COMPETITIVE EFFECTS OF WEEDS ON CONTAINER-GROWN ORNAMENTAL PLANTS

By

Greeshmanth Alluri

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Horticulture – Master of Science

2024

ABSTRACT

Weed-infested environments lead to the improper establishment of ornamental crops, particularly in containerized production, where weeds compete more for light, water, nutrients, and space with ornamental plants due to confined conditions. Hence, the objectives of this research project were to evaluate strategic fertilizer placement methods to assess the optimum container size for containerized ornamental production to mitigate weed proliferation while promoting ornamental plant growth. Two ornamental species, *Rosa rubiginosa* L. (rose) and *Spiraea japonica* L. f. (spirea), were studied for fertilizer placement studies, while two others, *Hydrangea macrophylla* (Thunb.) Ser. (hydrangea) and *Syringa vulgaris* L. (syringa), were evaluated for container size study. These experiments were conducted in a greenhouse setting at the Horticulture Teaching and Research Centre, Michigan State University, using two commonly found weeds in nurseries, *Digitaria Sanguinalis* (L.) Scop. (large crabgrass) and *Amaranthus hybridus* L. (smooth pigweed), at densities of 0, 1, 3, and 6 for both experiments. Both studies followed a randomized complete block design with the experiments repeated twice for each study. Results showed that sub-dressing can be an efficient fertilizer placement method that controls weeds and enhances ornamental growth. Three gallon containers appeared to promote ornamental growth, particularly in hydrangeas compared to other container sizes such as 1.5-gallon and 0.67-gallon but failed to eradicate weed proliferation. However, 0.67-gallon containers reduced the growth of both weed species compared to 1.5-gallon and 3-gallon containers, though they did not promote ornamental growth and, in turn, decreased ornamental growth. Therefore, future studies on container sizes should be conducted with different ornamental and weed species possessing different growth habits to determine the optimal container size.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my advisor, Dr. Debalina Saha. Thank you for welcoming me into your lab and to MSU, and for providing me with the opportunity to further my education. Your guidance and assistance have been invaluable in shaping me into a successful graduate student. I am thankful for your encouragement in helping me achieve my goals. I am also deeply grateful to Dr. Erin Burns and Dr. Sushila Chaudhari for serving on my advisory committee, offering invaluable feedback, and imparting their knowledge. Additionally, I extend my thanks to Carolyn Fitzgibbon, Greta Gallina, Manjot Kaur Sidhu, Rachel Mickey, and Michael Ambel-Lucas for their exceptional assistance with data collection and experimental setup, which greatly contributed to the smooth progression of my research. I am indebted to the Statistical Consulting Center in the College of Agriculture and Natural Resources at MSU for their invaluable support in data analysis. Also, I would like to thank Michigan State University Project GREEEN (Generating Research and Extension to meet Economic and Environmental Needs) and Michigan Department of Agriculture and Rural Development (MDARD) Horticulture Fund 2022-2023 for funding this entire project and Spring Meadows Nursery for donating all the ornamental plants that were used in this study. Finally, heartfelt appreciation goes to my friends and family for their unwavering love and support throughout this journey.

TABLE OF CONTENTS

CHAPTER 1: LITERATURE REVIEW

Alluri, G.; Saha, D. Emerging Perspectives on Non-Chemical Weed Management Tactics in Container Ornamental Production in the United States. Horticulturae 2024, 10, 281. https://doi.org/10.3390/horticulturae10030281

Abstract

Weeds are undesirable plants that can interfere with human activities and can hamper crop production and practices. The competition among ornamentals and weeds for space, nutrition, light, and moisture within a restricted area, such as in container production, can be intense and destructive. In response to increasing concerns regarding herbicide injuries and the effects of pesticide use on the environment, many growers are extremely interested in non-chemical pest-management approaches. There are various non-chemical strategies to control weeds in containers, which include scouting, sanitation practices, hand weeding, mulching, irrigation management, substrate stratification, mulch discs or geo discs, lid bags, and fertilizer placement. In a restricted growth environment, weeds have been shown to reduce crop growth significantly. Limited information is available on the effects of weed densities and container sizes on ornament–weed competition within containerized production and how the concepts of fertilizer placement can be used efficiently to control weeds in containers without using any herbicides on the ornamentals. There is an immediate need to evaluate the interference and competitive effects of pernicious weed species in container-grown ornamentals in the North Central United States and to develop effective non-chemical weed control strategies by altering fertilizer placement in container production.

1. Introduction

Controlling weeds in nursery container production is an important aspect, as they can compete with ornamental plants for soil, nutrients, water, light, and space within the container. As a result, there is a decrease in the quality, aesthetic, and market value of the ornamental plants, and sometimes ornamental crops can die due to severe competition with heavy infestations of weed species. In addition, weeds can harbor insects, pests, diseases, and pathogens, resulting in further reduction of market value.

Other than a select group of graminicides, which can be applied to certain ornamentals, there are virtually no post weed control options in container nursery production other than hand weeding. Thus, weed control is typically achieved through the use of preemergence herbicides in combination with supplemental hand weeding. Weed control in container nursery production is often the highest production cost encountered by nursery growers, often exceeding USD 4000 per acre [1,2]. A recent study in 2017, conducted by Ingram et al. [3], on three production scenarios for *Buxus microphylla* var. japonica 'Green Beauty' showed that weed control (which included hand weeding and herbicide application costs) is an important component for variable costs in nursery production as it can cost 38% of the total production cost per shrub in field production and 7% of the total production cost per shrub in number 1 containers [3]. In Michigan, the total financial impact of nursery and landscape production, including backward linked industries, is USD 1.26 billion [4]. According to Kundson [5], the ornamental/floriculture industries of Michigan directly employ 13,269 people and a total of 16,663 employees. So, a little improvement in weed control can help these nursery growers and greenhouse operators to improve their overall profitability and thereby directly impact Michigan's billion-dollar nursery production. If weeds are successfully controlled there can be improvements in the overall quality and market value of ornamentals and a reduction in labor costs, thereby increasing the profit margins of Michigan growers.

Over the past twenty years, ornamental production with respect to the world has changed significantly. In the global scenario of ornamental and cut flowerpot plant sales, the U.S. accounts for 12.5% in total and stands amongst the top three nations, preceded by China (18.6%) and Europe (31.0%) with second and first places, respectively. The greatest challenge for ornamental production is sustainability, and data to highlight the problematic concerns which need improvement through environmental contributions pertaining to production, storage, and transportation can be obtained from life cycle assessments (LCAs) of ornamentals [6].

In the U.S. for the past 15 years, amongst the nursery industry segment container production is a rapidly growing sector, which is likely to expand further. The critical problem faced in container-grown nurseries is weed infestations because resources like water, nutrients, and the availability of soil‐air are restricted to the capacity of the container, for which they compete with the main plant or ornamental [1]. According to growers in nurseries, based on the type of weed species being removed from the containers manually, they allocate an estimated cost of USD 500 to USD 4000/acre or USD 1235 to USD 9880/ha. A value of approximately USD 7000/acre or USD 17,290/ha is the estimated economic damage occurring due to the infestation of weeds [2]. The efficient control of weeds is indeed crucial because the intensity of destruction they create is undervalued generally [1]. If weed control approaches are upgraded by reducing the cost of expenses, it would remarkably impact the industry in a positive way [2].

To manage weeds efficiently, a good aggregate of robust sanitary measures, best cultural practices, and proper usage of pre-emergence herbicides is required. In container production, preventive measures are important to control weeds because in field production, crops are sown directly into the soil which makes it easy to effectively control weeds even after their germination by applying herbicides or by mechanical cultivation, whereas in the case of container crops a direct spraying of herbicides is not appropriate. So, for profitable weed management in containers, it is always suggested to prevent weeds even before they germinate [7]. Chemical methods of weed control may not be applied to greenhouse/enclosed structures or to several sensitive ornamental species due to the potentiality of herbicide injury. In addition, over usage of herbicides can lead to environment-related issues such as surface runoff, ground water contamination, and the off-target movement of herbicides. Repeated application of the same herbicide with a similar mechanism of action can even cause herbicide resistance among weed species. Taking these into consideration, non-chemical methods are more environmentally friendly in these instances. However, growers may not be aware of different types of non-chemical techniques that can be applied to these ornamental production systems. Hence, the objectives of this literature review article are to summarize the previous and current non-chemical weed control practices that are prevalent in the United States's ornamental crop production systems and to discuss the knowledge gaps and future research directions.

2. Importance of Ornamental Crop Production

The Green Industry, also referred to as the U.S. environmental horticulture sector, consists of various entities, such as horticultural nurseries and turf producers, contractors, landscape designers, retail garden centers, maintenance firms, home centers, mass merchandisers with landscape departments, and middlemen like brokers and horticultural distribution centers. Regardless of economic downturns, this industry is among the fastest-growing sectors within the country's agricultural economy, and it is frequently expanding and advancing [8]. Over the past three decades, the Green Industry has been known for its rapid growth, innovation, and constant evolution. Nonetheless, as demand growth slows down and operating margins become compact, it suggests that the industry is entering a stage of maturation [9]. In 2018, a survey (Green Industry Research Consortium) was conducted among 1727 participants to report their annual sales, which amounted to a total of USD 2.392 billion (B). On average, each firm had sales of USD 1.39 million (M). Wholesale market channels had sales totaling USD 1.74 B and averaging USD 1.34 M per firm, while retail sales had a total of USD 474 M, with an average of USD 0.53 M per firm. The survey also showed that the Southeast region stood out with annual sales of USD 542 M, while the Midwest (USD 489 M) followed by the Pacific (USD 485 M), Southcentral (USD 280 M), Northeast (USD 276 M), Appalachian (USD 135 M), Mountain (USD 125 M), and Great Plains (USD 61 M) reported lower sales. The retail sales accounted for 20 percent of the overall reported annual sales and varied across the regions, ranging from 7 percent in the Southeast to 73 percent in the Great Plains [10].

In 2019, the wholesale value of floriculture crops decreased by 7% when compared to the previous year. The top five states in 2019 were California, Florida, Michigan, New Jersey, and Ohio, which accounted for 69% of the total value or USD 3.04 billion [11]. In 2020, the wholesale value of floriculture crops increased by 9% when compared to the previous year. Growers with USD 10,000 or more in sales are estimated to have contributed to a total crop value of USD 4.80 billion, which is higher than the USD 4.42 billion recorded in 2019. The top five states in 2020, including Florida, California, Michigan, New Jersey, and Ohio, were responsible for 65% of the total value, with a combined contribution of USD 3.13 billion [12].

In 2018, the U.S. Green Industry survey respondents had a workforce of 35,719 individuals, with permanent employees making up 57.8% (20,631); temporary, part-time, or seasonal employees accounting for 35.4% (12,633); and out of the total number of employees, 6.9% (2455) were foreign national workers who are permitted to work in the United States under the H2A visa program. The regions with the most reported employment were the Southeast and Midwest, with 10,474 and 9162 employees, respectively [10]. The mean number of employees per company across the country was 20.8, comprising 11 full-time and permanent staff; 7.5 part-time, temporary, or seasonal workers; and 1.9 H2A laborers [10].

However, many firms (71%) indicated that they maintained their number of full-time/permanent employees over the past five years. Meanwhile, 11% of firms reported a decrease in employment, and 19% reported an increase. Similarly, around 68% of firms kept their number of part-time/temporary/seasonal employees consistent, while 12% reduced employment and 20% increased it [10].

3. Impact of Weeds on Ornamental Crop Production

Weeds are unwanted and undesirable plants that can hamper crop production and practices and can interfere with human activities. In a restricted area such as in container production, the competition between ornamentals and weeds can be intense and destructive as weeds compete for space, nutrient, moisture, and light. They cause substantial environmental damage and are accountable for ample losses [13] in ornamental production. In container-grown ornamentals, weed competition can greatly decrease the shoot dry weight of intended plants; for example, one eclipta per pot would reduce shoot growth by 43% on ‘Fashion’ azalea shoots [14]. Researchers have demonstrated that depending on the weed species, even one weed in a tiny (3.78 L) pot can affect the growth of an ornamental crop [1].

According to Berchielli-Robertson [14], the level of competition between weeds and ornamental plants varies, because in woody plants development during container production is greatly inhibited by competition from some weeds, but not all. Although, if weeds did not limit growth, a weed-infested container plant is a less marketable product than a weed-free product [1]. This is because the aesthetic value of the ornament reduces with the weed infestation, which becomes less attractive to the customers. According to Khamare et al. [15], in a nursery environment, there were reductions in biomass regardless of the species or container size. Furthermore, even when the plant growth indicators were comparable, the presence of weeds caused significant production delays. In addition, as the weed density rises, competition effects may begin slowly at first and then become more severe. After a certain point, no more effects would be seen as the plants experience heavy weed pressure. For example, when Japanese holly (*Ilex crenata* Thunb.) and ligustrum (*Ligustrum vulgare* L.) are grown with different levels of weeds in containers of different sizes, the shoot dry weight of Japanese holly was evidently reduced by 18% and 22%, 51% and 52%, 51% and 53%, and 40% and 53% in 3.8 L, 11.4 L, 24.7 L, and 56.8 L containers, respectively. On the other hand, the shoot dry weight of ligustrum was observed to be reduced by 28% and 35%, 55% and 56%, 41% and 43%, and 12% and 14% in same-sized containers, respectively [15].

Restricting annual weed growth in container production has turned into a major economic concern for growers [16]. While there has not been much research on managing weeds in containers, growers frequently use a variety of weed management techniques in this area [17]. In the current scenario, various chemical and non-chemical methods of weed control are in existence [2]. The use of chemical weed control in container nurseries has become a norm since the 1970s, when it was estimated that weed management accounted for approximately 20% of the overall production cost [17]. The key to successful weed control with herbicides involved a three-stage approach.

Firstly, if possible, weeds should be eradicated before planting by using a comprehensive post-emergence herbicide or soil sterilant. Annual weeds can be removed through cultivation; however, herbicides are more effective in eliminating perennials or weeds that have developed in under-ground storage tissue. Secondly, the emergence of new weeds should be deterred by applying pre-emergence herbicides, which is the primary method of controlling weeds in nurseries. Lastly, any escaped weeds should be tackled using post-emergence weed control techniques. However, it is not possible to find a single herbicide that can manage all weed types [18]. Oxyfluorfen, isoxaben, and simazine are pre-emergence herbicides that are effective against weeds of broadleaves. On the other hand, prodiamine, pendimethalin, and oryzalin are useful for controlling grasses and few small-seeded broadleaf weeds of pre-emergence, whereas Fluazifop-butyl, clethodim, and sethoxydim are post-emergence herbicides that are specifically designed for controlling grass weeds. For broad-spectrum weed control through directed spray applications, nonselective post-emergence herbicides like glufosinate, paraquat, and glyphosate are employed [18].

Going further, spreading granular herbicides with a cyclone spreader over the top of stock is a prevalent method for controlling weeds in containers. But, at the same time applying three to five granular herbicides a year resulted in consequent non-target herbicide damage [2]. According to Carpenter [19], nursery stock grown in containers with the highly porous media can be infused with activated carbon (C), upon which it is safe to incorporate broad-spectrum herbicides onto the surface of the container's activated C-free layer. So, injuries are prevented because the herbicides appear to become absorbed by the activated C before the plant roots do. However, herbicides have always had moderate success in reducing labor. A broad-spectrum herbicide, such as dichlobenil, provides significant weed control, but crop damage is possible [19].

