8.56	6.17-10.94	1
#5 Container	5.41	3.02-7.80	1

Figure A3.2.27 Experiment #2 bar plot of mean number of visible roots after 4 weeks under mist for each treatment combination. Standard error bars indicate a 95% confidence interval for the mean.