In response to increasing concerns regarding the effects of pesticide use on the environment, many growers are extremely interested in non-chemical pest-management approaches [20]. There are various non-chemical strategies to control weeds, which include prevention and exclusion, hand weeding, using mulch and cover crops, heat, weed mats, geo discs, and organic products. Although some of these options may only be suitable for weed management in containers, all of them can be used around containers and in non-crop areas. Additionally, it is rare to rely on just one alternative method as they tend to be less effective individually than synthetic herbicides. To achieve optimal weed control, it is often necessary to employ a combination of two or more alternatives [21]. For quite some time, cultural weed control methods like mulching have been utilized in outdoor spaces to prevent weed growth, yet their ability to control weeds in container plant production has not been fully explored. Another method that may help manage weeds is subirrigation, as long as the top layer of the potting mix remains dry, which makes it a less suitable environment for weed seeds to germinate and establish themselves [22]. The cost of manual hand weeding can be substantial, but it can be a suitable option for a small nursery environment. It is important to address weed growth early on when they are still small, as removing larger weeds from containers can result in a significant loss of growing media [23]. An important initial step in mitigating weed growth is to implement appropriate sanitary procedures during the production of liners and propagation. The "Sanitation-Exclusion- Prevention" approach helps to diminish or eliminate the growth and spread of weed seeds and propagules, making weed control efforts more manageable. Even simple measures such as cleaning equipment and containers and covering the storage areas of substrates can have a substantial impact on reducing weed prevalence [20]. According to Diver et al. [23], a new weed control agent, corn gluten meal, has been recently introduced into the market. It is derived from the processing of corn syrup and serves as a bioherbicide.

During the early spring, corn gluten meal is applied as a pre-emergent herbicide and its effectiveness is optimized when spread over the top one-fourth inch of soil. However, annual reapplication is necessary to maintain its potency. This meal comprised 10% nitrogen and provides a gradual nutrient release to the crops as a slow-release fertilizer. It has been patented and commercially sold as an herbicide [23]. But newer studies have uncovered that corn gluten hydrolysate (CGH), produced from corn gluten meal, outperforms corn gluten meal in weed management for cut flowers and can be applied at a lower rate for effective results [24]. Weed management practices are extremely site-specific and significantly different from one region to another; the nursery industry faces numerous challenges for the development of this knowledge [25].

4. Non-Chemical Techniques for Weed Control in Container Nursery Production

The following subsections are some of the major non-chemical techniques used for weed control in container nursery productions:

4.1.Scouting

Weed identification and thorough scouting are necessary for efficient weed control. The most important thing to keep in mind is that control should be exercised rather than total eradication [1]. Weed scouting plays a crucial role in contemporary integrated weed management; however, when performed manually, it could be laborious and time consuming [26]. Once identified, weeds should be categorized according to their lifespan, with perennials being more difficult to control. Weeds that have resisted current weed management methods and those listed as noxious by state or federal authorities must be given utmost priority. Additionally, any new weed species found should receive special consideration [1].

Historically, weed information has been gathered casually and without much regard for the species of weeds, their distributions, or densities. This was primarily due to the time and labor required to conduct thorough scouting, the resulting information being complicated, and the assumption that weeds were consistently and evenly distributed across a field. Furthermore, even if variations were detected, there was insufficient equipment to address them [27]. According to Wiles et al. [28], to recommend a post-emergence control treatment, the weed seedlings in a field must be sampled or scouted to determine the most appropriate treatment. Additionally, the effectiveness of the scouting approach must be evaluated to ensure that it is a cost-effective solution. So, to select an effective post-emergence weed control strategy, the dominant weed species needs to be identified. To achieve this, a scouting plan must be developed that specifies the shape and size of the quadrata, or sample units, in which weeds will be identified and counted. The sampling intensity, or the number of quadrats to be examined, is also included in the plan, as is the sampling strategy for determining the location of the quadrats within the field. This ensures a distinct approach to weed management [28].

It is recommended to conduct container nursery weed monitoring at least three to four times annually. The initial assessment should take place in the spring, with the aim of identifying weeds that managed to evade the fall pre-emergence program, as well as winter annuals that are currently sprouting. This should be followed by one or more summer evaluations to locate summer annuals that slipped through the spring pre-emergence program, as well as winter annuals that are persisting. Lastly, before the first frost in the fall, it is important to spot summer annuals and perennials that were not successfully controlled, as well as winter annual seedlings [1].

Weed scouting is typically performed by manually inspecting a field and using sampling techniques to estimate weed species distribution. This process can be time-consuming, making it an ideal candidate for automation. By utilizing robots to scout the entire field, humans could make decisions about weed management based on the robot's findings. Despite recent efforts to develop robots for automated weed control and scouting, critical areas still require improvement before these systems can be widely adopted [26].

4.2.Sanitation Practices

To effectively manage pests or weeds in a nursery or greenhouse setting, the most important factor is prevention. This can be accomplished by prioritizing sanitation practices to reduce the introduction and spread of weeds, insect pests, and diseases in greenhouse and nursery environments. It is crucial to use well-maintained tools and equipment and consistently adhere to sanitation protocols to prevent pests from being transferred through these channels. Weeds or pests can be contained by limiting the movement of non-sterile equipment, vehicles, and individuals around the setting. However, it is also crucial to set up a framework for comprehensive sanitation management and give training to guarantee that staff members adhere to correct sanitation procedures, which ensures a complete sanitation management plan [29].

The use of greenhouses for growing plants allows growers to prevent or minimize the entry of weed seeds. Nevertheless, weed seeds may still find their way into greenhouses through openings such as vents, windows, or doors. They also have the potential to be transmitted through water or introduced through plant materials, tools, equipment, human interventions, or animals. Ensuring that all the pavements and aisles leading to the greenhouse entrance are clear of vegetation, or mowing any grass and other vegetation on a regular basis and keeping them close to the ground will help to prevent weed seeds from being carried in by foot traffic. To further decrease the number of wind-borne seeds entering the greenhouse, consider using screen exclusions on the vents or windows. It is also important to keep the areas beneath the benches free of container media and plant debris as this will reduce weed germination. To prevent further weed seed germination and facilitate easy cleanup, one can consider using concrete floors or weed barrier fabrics over gravel. If intending to reuse containers, they should be washed thoroughly using pressurized water flow and chemical disinfectants to eliminate any dirt, pathogens, and weed seeds [30].

However, identifying the source of weed seeds in any nursery can be more challenging than it appears. Based upon the circumstances prevailing in each nursery, several sources for these seeds can differ. Some possible sources may include potting substrates, nearby areas where weeds are growing, and sometimes the pots themselves. Weed seeds are usually not present in potting materials such as pine bark, peat moss, and perlite. Even so, weeds may infiltrate these substrates if they are stored in bulk, either at the nursery premises or at the substrate supplier's location. Weeds in the proximity of production beds or substrate piles can introduce weed seeds through various means, including wind, physical dissemination {for example, bittercress (*Cardamine* sp.), which can disperse its seeds over several meters away}, and invasion by certain weeds that possess stoloniferous and rhizomatous traits [31].

During the period when the beds are not occupied by crops, it is critical to take steps to eliminate any existing weeds, either physically or chemically. If necessary, one can replace the old weed fabric or stones with new ones and sweep away any existing debris. To summarize, the simplest and most effective way to reduce weed seeds in containers is to practice good sanitation, specifically by keeping non-crop areas weed-free [7].

4.3. Hand Weeding

Hand weeding may be the most opted-for or recommended method of controlling weeds in ornamental production sites or nurseries where they are dispersed. Hand weeding, while time-consuming, should be an essential component of any weed management program to prevent weeds from reproducing or seeding. Consistent weed removal while they are small and before they start seeding can significantly reduce the number of annual weeds over time. It is also suggested that hand weeding must be conducted on a regular basis until plantings become well established [32].

Hand weeding necessarily requires significant amounts of both labor and financial resources, additional to the expense of herbicides [33]. The production of ornamental plants in container culture remains a highly challenging task, primarily due to the lower availability of post-emergence herbicide options and herbicide-sensitive ornamental plants, which leads to heavy dependence on hand weeding. Additionally, the wide diversity of crop species further exacerbates the difficulties of weed control in container production [25]. Further, growers of minor crops require more efficient herbicides as well as affordable or cost-effective alternatives to hand weeding to reduce the expenses associated with weed control [34].

Depending on the size of the nursery, annual weeding labor expenses varied from USD 608 to USD 1401 per hectare (equivalent to USD 246–USD 567 per acre). Nurseries with a land area of 4.4–9.7 hectares (11–50 acres) had lower costs, while those with a land area of less than 4 hectares (10 acres) and more than 20.2 hectares (50+ acres) faced higher expenses. Hourly wages in various nursery sizes were comparable, falling within the range of USD 3.53 to USD 3.97 [17]. According to North Carolina reports, the cost of hand weeding 1000 pots over a four-month period could be USD 1367 if no herbicides are used. This estimate is based on an hourly wage of USD 14.75, which is typically paid for labor by local nurseries [35].

The cost of production will rise because of higher labor expenses unless other instruments, like new herbicides and precision cultivators that can control more weeds, can be used to replace labor inputs. If such alternatives are not offered, it is likely that domestic demand for these products will transfer to foreign suppliers who can provide them at a lower price due to their reduced labor costs, hence fostering a low-cost economy [34].

4.4. Mulching

Mulching is one of the cultural practices adopted to control or suppress weed growth in container-grown ornamentals. Mulches act as a physical barrier and suppress weed growth either preventing weed seeds from germination and emergence by light exclusion, by the release of allelopathic chemicals, or by acting as a physical barrier. In general, mulches can be both organic (shredded bark, residues of plants, hardwood chips, rice hull, etc.) and inorganic (plastic material, rocks, etc.) types [36]. Organic mulching substances are considered to be very effective in controlling annual small-seeded weeds. But, in the case of perennial weeds mulches tend to be less effective because of weeds' nature in incorporating a considerable amount of strength in their roots or due to the innate ability of their underground parts to overcome the strong layer of mulch with their respective shoots, once they start growing or germinating [37]. However, inorganic mulching materials are much more prevalent in landscaping and field crops [36].

According to Amoroso et al. [38], both mulching and chemical control have similar abilities to suppress weed growth, because the plants which were mulched with biodegradable discs produced more dry weight of shoots when compared to the plants that were non-treated and non-mulched.

A study conducted by Giaccone et al. [39] showed that biodegradable chitosan-based mulching spray can control weeds effectively in container production. Biodegradable chitosan-based mulching spray is a derivative of chitin (chitin is second most available polysaccharide on the earth) composed of cationic carbohydrate biopolymer, which is generally insoluble in water but easily dissolves in most solutions of dissolved organic acids, such as acetic acid. In one study, mulching spray extracted from the scraps of crabs, shrimp and lobsters controlled the growth of weeds effectively in containers even under drastic infestation by weeds after its application, for not less than 2 months because of its film-forming nature. But it was also observed that mulch started degrading after 3 months of its application, which allowed a very small number of weeds to grow in containers. When compared with the performance of the herbicide oxadiazone, the biodegradable mulching spray showed better performance [39].

4.5.Irrigation Management

Container nursery growers are highly concerned with utilizing current water resources efficiently. To enhance water management, it is crucial to understand the current practices followed in commercial container production [40]. Nursery growers commonly prefer overhead irrigation as the most practical and regularly used irrigation system for the container production of woody ornamentals. However, drip or microjet irrigation are often used practically for materials grown in containers larger than 20 L [41]. An overhead irrigation system's infrastructure allows for great flexibility in terms of irrigating various container plants of variable sizes within an area. However, because container plants have a restricted root zone, they must be watered frequently, which can reduce the efficiency of irrigation in overhead sprinkler systems. The amount of water that is applied during irrigation and remains in the root zone so that plants can use it is referred to as the irrigation application efficiency. The irrigation system's infrastructure, the spacing of the container plants, the physical properties of the substrate, and the regularity of water distribution during irrigation are some of the elements that affect how well plants are watered or the efficiency of application [42].

According to Wilen et al. [22], subirrigation is an effective technique that could be employed in landscaping and certain farming methods to help reduce water loss due to evaporation while also potentially reducing weed growth. However, when using subirrigation for weed control, it is also crucial to be cautious and avoid excessive humidity of the soil or growing medium. For example, the study conducted by Wilen et al. [22] demonstrated that in subirrigated containers, the surface of the potting mix remained dry, preventing weed seeds from finding a suitable environment for germination and growth. Although different mulch depths had no effect on *Rhaphiolepis indica* L. growth as measured by dry weight, subirrigation had a negative impact on root, shoot, and total plant weight. Despite efforts to adjust irrigation times and frequency, the potting mix in the bottom half of subirrigated containers frequently became waterlogged. Because of this, most of the root growth occurred along the container wall and in the top half of the potting mix, compromising plant growth in the subirrigated treatments [22].

According to Stewart et al. [25], when compared to overhead systems, there is little knowledge about the impact of micro irrigation or drip irrigation techniques on weed management. Because only a portion of the substrate surface is moistened during each irrigation cycle, these methods are expected to reduce weed growth, especially in larger containers. This, however, may have unintended consequences for weed control, such as inhibiting the germination of some weed seeds, while potentially creating new problems, like how the use of micro or drip irrigation systems may cause issues such as ineffective herbicide activation due to scarcity of rainfall and might pose a risk of phytotoxicity due to insufficient overhead irrigation to remove herbicide residues from plant foliage, if any overhead applications are employed [25].

In context, there are plenty of options available for choosing the components, designs, and operation of irrigation systems to function in nurseries. Unfortunately, it is often noticed that the specific requirements of plants are generally neglected during the design phase of irrigation systems in nurseries. As the cost of water and water restrictions continue to keep on rising, it will become increasingly important to consider these needs. To achieve optimal irrigation efficiency, it is crucial to properly design overhead and micro irrigation systems that provide consistent water delivery, based on the plant's demand and with an appropriate amount of irrigation water scheduled [42].

4.6.Substrate Stratification

The process of "substrate stratification" entails layering several substrates or the same substrate with various textures in nursery containers. It has been recently suggested that using this technique will improve drainage, control substrate moisture levels, and increase nutrient use effectiveness. In theory, a layer substrate made up of larger particle bark on top and smaller particle bark at the bottom of the container would allow for rapid drying of the surface, which would inhibit weed germination while also retaining adequate moisture for crop development [43]. A recent study conducted by Khamare et al. [43] showed that coarse bark (<1.27 cm or 1.9 cm particle size) when used as the top substrate and finer bark (<0.96 cm particle size) when used as the bottom substrate in the container can reduce the growth of the weed species bittercress (*Cardamine flexuosa* With.) by 80% to 97%, and the liverwort (*Marchantia polymorpha* L.) coverage decreased by 95% to 99%.

By stratifying the substrate, a more favorable gradient of air and water can also be created to promote the growth and establishment of plants grown in containers. The traditional industry method of filling containers uniformly with a similar substrate leads to the lower part of the container remaining at or near full saturation, while the upper part where the plant is located drains rapidly and has less water readily accessible. The demand for excessive irrigation during the first development and establishment stages of these systems may be reduced by modifying the hydraulic characteristics of the top layer of the growing substrate. This change would make it possible to maintain a rooted liner with a root ball that is one-third to half the depth of the container while consuming less water, reducing irrigation volume and leachate in the process [44].

According to Fields and Criscione [45], the use of peat in horticulture is being scrutinized as consumer knowledge of peat-related environmental sustainability concerns rises. The horticultural industry has been forced to search for peat substitutes as a result. Substrate stratification is one such option, which includes vertically layering many media in a single container. According to studies, this strategy can increase resource efficiency by using less water and fertilizer, especially in substrates used for nurseries. However, the results showed that it is possible to grow profitable greenhouse plants like petunia while also lowering peat usage by more than 50% in terms of volume by overlaying high-priced peat-based medium over inexpensive pine bark [45].

In addition, stratifying the substrate may provide weed management advantages akin to mulching. Furthermore, this approach may have an edge over standard mulch materials such as pine bark nuggets or rice hulls, which are typically applied to the top layer of nursery containers. Growers have suggested that this method can be implemented using their existing equipment, but a cost–benefit analysis is necessary to ascertain if the benefits of substrate stratification surpass the rise in labor costs [43].

4.7.Mulch Discs (or Geo Discs) and Lid Bags

A typical weed disc is shaped like a circle with a center aperture or slit that enables it to be wrapped around the plant's stem. The ideal features of a weed disc consist of being effortless to apply, resisting displacement due to wind, lying flat and fitting tightly on the container substrate while allowing water to pass through, preventing weed germination and growth on its surface, it should be obtainable in a numerous range of sizes, and it should be sturdy and economical. Although weed discs have desirable properties, such as the ability to prevent weed growth and germination, weeds can still emerge through the elongated slit or around the container's inner rim. While using two weed discs in offset positions can improve control, it also increases control expenses [46]. In certain cases, due to excessive overhead irrigation, algae and mosses can start growing on top of plastic discs or geotextile discs, which can create additional problems.

A variety of products have been used or have the potential to be used in the Pacific Northwest (PNW) region of the United States along with Canada. Geotextile discs, coco discs, plastic discs, sawdust, Biotop, hazelnut (Corylus avellana L.) shells, and crumb rubber are among the materials used. Geotextile discs are a type of fabric made of polypropylene that is not woven and has one side coated with cupric hydroxide. Coco discs, on the other hand, are produced as a result of the processing of coconut (Cocos nucifera L.), in which longer fibers are extracted from the fruit pith of coconuts and used to make a variety of products, including weed discs. The thickness of coco disks is approximately 0.6 cm (0.25 in). Hazelnut shells are produced as a byproduct of the processing of hazelnut tree nuts and are crushed to a size of less than 0.6 cm (0.25 in). Plastic weed discs have been made in a variety of designs, but the majority are made of a thin and stiff plastic material that covers the surface of the container and includes preformed holes for water and air infiltration. Crumb rubber is made by removing the steel radials from tires and shredding the rubber components. Crumb rubber can be manufactured in a variety of sizes, all of which are less than 0.6 cm in length (0.25 in) [47]. In a study, Tex-R Geodisc (Texel USA, Henderson, NC, USA), a copper coated nonwoven polypropylene disc, was able to control weeds in containers for six months [48]. Based on this information, it appears that using weed discs properly in container nurseries could be a practical and cost-effective alternative to chemical weed control methods. When compared to herbicide treated bark, the black polyethylene sleeve known as the Mori Weed Bag and plastic lids known as Enviro LIDs provided inferior control of weeds in containers. Nursery growers have explored Enviro LIDs, which are plastic lids with perforated holes for watering that are designed to be placed over the top of the container [2].

According to Chong [46], among the non-chemical weed management techniques explored for containers, Weed Guard, Tex-R Geodisc, Biodisc, and Enviro LIDs are the only ones currently available on the market and, unfortunately, there are few studies on the usefulness of Enviro LIDs in the literature in real time.

4.8. Fertilizer Placement

Strategic fertilizer placement might be a feasible approach to control weeds in certain ornamental crops in container production, given that these ornamental species could be harmed in herbicide application during weed control [49]. However, the outcome can be varied because of varying responses from different plant species, the source of fertilizers, the method of application, and the amount applied, especially with different types of growing media. Many research studies have manifested that it is essential to assess the source of fertilizer, fertilizer quantities, and the application techniques of fertilizers used in container production [50].

According to Fain et al. [51], the placement of fertilizer has the potential to influence weed seed germination by influencing the availability of nutrients required for their growth. This is because certain seeds require a sufficient supply of nutrients to germinate and thrive. When the fertilizer is dibbled, it reduces the quantity of nitrogen, phosphorus, and potassium present on or near the surface of the container where the weed seeds typically sprout. This can create multiple challenges for small-seeded weeds, such as prostrate spurge (Euphorbia maculate), which have limited nutrient stock and struggle to acquire the necessary nutrients they need in containers, where fertilizer has been dibbled [51]. However, according to Hickleton [52], it is generally not advised for growers to employ dibbling due to the probable root damage produced by excessive salt concentrations, which is based on the observation of relatively low root weights found in the dibbled fertilizer placement method [49].

Similarly, according to Altland et al. [53], weed establishment and their growth were reduced across various herbicide rates by dibbling fertilizer rather than topdressing or incorporating it. Weed control was excellent even at lower herbicide rates when Controlled- Release Fertilizers (CRFs) were used, indicating that modifying fertilizer management could potentially result in lower herbicide rates. Also, crop shoot growth appeared to be similar when fertilizer was dibbled as compared with the topdressing of Controlled-Release Fertilizers (CRFs), and it exhibited slightly better growth than when incorporating the fertilizer into the soil [50].

However, according to Saha et al. [49], while previous research has focused on the effects of topdressing, incorporating, and dibbling fertilizer on weed growth, the impact of subdressing fertilizer on weed growth has not received much attention. So, if subdressing or dibbling were found to reduce weed growth or seed production significantly, nursery producers could use these alternative fertilizer placements as part of an integrated weed management program. This would aid in reducing the overall weed pressure in nursery crops grown in containers [49].

Ultimately, comprehending the impact of cultural practices such as fertilizer placement on weed control when utilizing regularly or frequently used herbicides can assist producers in efficiently managing their crops and weed control regimen [53].

At present, the nursery industry views the labor-intensive integrated weed management method as the sole practical strategy for weed control in potted plants. This method involves adhering to strict nursery hygiene standards while utilizing a combination of coir mats or bark mulch, herbicides, and physical hand weeding. Herbicides, mulch, and coir mat prices have all gone up in step with the rest of the supply chain. However, the effectiveness of the herbicides that are now available in the market is declining, and they may soon be subjected to regulations with rising environmental concerns [54].

5. Prospects and Future Directions

In a restricted growth environment, such as container plant production, weeds have been shown to reduce marketability and crop growth significantly. Most research focuses on weed competition in agronomic crops and limited research has been conducted on weed competition in container-grown ornamental plants.

More research needs to focus on this area as there are various types of ornamental plants with unique needs and many of them are very sensitive to herbicide injuries. Research data are required from various locations across the United States and even from different parts of the world where climatic and environmental conditions are varying. In addition, limited information is available on the effects of weed densities and container sizes on ornament–weed competition within containerized production and how the concepts of fertilizer placements (types and different depths) can be used efficiently to control weeds in containers without employing any herbicides on the ornamentals. Hence, there is an immediate need to evaluate the interference and competitive effects of pernicious weed species in container-grown ornamentals in the North Central United States and to develop effective non-chemical weed control strategies by altering fertilizer placement in container production.

Therefore, the objectives of our study were:

Objective 1: Evaluate the effects of fertilizer placement on weed competition and the growth of ornamental plants in container production.

Hypothesis: Altering fertilizer placement will reduce weed competition and improve the growth of ornamental plants grown in container production.

Objective 2: Determine how different types of weed species at various densities and in different container sizes affect the growth of ornamental plants.

Hypothesis: Increasing weed density and reducing container size will reduce growth of ornamental plants.

LITERATURE CITED

1. Case, L.; Mathers, H.; Senesac, A. A review of weed control practices in container nurseries. HortTechnology 2005, 15, 535–545. [CrossRef]

2. Mathers, H.M. Novel methods of weed control in containers. HortTechnology 2003, 13, 28 34. [CrossRef]

3. Ingram, D.L.; Hall, C.R.; Knight, J. Comparison of three production scenarios for Buxus microphylla var. japonica 'Green Beauty' marketed in a No. 3 container on the West coast using life cycle assessment. HortScience 2017, 52, 357–365. [CrossRef]

4. Michigan Department of Agriculture and Rural Development. Michigan Agriculture Facts & Figures. 2019. Available online: https://www.michigan.gov/mdard/about/mi_agriculture/michigan-agriculture-resources (accessed on 10 March 2023).

5. Knudson, W. The Economic Impact of Michigan's Food and Agriculture System; Working Paper No. 201807; Michigan State University Product Center: East Lansing, MI, USA, 2018.

6. Darras, A.I. Implementation of sustainable practices to ornamental plant cultivation worldwide: A critical review. Agronomy 2020, 10, 1570. [CrossRef]

7. Altland, J.E. Weed Control in Container Crops: A Guide to Effective Weed Management through Preventive Measures; Oregon State University Extension Service: Corvallis, OR, USA, 2003; p. 8823. Available online: https://ir.library.oregonstate.edu/concern/open_educational_resources/ht24wj80n (accessed on 10 March 2023).

8. Hall, C.R.; Hodges, A.W.; Haydu, J.J. The economic impact of the green industry in the United States. HortTechnology 2006, 16, 345–353. [CrossRef]

9. Hodges, A.W.; Khachatryan, H.; Palma, M.A.; Hall, C.R. Production and marketing practices and trade flows in the United States green industry in 2013. J. Environ. Hortic. 2015, 33, 125–136. [CrossRef]

10. Khachatryan, H.; Hodges, A.; Hall, C.; Palma, M. Production and marketing practices and trade flows in the United States green industry, 2018. South. Coop. Ser. Bull. 2020, 421, 2020–2021.

11. USDA; National Agricultural Statistics Service. Floriculture Crops 2019 Summary. 2020. Available online: https://www.nass. usda.gov/Publications/Todays_Reports/reports/floran20.pdf (accessed on 10 March 2023).

12. USDA; National Agricultural Statistics Service. Floriculture Crops 2020 Summary. 2021. Available online: https://downloads.usda.library.conell.edu/usdaesmis/files/0p0966899/s4656b62g/g445d913v/floran21.pdf (accessed on 10 March 2023).

13. Ekwealor, K.; Echereme, C.; Ofobeze, T.; Okereke, C. Economic importance ofweeds: A review. Asian J. Plant Sci. 2019, 3, 1–11. [CrossRef]

14. Berchielli-Robertson, D.L.; Gilliam, C.H.; Fare, D.C. Competitive effects of weeds on the growth of container-grown plants. HortScience 1990, 25, 77–79. [CrossRef]

15. Khamare, Y.; Marble, S.C.; Pearson, B.J.; Chen, J.; Devkota, P. Effect of Weed Competition on Growth of Container Grown Ornamentals Plants in Four Different Container Sizes. Horticulturae 2023, 9, 317. [CrossRef]

16. Fretz, T.A. Weed Competition in Container Grown Japanese Holly. HortScience 1972, 7, 485–486. [CrossRef]

17. Gilliam, C.H.; Foster, W.J.; Adrain, J.L.; Shumack, R.L. A survey of weed control costs and strategies in container production nurseries. J. Environ. Hortic. 1990, 8, 133–135. [CrossRef]

18. Altland, J.E.; Gilliam, C.H.; Wehtje, G. Weed control in field nurseries. HortTechnology 2003, 13, 9–14. [CrossRef]

19. Carpenter, P.L. Chemical Weed Control in Container-grown Nursery Stock1. HortScience 1973, 8, 385–386. [CrossRef]

20. Marble, S.C.; Koeser, A.K.; Hasing, G. A review of weed control practices in landscape planting beds: Part I–nonchemical weed control methods. HortScience 2015, 50, 851–856. [CrossRef]

21. Chappell, L.; Knox, G.; Stamps, R.H. Alternatives to Synthetic Herbicides for Weed Management in Container Nurseries; UGA Cooperative Extension: Athens, GA, USA, 2012; Volume 1410.

22. Wilen, C.A.; Schuch, U.K.; Elmore, C.L. Mulches and subirrigation control weeds in container production. J. Environ. Hortic. 1999, 17, 174–180. [CrossRef]

23. Diver, S.; Greer, L.; Adam, K.L. Sustainable Small-Scale Nursery Production. Appropriate Technology Transfer for Rural Areas (ATTRA) National Sustainable Small-scale Nursery Production. 2008. Available online: https://attra.ncat.org/wp-content/ uploads/2019/05/nursery.pdf (accessed on 10 March 2023).

24. Greer, L. Sustainable Cut Flower Production. Appropriate Technology Transfer for Rural Areas (ATTRA) National Sustainable Small-scale Nursery Production. 2000. Available online: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=6aca7ba0ab68bfeb03737e20da2482ff0ee6b4f1 (accessed on 10 March 2023).

25. Stewart, C.J.; Marble, S.C.; Pearson, B.J.; Wilson, P.C. Impact of container nursery production practices on weed growth and herbicide performance. HortScience 2017, 52, 1593–1600. [CrossRef]

26. Hall, D.; Dayoub, F.; Kulk, J.; McCool, C. Towards unsupervised weed scouting for agricultural robotics. In Proceedings of the 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 29 May–3 June 2017.

27. Clay, S.; Johnson, G. Scouting for weeds. Crop Manag. 2002, 1, 1–7. Available online: https://acsess.onlinelibrary.wiley.com/doi/ abs/10.1094/CM-2002-1206-01-MA (accessed on 10 March 2023).

28. Wiles, L.J.; Wilkerson, G.G.; Gold, H.J. Simulating weed scouting and weed control decision making to evaluate scouting plans. In Proceedings of the 24th Conference on Winter Simulation, Arlington, VA, USA, 13–16 December 1992; pp. 1166–1171.

29. Galanti, R.; Lutgen, H. Greenhouse and Nursery Sanitation. Tools, Equipment, Workers, and Visitors; Extension Publication OF-54; College of Tropical Agriculture and Human Resources, University Hawaii Manoa: Honolulu, HI, USA, 2021; pp. 1–7.

30. Marble, S.C.; Pickens, J. Weed Control for Ornamentals Inside Greenhouses and Other Enclosed Structures: ENH1267/EP528, 11/2015. EDIS 2020, 2016, 5. [CrossRef]

31. Neal, J.C. Weed control in woody liner production. Comb. Proc. Int. Plant Propagators Soc. 2000, 50, 528–531.

32. Wilen, C.A. UC IPM Pest Notes: Weed Management in Landscapes; UC ANR Publication 7441: Oakland, CA, USA, 2018.

33. Judge, C.A. Predicting Herbicide Dissipation in Container Nursery Crop Production-A Method for Improving Herbicide Performance and Reducing Hand Weeding. Master's Thesis, North Carolina State University Libraries, Raleigh, NC, USA, 2002. Available online: https://repository.lib.ncsu.edu/items/b19706ab-b0d0-4499-94d5-4f4eef10d114 (accessed on 10 March 2023).

34. Fennimore, S.A.; Doohan, D.J. The challenges of specialty crop weed control, future directions. Weed Technol. 2008, 22, 364–372. [CrossRef]

35. Darden, J.; Neal, J.C. Granular herbicide application uniformity and efficacy in container nurseries. Proc. South. Nurs. Assoc. Res. Conf. 1999, 44, 427–430.

36. Harpster, T.; Sellmer, J.; Kuhns, L. Controlling Weeds in Nursery and Landscape Plantings; Penn State Cooperative Extension, College of Agricultural Sciences: State College, PA, USA, 2012.

37. Mohler, C.L.; Teasdale, J.R.; DiTommaso, A. Manage Weeds on Your Farm: A Guide to Ecological Strategies. Sustainable Agriculture Research and Education. 2021. Available online: https://www.sare.org/wp-content/uploads/Manage-Weeds-on- Your-Farm.pdf (accessed on 10 March 2023).

38. Amoroso, G.; Frangi, P.; Piatti, R.; Fini, A.; Ferrini, F. Effect of mulching on plant and weed growth, substrate water content, and temperature in container-grown giant arborvitae. HortTechnology 2010, 20, 957–962. [CrossRef]

39. Giaccone, M.; Cirillo, C.; Scognamiglio, P.; Teobaldelli, M.; Mataffo, A.; Stinca, A.; Panico, A.; Immirzi, B.; Santagata, G.; Malinconico, M. Biodegradable mulching spray for weed control in the cultivation of containerized ornamental shrubs. Chem. Biol. Technol. Agric. 2018, 5, 21. [CrossRef]

40. Fare, D.C.; Gilliam, C.H.; Keever, G.J. Monitoring irrigation at container nurseries. HortTechnology 1992, 2, 75–78. [CrossRef]

41. Beeson, R.; Knox, G. Analysis of efficiency of overhead irrigation in container production. HortScience 1991, 26, 848–850. [CrossRef]

42. Mathers, H.M.; Case, L.T.; Yeager, T.H. Improving irrigation water use in container nurseries. HortTechnology 2005, 15, 8–12. [CrossRef]

43. Khamare, Y.; Marble, S.C.; Altland, J.E.; Pearson, B.J.; Chen, J.; Devkota, P. Effect of substrate stratification on growth of common nursery weed species and container-grown ornamental species. HortTechnology 2022, 32, 74–83. [CrossRef]

44. Fields, J.S.; Owen, J.S., Jr.; Altland, J.E. Substrate stratification: Layering unique substrates within a container increases resource efficiency without impacting growth of shrub rose. Agronomy 2021, 11, 1454. [CrossRef]

45. Fields, J.S.; Criscione, K.S. Stratified Substrates Can Reduce Peat Use and Improve Root Productivity in Container Crop Production. HortScience 2023, 58, 364–372. [CrossRef]

46. Chong, C. Experiences with weed discs and other nonchemical alternatives for container weed control. HortTechnology 2003, 13, 23–27. [CrossRef]

47. Altland, J.; Lanthier, M. Influence of container mulches on irrigation and nutrient management. J. Environ. Hortic. 2007, 25, 234–238. [CrossRef]

48. Appleton, B.L.; French, S.C. Weed suppression for container-grown willow oak using copper-treated fabric disks. HortTechnology 2000, 10, 204–206. [CrossRef]

49. Saha, D.; Marble, S.C.; Torres, N.; Chandler, A. Fertilizer placement affects growth and reproduction of three common weed species in pine bark–based soilless nursery substrates. Weed Sci. 2019, 67, 682–688. [CrossRef]

50. Blessington, T.M.; Garvey, E.J.; Howell, L.M. Effects of Application Methods of Controlled-release Fertilizers on Growth and Quality of Rhododendron obtusum 'Hinodegiri' Grown in Various Media1. HortScience 1981, 16, 676–677. [CrossRef]

51. Fain, G.B.; Knight, P.R.; Gilliam, C.H.; Olive, J.W. Effect of fertilizer placement on prostrate spurge growth in container production. J. Environ. Hortic. 2003, 21, 177–180. [CrossRef]

52. Hicklenton, P.R. Growth of capillary-irrigated Andorra juniper and Sarcoxie euonymus as affected by controlled release fertilizer type and placement. J. Environ. Hortic. 1990, 8, 92–95. [CrossRef]

53. Altland, J.E.; Fain, G.B.; Arx, K.V. Fertilizer placement and herbicide rate affect weed control and crop growth in containers. J. Environ. Hortic. 2004, 22, 93–99. [CrossRef]

54. Ranson, L.; Moston, S. Comparisons of Established Weed Control Methods in Container Nurseries against a Novel Weed Control Device. 2022. Available online: https://www.gardencity-plastics.com/pub/media/productattachments/files/downloads/DeeWeed+Poster+May+2022+Final.pdf (accessed on 10 March 2023).

CHAPTER 2: EVALUATING DIFFERENT FERTILIZER PLACEMENTS TO ADDRESS EMERGING WEED MANAGEMENT CHALLENGES IN ORNAMENTAL CONTAINER PRODUCTION IN NURSERIES

Abstract

Weeds are highly aggressive in nature and can impede the growth and development of almost every crop with which they compete. Particularly, their level of competition is even higher in containerized ornamental production compared to field crops due to the limited space in containers, and the struggle for natural resources between weeds and ornamentals is more pronounced. Hence, the objective of this study was to evaluate effective fertilizer placement methods among those typically considered in ornamental production, such as incorporation, top dressing, sub-dressing, and dibbling, and identify which fertilizer placement can promote ornamental growth while reducing weed proliferation. For this assessment, the two most common ornamental perennials in container production rose (*Rosa rubiginosa* L.), and spirea (*Spiraea japonica* L. f.), along with the two most common weeds, large crabgrass (*Digitaria Sanguinalis* L. Scop.) and smooth pigweed (*Amaranthus hybridus* L.) were evaluated across four fertilizer placements. Weeds were applied to each ornamental at densities of 0,1,3, and 6 across all the fertilizer placements. Data collection included measuring the growth indices of ornamentals at 1 and 8 weeks after planting (WAP) by calculating the average height and two widths of the plants, using the formula (height + width 1 + width 2)/3. Additionally, at 8WAP, total nitrogen analysis and fresh weights of both weeds and ornamentals were measured. Sub-dressing was found to be the most effective fertilizer placement for reducing weed proliferation while promoting ornamental growth. Dibbling was also effective in weed control but decreased ornamental growth. However, incorporation and top dress were proven to be efficient in promoting ornamental growth, but they couldn't stop weed proliferation. Hence, sub-dressing can be recommended as an optimum fertilizer placement strategy for ornamentals like rose and spirea competing with weeds such as large crabgrass and smooth pigweed.

1. Introduction

Weeds are undesirable plants that are aggressive in nature and highly competitive with almost every crop that they thrive with. They possess the innate ability to grow, survive, and reproduce even in unfavorable environmental conditions [9]. In the ornamental industry, weed control is the primary production issue that concerns many nursery producers. Hand weeding is the most popularly adopted weed control method in nursery production for managing weeds [16]. However, due to the sudden increase in labor costs, the expenditure on hand weeding has become almost unaffordable [16].

To effectively control weeds and produce 2.47 ha of ornamentals ready to be marketed in 2.4-liter (1 gal) sized containers, a rough estimate of 625 hrs. of manual labor is required for hand weeding [8,14]. Furthermore, depending on the type of weed species managed by human labor, an estimated value of $1235 - $9880/ha ($500 - $4000/acre) is spent on hand weeding [8,14]. Consequently, the total financial loss is valued at about $17,920/ha ($7000/acre) due to weed infestation [14].

A study conducted by Case et al. [4], demonstrated that smooth pigweed (*Amaranthus hybridus* L.), Large crabgrass (*Digitaria Sanguinalis* L. Scop.), Prostrate spurge (*Chamaescyce maculate* L. or *Eurphorbia maculate* L.), Hairy bittercress (*Cardamine hirsute* L.), Marestail (*Conyza canadensis* L.), Liverwort (*Marchantia polymorpha* L.), Common groundsel (*Senecio vulgaris* L.), and Common chickweed (*Stellaria media* L. Vill.) are a few of the most found weeds in container nursery production, either grassy or broad-leaved. Belonging to various families, they have distinct lifecycles ranging from annuals to perennials [4]. There is little evidence supporting preemergence herbicides like oxadiazon and oxyfluorfen are effective in controlling both broad-leaved weeds and grass weeds for the initial 12 weeks of planting in containers. In contrast, some preemergence herbicides such as alachlor and oryzalin + trifluralin, are found to be ineffective in providing control over any weeds in containers, while also causing phytotoxicity to container-grown plants as collateral damage [13]. Furthermore, granular preemergence herbicide premixes with a broader spectrum of weed control, such as oxadiazon + prodiamine and oxyfluorfen + oxadiazon, are commonly used in container production [4]. However, postemergence herbicide application is not common in container production due to its limited availability and the risk associated with using them on sensitive ornamentals, fearing that they might cause herbicide injury to those ornamental plants [18], but some studies suggest that when these herbicides are applied at twice the actual recommended rate, there might be a chance to attain control over weeds, while also cautioning about potential crop injury and herbicide resistance as further challenges [3,6,16]. On the other hand, ADAMS [1], suggests that herbicides can also be used to control weeds in nurseries. However, it is important to combine residual herbicides with cultural methods to achieve effective weed control [1].

Herbicides used in container production might pose several problems, including herbicide runoff from plastic containers or gravel. This issue is particularly concerning in the event of a chemical spill between the containers during application [14]. Other challenges include improper calibration of the equipment and occasional demand for multiple applications, which may further lead to spray drift and herbicide leaching, resulting in the offsite movement of chemicals [14]. However, the interest in herbicide usage in container production is declining these days because of increased environmental and financial concerns among growers [14].

To overcome the challenges associated with herbicide usage and lower the costs of manual labor in weed control, cultural methods, such as strategic fertilizer placements, can be considered in container production. Currently, several cultural methods including mulching, irrigation management, substrate stratification, mulch discs, and lid bags are in existence. These methods can be combined with proper sanitation protocols to ensure effective weed control [4,5,10,14]. However, it is important to maximize non-chemical alternatives consistently to provide additional benefits in addressing the evolving weed control challenges.

Previous studies have been performed on fertilizer placement methods, which focused on two specific methods, top-dressing and sub-dressing at different substrate depths [2,7,11,12,17]. Furthermore, research conducted by Saha et al. [15], evaluated the impact of four fertilizer placements on the seed production, biomass, and flowering of three weed species in container production but without any ornamental plants. There are knowledge gaps on how different weed densities can affect the growth of ornamentals and how different fertilizer placements can affect weed-ornament competition within a container and whether fertilizer placement can be used as a tool to control weeds in ornamental production. Hence, the objective of this study was to:

Objective: Evaluate the effects of fertilizer placement on weed competition and growth of ornamental plants in container production.

Hypothesis: Altering fertilizer placement will reduce weed competition and improve growth of ornamental plants grown in container production.

2. Materials and Methods

2.1 Location and Plant Materials

Two rounds of greenhouse trials were conducted at the Horticulture Teaching and Research Center (HTRC), Michigan State University (MSU) located at 3291 N College Rd, Holt, MI, 48842. The first round was conducted in the fall of 2022 starting from August 4, 2022, through October

30, 2022, and the second round was conducted during the fall of 2023, which extended from August 16, 2023, through November 20, 2023. The seeds of two of the most common weed species in ornamental production, Large Crabgrass, an annual grassy weed, and Smooth Pigweed, an annual broadleaf weed, were subjected to germination separately. These weeds species were allowed to grow until they reached the 4-6 leaf stage in the greenhouse, utilizing rectangular plastic trays of 35.75 inches (90.8 cm) long, 7.86 inches (19.96 cm) wide, 6.6 inches (16.76 cm) deep (manufactured by Dynamic Design, 465 Railroad Avenue, Camp Hill, PA 17011), filled with the commercial soilless media 'suremix' (70% peat moss, 21% perlite, 9% vermiculite; Michigan Grower Products Inc., Galesburg, MI). The media was blended with Osmocote fertilizer ® [N: P: K 17-5-11 (8 to 9 months)] (ICL Specialty Fertilizers, Dublin Ohio) at the manufacturer's labeled medium rate of 7.1 $g\ l^{-1}$. Irrigation was supplemented daily with 0.5 inches (1.3 cm) of water through an overhead sprinkler system at intervals of two times per day.

Two types of woody shrubs were evaluated in this study which included Rose (*Rosa rubiginosa* L.), and Spirea (*Spiraea japonica* L. f.), obtained from Spring Meadows (12601, 120th Ave, Grand Haven, MI 49417). These plant liners were brought into the greenhouse when they were approximately 10-12 inches (25-30 cm) in size and ready to be transplanted into the containers.

2.2 Planting Protocols and Experimental Treatments Outside Greenhouse

The rose and spirea liners were taken out from the greenhouse and transplanted into 1.5 gallons (5.6 L) of black-colored, round-shaped plastic containers which were 9 inches (22.8 cm) in diameter and 8.5 inches (22 cm) in height (manufactured by Nursery Supply Co LL, Louisville, KY 40208). A bark-based substrate composed of pine bark (80%) and peat (20%) (Renewed Earth, Inc., Kalamazoo, Michigan) was used as the growth medium. Before potting the ornamentals into containers, the growth media was mixed with the controlled-release fertilizer Osmocote® [N: P: K

17-5-11 (8 to 9 months)] (ICL Specialty Fertilizers, Dublin, Ohio) at the highest labeled rate of 35 grams per gallon container. This was done to provide the plants with maximum nutrient availability and to observe how the ornamentals and weeds compete at that level of maximum nutrient availability. Each container received an application of 52.5 grams of fertilizer, considering the use of 1.5-gallon pots. Four different controlled-release fertilizer placements were considered while potting up the ornamentals, including incorporation, top dressing, sub-dressing, and dibble. In case of incorporation, the controlled-release fertilizer was thoroughly mixed with the growth medium before transferring into the containers and then ornamentals were planted. In contrast, for topdressing the fertilizer was evenly spread over the uppermost layer of the growth medium after the liner was planted in the container. In the case of sub-dressing, the fertilizer was placed at a depth of 2-3 inches (5.08 - 7.62 cm) within the substrate from the top of the container, and the liner was planted before covering up the substrate above. For the dibbling, the fertilizer was carefully placed in a pocket near the root zone just beneath the ornamental plant within the container. These tasks were performed outside the greenhouse before the pots were moved back into the greenhouse.

2.3 Experimental Design and Treatments Inside Greenhouse

The experimental design utilized a randomized complete block design (RCBD) with four replications (N=4) for each treatment and four different factors, the ornamentals (rose & spirea), the fertilizer placement methods (incorporation, topdressing, sub-dressing & dibbling), the weed species (large crabgrass & smooth pigweed), and the weed densities of (0,1,3 and 6) during both the rounds. Each indicated a distinct application condition concerning the research objective. Two of the total four treatments were applied outside the greenhouse during the potting of containers, which included four fertilizer placement methods and the potting of two ornamental species. Further, the containers were moved into the greenhouse and placed on benches in randomized patterns to minimize the potential for systemic bias and to ensure that each container had an equal chance of receiving any of the four treatment levels. All those plants in the containers received 0.5 inches (1.3 cm) of water twice a day via an overhead sprinkler irrigation system and were allowed to grow until they were well-established (held sturdy in the container) for up to one week after being transplanted. Following this, the weed seedlings of large crabgrass and smooth pigweed at the 4-6 leaf stage were carefully introduced to each container–grown ornamental plant at different densities of 0, 1, 3, and 6 per container by transplantation. These containers continued to receive 0.5 inches (1.3 cm) of irrigation twice a day via overhead sprinkler till the end of the experiment.

2.4 Plant Measurements and Data Collection

The containers were randomly chosen and moved out from each bench with photographs captured at both 1 WAP and 8 WAP. The growth indices for all the ornamental plants in each container were collected using a standard ruler for every randomized block placed on benches in a sequential order to ensure that each individual block was measured before moving on to the next block. The measurements were taken twice during the experiment, initially at the beginning phase of planting (1 WAP) after applying all the treatments to the containers, and subsequently recorded at the end of the experiment at 8 WAP by calculating the average height and two perpendicular widths of the plants by using the formula (height + width 1 + width 2)/3. Additionally, at 8 WAP both the ornamentals and weed species were as usual irrigated with 0.5 inches (1.3 cm) of water before being cut at the base at the soil surface line in each container. Their above-ground biomasses were measured separately using a weighing scale (OHAUS CORPORATION, 8 Campus Drive, Suite 105, Parsippany, NJ 07054, USA.), followed by carefully packing them in bags made of paper with the dimensions of 14 inches (35.56 cm) in width × 4 inches (10.16 cm) in height for weeds and 11.5 inches (29.21 cm) in width × 5 inches (12.7 cm) in height for ornamentals. These individual packages were placed inside medium-sized carton boxes (made up of cardboard) and were sent to an external laboratory (A&L Great Lakes Laboratories, Inc., Fort Wayne, Indiana.) for total nitrogen analysis in December 2022. However, it should be noted that the total nitrogen analysis for both weed and ornamental samples was performed only during the first round of the experiment and not during the second round, which could be attributed to funding constraints.

2.5 Statistical analysis

Data were analyzed in SAS (Ver. 9.4, SAS Institute, Cary, NC) employing the "PROC GLIMMIX" method to assess the model, verify assumptions, and determine the necessity of data transformations. Normality was assessed via the Shapiro-Wilk test, and homogeneity of variance was examined using Levene's test. Both assumptions were satisfied, eliminating the need for data transformation. A four-factor analysis of variance (ANOVA) was then performed to determine the treatment effects on various response variables. The four-factor treatments—ornamentals, weed species, density of weed species, and fertilizer placements—along with their interactions were considered fixed effects in weed response variables such as weed fresh weights and weed nitrogen %. In contrast, another model was applied for ornamental response variables, utilizing ornamentals, weed species density, and fertilizer placements as fixed effects. Here, we combined weed species and weed density as a single factor because there were no weed species present in the ornamental response variables, especially in the control set where only ornamentals were present in the containers, without any weeds. This absence of weeds in the control set made it impossible to separate means, as it required the presence of both ornamentals and weeds for comparative analysis. Blocks were uniformly treated as random effects in both models. Mean separations were carried out utilizing Tukey's Honest Significant Difference (HSD) method via LSMEANS prompt of PROC GLIMMIX.

3. Results

3.1 Weed fresh weights & nitrogen percent.

In the analysis conducted at 8 WAP, a comparison of weed fresh weights and total nitrogen % across all weed control treatments displayed significant findings. Specifically, the ANOVA indicated a significant interaction between weed species and the density of weeds concerning both weed nitrogen % and weed fresh weights. Additionally, significant interactions were observed between ornamentals and weed species among the weed nitrogen %. Moreover, the fertilizer placement factor among weed fresh weights also exhibited significant effects. All reported p-values < 0.05, highlighting the significance of treatment effects (Table 2.1). The weed nitrogen % ranged from 3.55 % to 4.69 % across all weed species and density of weed interactions. Particularly, the smooth pigweed at a density of weeds at 6 exhibited the highest weed nitrogen % (4.69 %), while the large crabgrass at a density of weeds at 6 had the lowest (3.55 %). However, there were no differences observed in weed nitrogen % between smooth pigweed at the density of weeds at 1 and 3 compared to smooth pigweed at a density of weeds at 6, nor between large crabgrass at a density of weeds at 6 compared to large crabgrass at the density of weeds at 1 and 3. Likewise, the weed fresh weights varied between 81.72 g to 230.77 g across all weed species and the density of weed interactions. The large crabgrass at a density of weeds at 3 displayed the highest weed fresh weight (230.77 g), followed by smooth pigweed at a density of weeds at 6 which exhibited an intermediate level of fresh weight. In contrast, smooth pigweed at a density of weeds at 1 indicated the lowest fresh weight (81.72 g). However, significant differences were observed in weed fresh weights between the combinations of large crabgrass at a density of weeds at 3, smooth pigweed at a density of weeds at 6, and smooth pigweed at a density of weeds at 1. Similarly, the weed nitrogen % ranged from 3.60 % to 5.03 % across all the interactions between ornamental and weed species.

Among these interactions, spirea with smooth pigweed exhibited the highest nitrogen % (5.03 %), followed by rose with smooth pigweed at an intermediate level, and rose with large crabgrass at the lowest level (3.60 %). However, there was no difference in weed nitrogen % between the interactions of rose with large crabgrass and spirea with large crabgrass (Table 2.3).

At 8 WAP, the weed fresh weights varied significantly among the fertilizer placements, ranging from 101.33 g to 208.96 g. Incorporation resulted in the highest weed fresh weights (208.96 g), followed by top dressing and sub dressing at an intermediate level while dibbling resulted in the lowest weights (101.33 g). However, there was no significant difference in weed fresh weights between top dressing and sub dressing (Table 2.4).

3.2 Ornamental fresh weight & ornamental nitrogen percent.

At 8 WAP, a comparison of the ornamental fresh weights and ornamental nitrogen % across all weed control treatments revealed significant interactions, as determined by ANOVA. These interactions included those between ornamentals and fertilizer placements, ornamentals and weed species density, and weed species density and fertilizer placements among ornamental fresh weights. Additionally, there was a significant interaction between ornamentals and fertilizer placements among the ornamental nitrogen %. Moreover, the single-factor analysis of weed species density showed significant effects on ornamental nitrogen %. All these findings had p-values < 0.05, indicating the significant treatment effects (Table 2.2). The ornamental fresh weights ranged from 6.25 g to 22.50 g across all the ornamental and fertilizer placement interactions. The highest fresh weights (22.50 g) were observed between rose and incorporation, followed by rose and dibble, and spirea and dibble (6.25 g) in descending order. However, significant differences were observed among the ornamental fresh weights of rose and incorporation, rose and dibble, and spirea and dibble. In continuation, the ornamental fresh weights varied between 6.09 g to 26.46 g across all the interactions of ornamentals and weed species density. Among these, the rose with control of weed species exhibited the highest fresh weight (26.46 g), while the spirea with large crabgrass at 6 densities of weeds showed the lowest (6.09 g). However, the ornamental fresh weights of spirea with large crabgrass at 6 densities of weeds and rose with smooth pigweed at 6 densities of weeds were found to be significantly different from each other. Furthermore, the ornamental fresh weights ranged from 5.40 g to 28.47 g across various interactions of the weed species density and fertilizer placement. The interaction of weed species control when incorporated, resulted in the highest ornamental fresh weights (28.47 g), whereas the large crabgrass at 6 densities of weeds when dibbled exhibited the lowest ornamental fresh weights (5.40 g). However, all other interactions did not show significant differences among themselves, although they differed from both the weed species control when incorporated, and large crabgrass at 6 densities of weeds when dibbled (Table 2.5).

Similarly, at 8 WAP the ornamental nitrogen % varied between 2.36 % to 3.47 % across the interactions of ornamental and fertilizer placements. The highest level was observed with spirea and top dressing (3.47 %), while the lowest was associated with rose and dibble (2.36 %). However, the spirea and top dress exhibited a significantly different ornamental nitrogen level compared to all other ornamental and fertilizer placement interactions. Additionally, the ornamental nitrogen % varied among the weed species density, ranging from 2.67 % to 3.00 %. The control at 0 density of weeds exhibited the highest level of ornamental nitrogen (3.00 %), while large crabgrass at 6 densities of weeds showed the lowest (2.67 %). However, the ornamental nitrogen % between control at 0 density of weeds and large crabgrass at 6 densities of weeds were significantly different from each other but not from all other interactions (Table 2.6).

3.3 Ornamental initial & final growth indices

When the ornamental initial growth indices at 1 WAP and final growth indices at 8 WAP were observed across all weed control treatments, the ANOVA displayed significant treatment effects. Specifically, the interaction between ornamental and weed species density, as well as the interaction between ornamentals and fertilizer placements, demonstrated p-values < 0.05, indicating statistical significance at both 1 WAP and 8 WAP (Table 2.2). At 1 WAP, the ornamental initial growth indices ranged from 7.21 inches to 10.07 inches across all the ornamental and weed species density interactions. The rose with control at 0 density of weeds exhibited the highest initial growth indices (10.07 inches), whereas the spirea with smooth pigweed at 6 densities of weeds scored the lowest (7.21 inches). However, there was no significant difference observed in initial growth indices between spirea with smooth pigweed at 6 densities of weeds and rose with smooth pigweed at 6 densities of weeds. In continuation, at 1 WAP the ornamental initial growth indices varied between 7.36 inches to 9.79 inches across all the ornamental and fertilizer placement interactions. The rose when top dressed resulted in the highest growth (9.79 inches), while the spirea when dibbled exhibited the lowest (7.36 inches). However, there was no significant difference in initial growth indices between roses when top dressed and dibbled, indicating similar growth patterns (Table 2.).

Similarly, at 8 WAP the ornamental final growth indices varied between 7.78 inches to 15.70 inches across all the ornamental and weed species density interactions. Among these interactions, the rose with control at 0 density of weeds exhibited the highest final growth indices (15.70 inches), while the spirea with large crabgrass at 3 densities of weeds recorded the lowest (7.78 inches). However, there was a significant difference in the final growth indices between the rose with control at 0 density of weeds and the spirea with control at 0 density of weeds. Furthermore, at 8WAP, the ornamental final growth indices varied between 7.84 inches to 14.24 inches across all the ornamental and fertilizer placement interactions. The rose when incorporated resulted in the highest growth (14.24 inches), while the spirea when top-dressed exhibited the lowest (7.84 inches). However, there was no significant difference in final growth indices of rose and incorporation, rose and top dress, and rose and sub dress (Table 2.7).

4. Discussion

Our study assessed different fertilizer placements such as incorporation, topdressing, subdressing, and dibbling in container production systems of nurseries and greenhouses to understand their impact on weed growth and ornamental development. We aim to enhance ornamental growth while minimizing weed proliferation, providing a non-chemical weed control alternative to growers. Chemical weed control has severe impacts on the environment, such as herbicide leaching and runoff, and poses sustainability issues, particularly in container production where preemergence and granular herbicides are limited [14]. Therefore, exploring alternative options is crucial. Additionally, the need to lower operational costs in container production drives the development of non-chemical weed management strategies. In our experiment, we studied how perennial ornamentals like roses and spirea respond to different fertilizer placements while also aiming to decrease weed growth, focusing on common weed species like large crabgrass and smooth pigweed that are typically found in container production.

At 8 WAP, the results indicated that both roses and spirea, when incorporated and top dressed led to higher ornamental fresh weights and ornamental nitrogen % compared to sub dressing and dibbling. Specifically, it is worth noting that even sub dressing performed well and was dominant to top dressing when used a fertilizer placement method with spirea. In the case of roses as well, sub dressing almost resembled top dressing in terms of ornamental fresh weight. However, the ornamental nitrogen % was unanimously found to be higher in incorporation and topdressing, outcompeting the sub dress and dibbling.

In accordance with the results of ornamental fresh weights and ornamental nitrogen %, the ornamental growth indices at both 1 WAP and 8 WAP also indicated that incorporation and top dressing with both spirea and rose resulted in highest ornamental growth compared to sub dress and dibbling. Specifically, it is worth noting that sub dressing favored the growth of both the ornamental species almost as much as top dressing did. However, it is evident that roses exhibited greater growth overall compared to spirea. These observations partially align with the study conducted by Khamare et al [12], wherein they found that incorporation and topdressing were consistent in controlling weeds and promoting ornamental growth when combined with substrate stratification and mulching. However, hibiscus plants were found to exhibit slightly better growth when fertilizer was applied as a top dressing rather than being incorporated. Nevertheless, both methods did not affect the commercial-level growth of hibiscus. In contrast, the weed species bittercress biomass increased considerably with top-dressed fertilizer compared to incorporation. Liverwort growth was significantly reduced in all substrate and mulched treatments compared to the industry standard, regardless of fertilizer application method. Therefore, recommendations cannot be made to the growers because the control consistency is highly species-specific [12].

Furthermore, the weed fresh weights were also found to be higher with incorporation and top dressing, but lower with sub dressing and dibbling, regardless of the density of weed species present in each container. This suggests that sub-dressing and dibbling were consistent in reducing weed proliferation. Specifically, the combination of smooth pigweed with both rose and spirea exhibited the highest weed nitrogen %, indicating that smooth pigweed is more competitive against both rose and spirea compared to large crabgrass, across all the density rates of weed species present in each container (1, 3, and 6). However, all the weed nitrogen % interactions strongly demonstrate that smooth pigweed is more competitive than large crabgrass irrespective of their densities. This finding is consistent with several previous studies, one of which evaluated how various fertilization methods affected weed growth and herbicide efficiency, focusing on large crabgrass (*Digitaria sanguinalis* L.), eclipta (*Eclipta prostrata* L.), and spotted spurge (*Euphorbia maculata* L.) as weed species [17]. The results indicated that topdressing fertilizer resulted in higher weed growth compared to sub-dressing or incorporation. Additionally, weed growth was also found to be increased with higher fertilizer rates. Regardless of fertilizer treatment used, herbicides were generally found to be effective in controlling weeds, although the results varied by species. The study suggested that sub-dressing fertilizer as a non-chemical weed control approach for container-grown ornamental crops, although no ornamentals were employed in the study. As a result, these findings while not specific to any ornamentals but inclined towards sub dressing for reduced weed control as observed in our study, while also highlighting the role of top dressing in increased weed proliferation, consistent with our findings [17]. Similarly, another study by Saha et al [15], demonstrated that compared to standard methods like top dressing and incorporation, sub-dressing and dibbling resulted in significant reductions in weed biomass and weed seed development in ornamental container production. These techniques specifically inhibited the growth and reproduction of weed species, including spotted spurge, large crabgrass, and eclipta, suggesting their potential application into an integrated weed management program for nursery crops produced in containers. However, it is also important to note that these recommendations are not specific to any particular kind of ornamental species [15]. Nonetheless, the study by Saha et al [15], supports our findings, as our study also indicates that incorporation and topdressing not only increased ornamental growth of both rose and spirea but also increased the growth of weeds such as spirea, while sub-dressing and dibbling were found to reduce the weed growth.

Another study conducted by, Khamare et al [11] found that sub-dressing fertilizer significantly impacted the growth of eclipta but had a considerably minimal impact on ornamental species Ligustrum (*Ligustrum lucidum* W.T. Aiton) and Japanese boxwood (*Buxus microphylla* Siebold & Zucc.) which aligns with our findings. Placing fertilizer below the surface of growth media in the container inhibited the growth of eclipta indicating that it might be useful for controlling weeds. However, further research is required to determine the ideal sub dressing depth for different sized ornamental plants [11].

The high ornamental growth observed in both rose and spirea when fertilizer was incorporated can be attributed to the fact that in this method the fertilizer is thoroughly distributed throughout the container during the mixing process of growth media prior to planting. Hence, the ornamentals can effectively utilize the available nutrients for their growth. Similarly, the comparable growth observed in cases of top dressing and sub dressing may be explained by the accessibility of the fertilizer to the ornamental roots. In top dressing, the fertilizer is applied to the top layer of the container, making it readily available to the roots. In contrast, the success of sub dressing can be attributed to the tap root system characteristic of both dicotyledonous ornamentals rose, and spirea. This primary tap root system allows these ornamental plants to penetrate deeper into the soil, accessing the layer of fertilizer applied through sub dressing and effectively utilizing the nutrients for their growth.

In the case of weeds as well, the higher proliferation of smooth pigweed and large crabgrass occurred when fertilizer was either incorporated or top dressed. This phenomenon can be attributed to the fact that, in case of incorporation the fertilizer is thoroughly distributed throughout the container during the mixing process of growth media prior to planting, which effectively makes the nutrients available to the developing weeds and enhances their growth. Similarly, in the case of top dressing, the fertilizer is applied to the top layer of the container, making it readily available to the roots of the weeds, as observed with ornamentals. However, the lower proliferation of weeds in case of sub dressing and dibble is because the weed transplants were smaller than the ornamentals. This size difference prevents the weeds from reaching the fertilizer zone deep below in the case of sub dressing and dibbling, resulting in lower fresh weights in these instances.

Interestingly, it is important to note that smooth pigweed managed to remain more competitive in sub dressing, because of its dicot nature and possession of tap root system (capable of spreading deep into growth media vertically), similar to ornamental roses and spirea. Hence, smooth pigweed was more dominant overall than large crabgrass in proliferation. Even though the weed transplants of both the weeds were smaller than the ornamentals, the taproot nature of smooth pigweed favored its growth, especially in sub dressing. However, dibbling resulted in very little proliferation of both the weeds because the fertilizer in the case of dibbling is placed just below the root pocket of ornamentals, making it almost inaccessible to the weeds that are spread throughout the container.

Overall, it is evident that sub dressing could be recommended as an optimal fertilizer placement for containerized ornamental production in nurseries and greenhouses. This recommendation is supported by its promotion of ornamental growth similar to that that of top dressing, while also aiding in reduction of the weed proliferation, a limitation not addressed by top dressing and incorporation methods. However, dibbling also showed effective weed control for both large crabgrass and smooth pigweed. But it simultaneously decreased the growth of ornamentals such as roses and spirea. Hence, dibbling cannot be recommended as optimal fertilizer placement in ornamental production of woody perennials like rose and spirea. This outcome might be due to the fact that positioning of fertilizer just below the pocket near root zone of the ornamental plant liners potentially contributed to phytotoxic effects in the plants leading to their reduced growth, as demonstrated by [15]. However, Altland et al [2], suggests that dibbling fertilizer was effective in controlling weeds such as common groundsel, prostrate spurge, and creeping wood sorrel. The results of the study conducted by Altland et al [2] also highlighted the synergistic effect of increasing the herbicide rate combined with the dibbling approach, which improved weed control. The study demonstrated that dibbling fertilizer promoted greater shoot growth in ornamental plants such as azalea, holly, lavender, and wintercreeper euonymus [2]. However, these findings deviate from the results of our study, particularly within the context of ornamentals.

5. Conclusions

Overall, sub-dressing was identified as the most effective fertilizer placement for reducing weed proliferation while not hindering the growth of ornamental plants that stay in the competition. Similarly, dibbling has the potential and efficacy in controlling weeds but is constrained by its tendency to cause collateral damage to ornamental plants due to its phytotoxic effects. In contrast, incorporation and top dressing were found to be excellent in promoting the growth of both the ornamental rose and spirea but were less effective in hindering the proliferation of spirea and large crabgrass as well. Hence, sub-dressing can be recommended to the growers as an optimum fertilizer placement method that reduces the competition of weeds with the desired ornamentals. However, it is important to acknowledge that the efficacy of sub-dressing may vary depending on the multitude of species that a grower aims to produce, as it is highly specific to the species that are under consideration.

Further research could be directed towards ornamentals and weeds that possess different growth habits, root structures, and life cycles, across various growing media. This investigation could offer insights into the effectiveness of sub-dressing as a fertilizer placement method in container production, particularly when considering different species with distinct characteristics. Additionally, evaluating the behavior of sub-dressing at various depths within the containers, across different variants of weeds and ornamentals with distinct root structures and lifecycles as highlighted above, would provide insights into how sub-dressing could be applied to plant species of varying characteristics, optimizing their growth at specific depths.

TABLES

Table 2.1: Analysis of Variance (ANOVA) results for ornamentals, weed species, fertilizer placements, and density of weeds of weed fresh weights and weed nitrogen % at 8 weeks after planting (WAP)

	P-value	
Source	Weed fresh weights	Weed nitrogen %
Ornamental	0.5542	< 0.0001*
Weed species	< 0.0001*	< 0.0001*
Ornamental * Weed species	0.5224	< 0.0001*
Density	< 0.0001*	0.6238
Ornamental * Density	0.4250	0.9246
Weed species * Density	0.0440*	0.0394*
Fertilizer	< 0.0001*	0.6971
Ornamental * Fertilizer	0.9438	0.0992
Weed species * Fertilizer	0.1990	0.9171
Density * Fertilizer	0.3880	0.4206

*Significant ($P \leq 0.05$) main effects or interactions

Table 2.2: Analysis of Variance (ANOVA) results for ornamentals, weed species, fertilizer placements, and density of weeds of ornamental fresh weights, ornamental nitrogen % at 8 weeks after planting (WAP), and ornamental initial growth indices at 1 WAP and ornamental final growth indices at 8 WAP

	P-value			
Source	Ornamental fresh weight	Ornamental nitrogen %	Ornamental initial growth indices	Ornamental final growth indices
Ornamental	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*
Weed species _density	< 0.0001*	0.0002*	< 0.0001*	< 0.0001*
Ornamental * Weed species _density	0.0002*	0.8215	0.0016*	0.0013*
Fertilizer	0.0006*	< 0.0001*	0.0004*	0.0001*
Ornamental * Fertilizer	0.0201*	< 0.0001*	0.0383*	0.0172*
Weed species _density * Fertilizer	< 0.0001*	0.3651	0.3004	0.0501

*Significant ($P \leq 0.05$) main effects or interactions

Table 2.3: Mean weed nitrogen percent and weed fresh weights of interactions weed species * Density of weeds and Ornamental * Weed species at 8 weeks after planting.

Interactions	Response Variables	
	Weed Nitrogen (%)	Weed Fresh Weights (g)
Weed species * Density		
Large crabgrass * 1	3.74 B	136.30 CB
Large crabgrass * 3	3.69 B	230.77 A
Large crabgrass * 6	3.55 B	224.91 A
Smooth pigweed * 1	4.42 A	81.72 C
Smooth pigweed * 3	4.64 A	109.77 CB
Smooth pigweed * 6	4.69 A	156.31 B
Ornamental * Weed species		
Spirea * Smooth pigweed	5.03 A	
Rose * Smooth pigweed	4.15 B	
Spirea * Large crabgrass	3.73 C	
Rose * Large crabgrass	3.60 C	

* Means within a column followed by the same letter are not significantly different from each other. Mean separation by Tukey's HSD test.

Table 2.4: Mean weed fresh weights of fertilizer placements at 8 weeks after planting.

Treatment	Response Variable
Fertilizer Placement	Weed Fresh Weights (g)
Incorporation	208.96 A
Top dress	159.17 B
Sub dress	157.05 B
Dibble	101.33 C

***** Weed fresh weights followed by the same letter are not significantly different from each other within a column. Mean separation by Tukey's HSD test

Table 2.5: Mean ornamental fresh weight of interactions ornamental * fertilizer placements, ornamental * weed species density, and weed species density * fertilizer placements at 8 weeks after planting.

Interactions	Response Variable Ornamental Fresh Weights (g)
Ornamental * Fertilizer	
Rose * Incorporation	22.50 A
Rose * Top dress	20.80 A
Rose * Sub dress	20.52 A
Rose * Dibble	13.08 B
Spirea * Incorporation	8.13 CB
Spirea * Top dress	6.96 C
Spirea * Sub dress	7.10 CB
Spirea * Dibble	6.25 C
Ornamental * Weed species density	
Rose * Control _0	26.46 A
Rose * Large crabgrass _1	23.83 BA
Rose * Large crabgrass _3	16.97 BC
Rose * Large crabgrass _6	10.85 ECD
Rose * Smooth pigweed _1	23.16 BA
Rose * Smooth pigweed _3	16.19 BCD
Rose * Smooth pigweed _6	17.11 BC
Spirea * Control _0	7.77 ED
Spirea * Large crabgrass _1	6.56 E
Spirea * Large crabgrass _3	6.09 E
Spirea * Large crabgrass _6	7.29 ED
Spirea * Smooth pigweed _ 1	8.00 ECD
Spirea * Smooth pigweed _ 3	7.37 ED
Spirea * Smooth pigweed _ 6	6.67 E
Weed species density * Fertilizer	
Control_ 0 * Incorporation	28.47 A
Control_ 0 * Top dress	15.02 BC
Control_ 0 * Sub dress	16.05 BC
Control_ 0 * Dibble	8.93 BC
Smooth pigweed_ 1 * Sub dress	21.21 BA
Large crabgrass_ 1 * Top dress	20.43 BA
Large crabgrass_ 1 * Sub dress	17.64 BAC
Smooth pigweed_ 1 * Top dress	16.83 BAC
Smooth pigweed_ 6 * Incorporation	16.31 BA

Table 2.5 (Cont'd)

Large crabgrass_ 1 * Incorporation	14.45 BC
Smooth pigweed_ 3 * Dibble	14.24 BC
Smooth pigweed_ 1 * Incorporation	13.50 BC
Large crabgrass_ 3 * Sub dress	12.87 BC
Large crabgrass_ 3 * Top dress	12.66 BC
Large crabgrass_ 6 * Incorporation	12.27 BC
Smooth pigweed_ 3 * Incorporation	11.11 BC
Smooth pigweed_ 3 * Top dress	11.10 BC
Large crabgrass_ 3 * Incorporation	11.08 BC
Smooth pigweed_ 1 * Dibble	10.78 BC
Smooth pigweed_ 6 * Top dress	10.71 BC
Smooth pigweed_ 3 * Sub dress	10.66 BC
Smooth pigweed_ 6 * Dibble	10.52 BC
Large crabgrass_ 6 * Top dress	10.40 BC
Smooth pigweed_ 6 * Sub dress	10.00 BC
Large crabgrass_ 3 * Dibble	9.50 BC
Large crabgrass_ 1 * Dibble	8.28 BC
Large crabgrass_ 6 * Sub dress	8.21 BC
Large crabgrass_ 6 * Dibble	5.40 C

* Ornamental fresh weights within a column followed by the same letter are not significantly different from each other. Mean separation by Tukey's HSD test.

Table 2.6: Mean ornamental nitrogen % of interactions ornamental * fertilizer placements, and single treatment weed species density at 8 weeks after planting.

Interaction/Treatments	Response Variable Ornamental Nitrogen (%)
Ornamentals * Fertilizer	
Rose * Incorporation	2.66 C
Rose * Top dress	2.71 C
Rose * Sub dress	2.61 CD
Rose * Dibble	2.36 D
Spirea * Incorporation	2.86 CB
Spirea * Top dress	3.47 A
Spirea * Sub dress	2.98 B
Spirea * Dibble	2.75 CB
Weed species density	
Control_ 0	3.00 A
Large crabgrass_ 1	2.90 BA
Smooth pigweed_ 6	2.83 BA
Smooth pigweed_ 3	2.78 BA
Smooth pigweed_ 1	2.70 B
Large crabgrass_ 3	2.70 B
Large crabgrass_ 6	2.67 B

* Means within a column followed by the same letter are not significantly different from each other. Mean separation by Tukey's HSD test.

Table 2.7: Mean Ornamental Initial Growth Indices and Ornamental Final GI of interactions Ornamentals *Weed species density and Ornamental * Fertilizer placements at 1 and 8 weeks after planting.

Interactions	Response Variable	
	Ornamental Initial GI At 1WAP (in.)	Ornamental Final GI At 8WAP (in.)
Ornamentals * Weed species density		
Rose * Control_ 0	10.07 A	15.70 A
Rose * Large crabgrass_ 3	10.03 A	12.80 BDC
Rose * Large crabgrass_ 1	9.99 A	13.88 BAC
Rose * Large crabgrass_ 6	9.86 A	10.38 EDF
Spirea * Large crabgrass_ 6	8.49 B	7.88 F
Rose * Smooth pigweed_ 3	8.40 B	11.96 EDC
Rose * Smooth pigweed_ 1	8.34 B	15.39 BA
Spirea * Control_ 0	8.33 B	9.60 EF
Rose * Smooth pigweed_ 6	8.25 B	12.70 BDC
Spirea * Smooth pigweed_ 1	8.09 B	7.96 F
Spirea * Large crabgrass_ 1	7.99 B	7.91 F
Spirea * Smooth pigweed_ 3	7.64 B	8.27 F
Spirea * Large crabgrass_ 3	7.56 B	7.78 F
Spirea * Smooth pigweed_ 6	7.21 B	8.26 F
Ornamental * Fertilizer		
Rose * Top dress	9.79 A	14.11 A
Rose * Dibble	9.25 BA	11.39 B
Rose * Incorporation	9.18 BA	14.24 A
Rose * Sub dress	8.88 BC	13.29 BA
Spirea * Incorporation	8.41 BCD	9.18 C
Spirea * Top dress	8.20 ECD	7.84 C
Spirea * Sub dress	7.61 ED	8.01 C
Spirea * Dibble	7.36 E	7.92 C

* Means within a column followed by the same letter are not significantly different from each other. Mean separation by Tukey's HSD test.

* WAP represents weeks after planting.

LITERATURE CITED

1. ADAMS, D. (1990). Chemical weed control in containerized hardy ornamental nursery stock. *Professional Horticulture*, *4*(2), 70-75.

2. Altland, J. E., Fain, G. B., & Arx, K. V. (2004). Fertilizer placement and herbicide rate affect weed control and crop growth in containers. *Journal of Environmental Horticulture*, *22*(2), 93-99.

3. Altland, J. E., Gilliam, C. H., Olive, J. W., Edwards, J. H., Keever, G. J., Kessler Jr, J. R., & Eakes, D. J. (2000). Postemergence control of bittercress in container-grown crops. *Journal of Environmental Horticulture*, *18*(1), 23-28.

4. Case, L., Mathers, H., & Senesac, A. (2005). A review of weed control practices in container nurseries. *HortTechnology*, *15*(3), 535-545.

5. Chong, C. (2003). Experiences with weed discs and other nonchemical alternatives for container weed control. *HortTechnology*, *13*(1), 23-27.

6. Christopher Marble, S., Gilliam, C. H., Wehtje, G. R., Hoogmoed, A. J. V., & Palmer, C. (2011). Early postemergence control of spotted spurge in container production. *Journal of Environmental Horticulture*, *29*(1), 29-34.

7. Fain, G. B., Knight, P. R., Gilliam, C. H., & Olive, J. W. (2003). Effect of fertilizer placement on prostrate spurge growth in container production. *Journal of Environmental Horticulture*, *21*(4), 177-180.

8. Fretz, T. A. (1972). Control of Annual Weeds in Container Grown Nursery Stock1. *Journal of the American Society for Horticultural Science*, *97*(5), 667-669.

9. Hartwig, N. L. (1999). Introduction To Weeds And Herbicides.

10. Khamare, Y., Marble, S. C., Altland, J. E., Pearson, B. J., Chen, J., & Devkota, P. (2022). Effect of substrate stratification on growth of common nursery weed species and container-grown ornamental species. *HortTechnology*, *32*(1), 74-83.

11. Khamare, Y., Marble, S. C., & Chandler, A. (2020). Fertilizer placement effects on eclipta (Eclipta prostrata) growth and competition with container-grown ornamentals. *Weed Science*, *68*(5), 496-502.

12. Khamare, Y., Marble, S. C., Pearson, B. J., Chen, J., & Devkota, P. (2023). Evaluation of Substrate Stratification, Fertilizer Placement, and Mulching on Growth of Common Nursery Weed Species and Container-Grown Ornamental Species. *Horticulturae*, *9*(7), 747.

13. Lamont, G., O'Connell, M., & Nicholls, P. (1985). An evaluation of pre-emergent herbicides for container-grown ornamental plants. *Scientia Horticulturae*, *26*(3), 241-251.

14. Mathers, H. M. (2003). Novel methods of weed control in containers. *HortTechnology*, *13*(1), 28-34.

15. Saha, D., Marble, S. C., Torres, N., & Chandler, A. (2019). Fertilizer placement affects growth and reproduction of three common weed species in pine bark–based soilless nursery substrates. *Weed Science*, *67*(6), 682-688.

16. Saidak, W., & Nelson, S. (1962). Weed control in ornamental nurseries. *Weeds*, *10*(4), 311-315.

17. Stewart, C. J., Marble, S. C., Jackson, B. E., Pearson, B. J., & Wilson, P. C. (2018). Effects of three fertilization methods on weed growth and herbicide performance in soilless nursery substrates. *Journal of Environmental Horticulture*, *36*(4), 133-139.

18. Alluri, G., & Saha, D. (2024). Emerging Perspectives on Non-Chemical Weed Management Tactics in Container Ornamental Production in the United States. Horticulturae, 10(3), 281.

CHAPTER 3: EVALUATING DIFFERENT CONTAINER SIZES AND WEED DENSITIES TO ADDRESS WEED-ORNAMENTAL COMPETITION IN CONTAINER NURSERY PRODUCTIONS

Abstract

Weeds always thrive to stay in tough competition with the human-desired vegetation. Specifically, the competition is intense within the confined spaces of containers in ornamental production, wherein these weeds exhibit a greater urge to acquire nutrients, water, light, and space to outcompete the growth of ornamental plants, thereby reducing the marketability and profitability of infested containers. Hence, the objective of this study was to evaluate the optimum container size that helps reduce weed competition while promoting ornamental growth simultaneously. Commonly used container sizes such as 3-gallon, 1.5 gallon, and 0.67 gallon were assessed with the two most commonly found woody shrubs in ornamental production, Hydrangea (*Hydrangea macrophylla* Thunb. Ser.), and Syringa (*Syringa vulgaris* L.), along with the two most prevalent weed species, large crabgrass (*Digitaria Sanguinalis* L. Scop.) and smooth pigweed (*Amaranthus hybridus* L.). Weeds were applied to each ornamental at densities of 0, 1, 3, and 6 in the three selected container sizes and allowed to grow for 8 weeks after planting (WAP). Data collection included measuring the growth indices of both ornamentals and weeds at 1 WAP and 8 WAP by calculating the average height and two widths of the plants, using the formula (height + width 1 + width 2)/3. Additionally, at 8 WAP, the Photosynthetic Active Radiation (PAR) of the ornamentals was measured using the instrument MutlispeQ V 2.0 – PhotosynQ along with measuring the fresh weights of both weeds and ornamentals. The 3-gallon containers were found to enhance the growth of ornamentals, particularly favoring the hydrangeas compared to syringa, but weed proliferation was also enhanced simultaneously. However, in 0.67-gallon containers, weed competition of both weed species was completely hindered, but this did not favor ornamental growth. Particularly, the outcomes are highly specific to the species competing within the confined spaces of containers.

1. Introduction

Effective weed management strategies are essential for producing high-quality and successful ornamentals in nurseries and greenhouses. Weeds can affect both the productivity and production quality of ornamentals, especially in containers where nutrient availability and water content are limited, due to restricted space within containers [13]. Depending on the particular species of the ornamental plant and the weed, the extent to which they affect competition can vary drastically [2,3,8].

Previous studies have demonstrated that weeds have a negative impact on container-grown ornamentals. For instance, Fretz [8], demonstrated that growers are facing a major economic issue in managing the spread of annual weeds, such as redroot pigweed (*Amaranthus retroflexus* L.) and large crabgrass {*Digitaria sanguinalis* (L.) Scop} in container production because of the manual labor required for hand weeding. According to his findings, the dry weight of Japanese holly {*Ilex crenata* (Thunb.) cv. *convexa* Makino.} in 2.4-liter containers was reduced by 47% and in 6.0-liter containers by 30% with the presence of a single redroot pigweed plant. Fretz [8], also observed that the dry weight of Japanese holly in 2.4-liter containers decreased by 60% and in 6.0-liter containers by 35% when a single large crabgrass plant was present [8]. A similar study conducted by Berchielli-Robertson [3], demonstrated that an increase in the populations of eclipta {*Eclipta alba* (L.) Hasskarl} and prostrate spurge (*Euphorbia supina* Raf.) led to a reduction in the shoot dry weight of both 'Fashion' (*Rhododendron x* 'Fashion') and 'Gumpo White Sport' azalea (*Rhododendron eriocarpum*). Although prostrate spurge had the same impact on ‘Crimson Pigmy’ barberry (*Berberis thunbergii*) in both small (3.8-liter) and large (15.2-liter) containers, eclipta only decreased the shoot dry weight of barberry in larger containers [3]. Additionally, in support of earlier findings, several other researchers have indicated that prevalent weed species in container production, such as eclipta {*Eclipta prostrata* (L.) L.}, large crabgrass, spotted spurge (*Euphorbia maculata* L.), and prostrate spurge growth (*Chamaesyce prostrata*) play a major role in influencing and hindering the growth of ornamentals within the containers space [7,11,15].

In the present day, the demand for ornamental plants has increased drastically. The rising demand is not only for large-scale production but also for the supply of healthy vigorous and attractive ornamentals in clean and weed-free containers [1]. So, apart from the need for weed-free containers at the point of sale, there are more important reasons to eliminate weed development in containers. This includes the possibility of weeds and ornamentals competing with one another, which may prevent the ornamentals from growing to their full potential [1]. Even one weed seedling can pose a serious threat to ornamental plant growth in a container. Additionally, mature plants grown in weed-infested environments may show decreased vigor, smaller leaves, and general poor health events that can have a detrimental effect on the container's marketability [1]. One of the main challenges faced by growers in producing high-quality plants economically is the unacceptably high manual weeding costs and the scarcity of skilled labor for performing such tasks [1]. A survey conducted by Gilliam et al [9], revealed that the expenses associated with hand weeding varied between $608 and $1401 per hectare ($246 to $567 per acre), while the hourly rates for hand weeding labor ranged from $3.53 to $3.97 per hour [9].

Chemical control might be considered as a potential alternative to overcome manual hand-weeding costs in weed management. However, growers in container production face very limited options for postemergence solutions, except for a specific group of graminicides. Due to these limitations, effective weed management in container production mainly depends on preemergence herbicides and additional manual weeding efforts [16]. Granular herbicides such as oxadiazon, pendimethalin plus oxyfluorfen, and oryzalin plus oxyfluorfen are frequently used in container nurseries for their broad-spectrum weed control [4]. Recently, newer granular herbicide combinations such as oxyfluorfen plus oxadiazon and oxadiazon plus prodiamine have gained popularity among nursery growers [4]. Flumioxazin, a recent addition to the nursery industry, is now approved for preemergence and early postemergence weed control in much of the U.S. Glyphosate is typically used postemergence. However, in container production preemergence herbicides are more common [4]. On the other hand, due to increasing financial and environmental concerns, recent research efforts have been directed toward reducing herbicide usage while ensuring profitable ornamental production at the same time [4,9,14].

Previous research efforts have explored various nonchemical alternatives, such as strategic fertilizer placement methods, mulching, substrate stratification, weed discs, lid bags, and irrigation methods to assess their impact on the competitive effect of weeds on container-grown ornamentals. These alternatives serve as potential supplements or alternatives to chemical weed control, aiming to balance the costs and achieve maximum weed control. However, there are limitations concerning their usage. For instance, weed bags may face challenges such as under-performance, insufficient demand, high costs, and inefficiencies in production and supply by manufacturers. Mulches, despite being proven effective as a non-chemical alternative, there are limitations like initial input cost, effectiveness over time, potential impacts on ornamental growth, decomposition, and maintenance problems. Similarly, fertilizer placement methods, substrate stratification, and irrigation methods also have their respective limitations. However, despite their limitations, these options remain viable to address the environmental concerns due to chemicals [2,5,6,10,13,14,16].

Keeping this in mind, to advance non-chemical weed management techniques in container production, and to study the competitiveness of weeds with the ornamentals within the confined sizes of containers, our goal of this study is to evaluate the effect of different container sizes on controlling weed growth and supporting ornamental growth. Hence, the objective and hypothesis of this study was to:

Objective: Determine how different types of weed species at various densities and in different container sizes affect the growth of ornamental plants.

Hypothesis: Increasing weed density and reducing container size will reduce growth of ornamental plants.

2. Materials and Methods

2.1 Location and Plant Materials

Two rounds of greenhouse experiments were conducted at the Horticulture Teaching and Research Center (HRTC) of Michigan State University, located at 3291 N College Rd, Holt, MI, 48842 during the summer and fall of 2023. Seeds of two of the most prevalent weed species in ornamental production, large crabgrass an annual grassy weed, and smooth pigweed (*Amaranthus hybridus* L.) an annual broad-leaf weed were germinated separately. They were grown until they attained the 4-6 leaf stage in the greenhouse, using rectangular plastic trays of 35.75 inches (90.8 cm) long, 7.86 inches (19.96 cm) wide, and 6.6 inches (16.76 cm) deep (manufactured by Dynamic Design, 465 Railroad Avenue, Camp Hill, PA 17011), filled with commercial soilless media 'sure-mix' (70% peat moss,21% perlite,9% vermiculite; Michigan Grower Products Inc., Galesburg, MI). The media was mixed with Osmocote® fertilizer [N: P: K 17-5-11 (8 to 9 months)] (ICL Specialty Fertilizers, Dublin Ohio) as per the manufacturer's labeled medium rate of 7.1 grams per liter. Irrigation was provided daily with 0.5 inches (1.3 cm) of water, via an overhead sprinkler system at intervals of three times per day.

Two types of woody shrub ornamentals including, Hydrangea (*Hydrangea macrophylla* Thunb. Ser.), and Syringa (*Syringa vulgaris* L.) obtained from Spring Meadows Wholesale

Nursery (12601, 120th Ave, Grand Haven, MI 49417) were used in this study. The woody shrub liners were about 10–12 inches (25–30 cm) in size when they were brought into the greenhouse and were ready to be transplanted into the containers.

2.2 Planting Procedure and Experimental Treatments Outside Greenhouse

Liners of hydrangea and syringa were taken out of the greenhouse and they were planted in containers of three different sizes 0.67 gallons (2.54 liters) which were 6.6 inches (16.77 cm) in diameter and 6 inches (15.24 cm) in height, 1.5 gallons (5.67 liters) which were 9 inches (22.8 cm) in diameter and 8.5 inches (22 cm) in height, and 3 gallons (11.35 liters) which were 11.3 inches (28.7 cm) in diameter and 9.4 inches (23.88 cm) in height, obtained from Proven Winners LLC., (Sycamore, IL 60178). A standard bark-based substrate, composed of pine bark (80%) and peat moss (20%) (Renewed Earth, Inc., Kalamazoo, Michigan), was mixed with the controlled-release fertilizer Osmocote® [N: P: K 17-5-11 (8 to 9 months)] (ICL Specialty Fertilizers, Dublin Ohio) at the manufacturer's labeled highest rate of 35 grams per gallon container, was used as a container growing medium. The fertilizer was used at the highest manufacturer-labeled rate to ensure that the weeds and ornamentals competing in each container receive maximum nutrient availability, thereby avoiding any nutrient deficiency stress. This practice allows observation of their performance and competition under stress-free and favorable conditions, which is common in most nurseries and greenhouses.

2.3 Experimental Design and Treatments Inside Greenhouse

The experimental design utilized a randomized complete block design (RCBD) with six replications (N=6) and four different treatment levels, the container sizes (0.67 gallons, 1.5 gallons, and 3 gallons), the weed species (large crabgrass and smooth pigweed), and the density of weeds (0, 1, 3 and 6), and the ornamental species (hydrangea and syringa). Each indicated a distinct application condition concerning the research objective, and each treatment was applied randomly to the individual containers within each block throughout the experiment. The application of the size of the containers and ornamental potting occurred outside the greenhouse. After the potting of the ornamentals, all containers were moved into the greenhouse and placed on each bench in a randomized pattern to minimize the potential for systemic bias and to make sure that each container had an equal chance of receiving any of the four treatment levels. All those plants received 0.5 inches (1.3 cm) of water thrice a day via overhead sprinkler irrigation and were allowed to grow till they were well established in the containers up to one week after being transplanted. Then the weed seedlings of large crabgrass and smooth pigweed at the 4-6 leaf stage were carefully introduced to each container-grown ornamental plant at different densities of 0, 1, 3, and 6 per pot by transplantation, with the density of 0 being the control set. These containers received 0.5 inches (1.3 cm) of water thrice a day via an overhead sprinkler irrigation system until the end of the experiment.

2.4 Plant Growth Measurements and Data Collection

The containers were randomly chosen from the experiments and moved out from each bench with photographs captured at both the beginning week after planting (1 WAP) and 8 WAP. At 8 WAP, the photosynthetic active radiation (PAR) of the topmost leaf of each ornamental plant within each container was measured using the instrument "MutlispeQ V 2.0 – PhotosynQ" (PHOTOSYNQ INC., 325 E. Grand River Ave, East Lansing, MI, 48823) which describes the wavelengths of light available to that the ornamental within the visible range of 400-700nm. The growth indices for ornamental plants were collected using a standard ruler. The measurements were taken twice during the experiment, initially at the beginning phase of planting after applying all the treatments to the containers (1 WAP), and subsequently recorded during the end of the experiment at 8 WAP by calculating the average height and two widths of the plants, using the formula (height + width 1 + width 2)/3. Additionally, at 8 WAP, both the weed species and the ornamentals were irrigated with 0.5 inches (1.3 cm) of water as usual. They were then cut from their bases at the soil surface line in each container, and their shoot fresh biomasses were recorded separately using a weighing scale (OHAUS CORPORATION, 8 Campus Drive, Suite 105, Parsippany, NJ, 07054).

2.5 Statistical Analysis

The data analysis was conducted utilizing SAS (Ver. 9.4, SAS Institute, Cary, NC) employing the "PROC GLIMMIX" method to check the model, verify assumptions, and to evaluate the necessity of data transformations. The normality of the data was assessed using the Shapiro-Wilk test, while Levene's test was utilized to evaluate the homogeneity of variance. Both assumptions regarding normality and equal variance were satisfied, making data transformation unnecessary. A four-factor analysis of variance (ANOVA) was performed to determine the impact of treatments on various response variables. The four-factor treatments—ornamentals, weed species, density of weed species, and container sizes—and their interactions were considered fixed effects in weed response variables, such as weed fresh weights. In contrast, a distinct model was applied for ornamental response variables introducing ornamentals, weed species density, and container sizes as three fixed effects, with weed species and density of weed species combined due to the inability to separate means in the control set of ornamental response variables. Ornamental response variables, such as ornamental fresh weights, ornamental PAR, and ornamental initial and final growth indices, had a control set where weed species were absent (control), indicating only ornamentals were present in the containers. In contrast, weed response variables lacked a control set. However, in both models, the blocks were treated as random effects. Mean separations were carried out utilizing Tukey's Honest Significant Difference (HSD) method through the LSMEANS prompt of PROC GLIMMIX.

3. Results

3.1 Weed fresh weights

At 8 WAP (Table 3.3), a comparison of weed fresh weights across all weed control treatments revealed significant treatment effects, as indicated by ANOVA displaying p-values < 0.05 for the interactions between ornamental and weed species, weed species and density of weeds, weed species and container sizes, and density of weeds and container sizes (Table 3.1). The weed fresh weights ranged from 98.56 g to 376.23 g across various interactions between the ornamental and weed species. Among these interactions, syringa with large crabgrass exhibited the highest weed fresh weight (376.23 g), followed by hydrangea with large crabgrass at an intermediate. In contrast, hydrangea with smooth pigweed showed the lowest fresh weight (98.56 g). However, there was no significant difference in weed fresh weights between hydrangea with smooth pigweed and syringa with smooth pigweed.

Likewise, the weed fresh weights varied between 36.11 g to 442.19 g across different weed species and the density of weed interactions. Notably, the interaction of large crabgrass at a density of weeds at 6 displayed the highest weed fresh weight (442.19 g), followed by large crabgrass at a density of weeds at 3 at an intermediate level. In contrast, the fresh weight was lower for smooth pigweed at a density of weeds at 1 (36.11 g). However, there was no significant difference in weed fresh weights among interactions such as smooth pigweed at a density of weeds at 6, smooth pigweed at a density of weeds at 3, and large crabgrass at a density of weeds at 1. Similarly, the weed fresh weights ranged from 39.55 g to 495.78 g across various interactions of weed species and container sizes. Particularly, the interactions between large crabgrass in 3-gallon containers displayed the highest weed fresh weight (495.78 g), followed by large crabgrass in 1.5-gallon containers at an intermediate level. In contrast, the fresh weight was lower for smooth pigweed in 0.67-gallon containers (39.55 g). However, significant differences in weed fresh weights were observed among interactions such as large crabgrass in 3-gallons and smooth pigweed in 3-gallon containers. Furthermore, the weed fresh weights varied from 22.41 g to 474.23 g across different interactions of the density of weeds and container sizes. Specifically, the interactions between the density of weeds at 6 in 3-gallon containers exhibited the highest weed fresh weight (474.23 g), followed by the density of weeds at 3 in 3-gallon containers at an intermediate level. In contrast, the fresh weight was lower for the density of weeds at 1 in 0.67-gallon containers (22.41 g). However, a significant difference in weed fresh weights was observed between the density of weeds at 6 in 3-gallon containers and the density of weeds at 1 in 0.67-gallon containers (Table 3.3).

3.2 Ornamental fresh weights

At 8 WAP (Table 3.4), a comparison of ornamental fresh weights among all weed control treatments revealed significant treatment effects, as indicated by ANOVA displaying p-values < 0.05 for the interactions between ornamental and weed species density, and ornamental and container sizes (Table 3.2). The ornamental fresh weights ranged from 21.30 g to 146.86 g depending on the interactions between the ornamental and weed species density. Within these interactions, hydrangea with smooth pigweed at 6 densities of weeds exhibited the highest ornamental fresh weight (146.86 g). In contrast, syringa with large crabgrass at 6 densities of weeds showed the lowest fresh weight (21.30 g). However, there was a significant difference in ornamental fresh weights between hydrangea with smooth pigweed at 6 densities of weeds and hydrangea with large crabgrass at 6 densities of weeds. Similarly, the ornamental fresh weights varied from 22.81 g to

149.61 g across different interactions of ornamental and container sizes. Specifically, the interactions of hydrangea in 3-gallon containers exhibited the highest ornamental fresh weight (149.61 g), followed by hydrangea in 1.5-gallon containers, and hydrangea in 0.67-gallon containers showing intermediate weights. In contrast, the fresh weight was lower for syringa in 0.67-gallon containers (22.81 g). However, there was no significant difference in ornamental fresh weights observed among syringa in 0.67-gallon, syringa in 1.5-gallon, and syringa in 3-gallon containers (Table 3.4).

3.3 Ornamental PAR

At 8 WAP (Table 3.5), significant treatment effects were observed in the comparison of ornamental PAR across all weed control treatments. This was demonstrated by ANOVA indicating p-values < 0.05 for the interactions between ornamental and weed species density, as well as between weed species density and container sizes (Table 3.2). The ornamental PAR varied from 26.99 $\mu mol\ m^{-2}\ s^{-1}$ to 54.03 $\mu mol\ m^{-2}\ s^{-1}$ depending on the interactions among the ornamental and weed species density. Within these interactions, syringa with smooth pigweed at 1 density of weeds exhibited the highest ornamental PAR (54.03 $\mu mol\ m^{-2}\ s^{-1}$). In contrast, syringa with large crabgrass at 6 densities of weeds showed the lowest PAR (26.99 $\mu mol\ m^{-2}\ s^{-1}$). However, there was no significant difference in ornamental PAR between syringa with smooth pigweed at 1 density of weeds and hydrangea with smooth pigweed at 6 densities of weeds. Likewise, across various interactions of weed species density and container sizes, the ornamental PAR ranged from 22.51 $\mu mol\ m^{-2}\ s^{-1}$ to 55.97 $\mu mol\ m^{-2}\ s^{-1}$. Specifically, the interactions between smooth pigweed at a density of 6 in 0.67-gallon containers exhibited the highest ornamental PAR (55.97 $\mu mol\ m^{-2}\ s^{-1}$). In contrast, the PAR was lower for large crabgrass at a density of 3 in 0.67-gallon containers (22.51 $\mu mol\ m^{-2}\ s^{-1}$). However, no significant difference in ornamental PAR was observed between smooth pigweed at a density of 6 in 0.67-gallon containers, and smooth pigweed at a density of 1 in 0.67-gallon containers (Table 3.5).

3.4 Ornamental initial & final growth indices

The analysis of ornamental initial growth indices at 1 WAP and final growth indices at 8 WAP across all weed control treatments revealed significant treatment effects. ANOVA indicated that the interaction between ornamental species and container size significantly influenced ornamental initial growth indices, while both ornamental species and container sizes independently affected ornamental final growth indices ($p < 0.05$) (Table 3.2). Therefore, at 1 WAP, the ornamental initial growth indices varied between 9.27 inches to 17.45 inches across all the ornamental and container size interactions. Notably, the hydrangea in 3-gallon containers had the highest initial growth indices (17.45 inches), while the syringa in 1.5-gallon containers showed the lowest (9.27 inches). However, a significant difference in initial growth indices was observed between the syringa in 1.5-gallon containers and the syringa in 3-gallon containers, as well as the hydrangea in 0.67-gallon containers (Table 3.6).

In continuation, at 8 WAP, the ornamental final growth indices ranged from 14.96 inches to 16.02 inches across the three distinct container sizes. Notably, the final growth indices were higher in 3-gallon containers (16.02 inches) compared to 0.67-gallon containers (14.96 inches). However, there was no significant difference observed in ornamental final growth indices between 1.5-gallon containers and either 3-gallon or 0.67-gallon containers. Similarly, at 8 WAP, the ornamental final indices were observed to be higher in hydrangeas at 18.11 inches, while syringa exhibited a lower measurement of 13.02 inches. This suggests that syringa tends to exhibit lesser growth compared to hydrangeas across all container sizes overall (Table 3.7).

4. Discussion

In this study, we evaluated three different sizes of containers used in ornamental container nursery production in greenhouse environments. Our primary goal was to identify the most suitable container size that balances weed management with optimal growth conditions for ornamental plants within the restricted space of the containers. Through the development of this nonchemical weed management strategy, we aimed to introduce an environment-friendly alternative to the widespread reliance on chemical herbicides for weed control.

This shift is particularly important in addressing the substantial environmental and sustainability issues associated with conventional herbicide usage within the ornamental industry. So, moving forward we studied the growth and establishment responses of two woody shrubs, hydrangea and syringa to varying container sizes of 3-gallon, 1.5-gallon, and 0.67-gallon. Also, we assessed the impact of these container sizes on weed growth, particularly considering common weeds found in container production, such as large crabgrass and smooth pigweed.

At 8 WAP the ornamental fresh weight measurements indicated that hydrangeas have produced more ornamental growth than syringas across all three container sizes: 3-gallon, 1.5-gallon, and 0.67-gallon, with the maximum fresh weight observed in 3-gallon containers. Specifically, it is noteworthy that syringas also exhibited comparable fresh weight, following a similar trend to hydrangeas, with the highest growth in the 3-gallon containers, followed by 1.5-gallon and then 0.67-gallon. Nonetheless, the extent of growth observed in hydrangeas is not comparable to that of syringas. The ornamental growth indices at both 1 WAP and 8 WAP also exhibited a similar trend, showing that hydrangeas are more competitive than syringas across all three container sizes in descending order, starting from 3-gallon, then 1.5-gallon, and finally, 0.67-gallon, where 3-gallon containers showed the highest growth of hydrangeas. Syringas also followed a similar trend with 3-gallon containers producing the highest growth and 0.67-gallons showing the lowest, but the extent of growth is again not comparable to that of hydrangeas in all three container sizes. Furthermore, the ornamental PAR values also support the previous outcomes, demonstrating that hydrangeas are more competitive than syringas. The reason hydrangeas have thrived well in large containers compared to syringa can be attributed to their possession of fibrous roots. Despite both hydrangeas and syringa having fibrous and shallow roots, the horizontally wide-spreading nature of hydrangeas, as opposed to the more upright growth habit preferred by syringas, allows the hydrangeas to spread and grow more robustly in all three container sizes. Furthermore, the fertilizer incorporated into the growing media within the container favors the wide-spreading fibrous roots of hydrangeas, enabling them to acquire nutrition more rapidly than syringa do.

At 8 WAP, the weed fresh weights indicated that large crabgrass is more competitive than smooth pigweed. Additionally, it is evident that large crabgrass is more competitive with syringa than with hydrangea, particularly when large crabgrass density is higher, such as at densities of 6 and 3 compared to a density of 1 in the containers. Specifically, it is noteworthy that weed fresh weights were higher in 3-gallon containers and 1.5-gallon containers, while weed fresh weight was observed lower in 0.67-gallon containers across all weed densities applied. The higher proliferation of large crabgrass, particularly with syringa, can be attributed to the fact that syringa is less competitive with large crabgrass than hydrangeas. This same rationale applies to large crabgrass as well. Large crabgrass, being a monocot with fibrous roots, can spread across the soil (growing media) in the container to absorb nutrients more effectively from the fertilizer already incorporated into the growth media, compared to dicotyledonous smooth pigweed, which possesses a taproot that does not spread to the same extent as large crabgrass. This might explain why large crabgrass is more prolific than smooth pigweed, especially in competition with syringa.

These observations bear resemblance to several previous studies where researchers evaluated weed competition in Japanese holly (*Ilex crenata* Thunb.) and Ligustrum (*Ligustrum lucidum* W.T.Aiton) [12]. They found that weeds caused a significant decrease in shoot dry weight for both plants across the four container sizes assessed. Japanese holly experienced a 50-55% decline, whereas Ligustrum reported a 12-22% decrease. The weed species included Eclipta (*Eclipta prostrata*), Phyllanthus (*Phyllanthus tenellus* Roxb.), garden spurge (*Euphorbia hirta* L.), artillery weed {*Pilea microphylla* (L.) Liebm.}, bluemink (Ageratum *houstonianum* Mill.), and Spanish needles (*Bidens alba* DC.). Weed competition consistently had a negative impact on ornamental plant growth across all container sizes, ranging from 3.8 L to 56.8 L [12]. However, Khamare et al [12], evaluated the containers of larger sizes and conducted a long-term assessment of the effects of weed competition on ornamentals growth. In contrast, our study aims to understand the competition between weeds and ornamentals during the early stages of plant growth. Additionally, focusing on containers of smaller sizes, which a consumer would typically prefer when purchasing from growers or nurseries. This preference benefits the grower by lowering the input costs for weed management and allows them to choose the optimal container size at the beginning of planting which ultimately benefits the grower's business.

Another study conducted by Fretz [8], investigated into how different weed species, such as redroot pigweed and large crabgrass, affect Japanese holly plants in nursery containers of different sizes (2.4 L and 6.0 L). It was discovered that competing weed density significantly lowered the dry weight of Japanese holly compared to weed-free conditions with higher decline observed when large crabgrass was present. In addition, as weed density increased in larger nursery containers, the dry weight of 1-year-old Japanese holly plants decreased. This highlights the influence of weed competition and container size on Japanese holly development in container nursery environments

[8]. Specifically, the findings regarding large crabgrass in Fretz [8], study align with our findings. It is evident from our research that large crabgrass exhibits greater competitiveness compared to smooth pigweed. Similarly, the smooth pigweed utilized in our study shares similar characteristics with the redroot pigweed examined in Fretz's [8] study, and it was found to be less effective than large crabgrass. In contrast, another study by, Berchielli-Robertson et al [3] found that weed species such as eclipta, prostrate spurge, and wood sorrel exhibited different levels of competitiveness with container-grown ornamental plants such as 'Fashion' azalea and 'Crimson Pigmy' barberry. The study discovered that container size influences the competitive effects of these weeds on plant growth, with smaller containers being more susceptible to weed interference [3]. However, this outcome does not align with the findings of our study, which could be attributed to the fact that our study did not assess the outcome after a long period of growth, unlike the two-year duration examined by the researchers in this study. Additionally, our study reveals that small containers reduce weed competition. Furthermore, they investigated only one or two container sizes, and their evaluation involved varying densities of weeds, with either single or multiple weed species, to determine their effects, whereas our study evaluated three container sizes [3,8]. In summary, the 3-gallon containers supported good ornamental growth, particularly in the hydrangeas, however, they exhibited limited effectiveness in suppressing weeds. In contrast, the 0.67-gallon containers provided efficient weed control but compromised the ornamental growth.

5. Conclusions

This experiment evaluated three different sizes of containers commonly used for ornamental production in nurseries and greenhouses, aiming to enhance ornamental growth while reducing weed proliferation, thereby increasing marketability, and benefiting the economic returns of the produce. Overall, the 0.67-gallon containers were found to effectively reduce weed competitiveness; however, the confined space within these containers also inhibited ornamental growth. In contrast, the 3-gallon containers provided a better environment for ornamental growth and development, but the larger surface area of these containers led to increased weed competition with ornamental plants. Furthermore, it's noteworthy that competition dynamics may vary with different species beyond those assessed in our study. In conclusion, the outcomes are highly specific to the species competing within the confined spaces of containers.

Further research can be directed towards investigating the competitive dynamics between weeds and annual or biennial ornamentals with lower growth habits, particularly in container sizes of 0.67 gallons and 3 gallons and research can focus on long-term studies such as 2–3-year period. These container sizes were chosen based on their common usage in horticultural practice and their potential relevance to plant growth dynamics. Considering the unique life cycles of annuals and biennial ornamentals compared to perennials, exploring their efficacy in weed suppression within containers is essential. Additionally, this research would provide insights into whether container sizes, as a non-chemical alternative, effectively align with growth habits of ornamental species.

TABLES

Table 3.1: Analysis of Variance (ANOVA) results for ornamentals, weed species, container sizes, and density of weeds of weed fresh weights at 8 weeks after planting (WAP)

	P-value
Source	Weed fresh weights
Ornamental	< 0.0001*
Weed species	< 0.0001*
Ornamental * Weed species	< 0.0001*
Density	< 0.0001*
Ornamental * Density	0.2765
Weed species * Density	0.0003*
Container size	< 0.0001*
Ornamental * Container size	0.4598
Weed species * Container size	< 0.0001*
Density * Container size	0.0023*

*Significant ($P \leq 0.05$) main effects or interactions

Table 3.2: Analysis of Variance (ANOVA) results for ornamentals, weed species, container sizes, and density of weeds of ornamental fresh weights and ornamental PAR at 8 weeks after planting (WAP), and ornamental initial growth indices at 1 WAP and ornamental final growth indices at 8 WAP

	P-value			
Source	Ornamental fresh weights	Ornamental PAR	Ornamental initial growth indices	Ornamental final growth indices
Ornamental	< 0.0001*	0.1902	< 0.0001*	< 0.0001*
Weed species _density	< 0.0001*	< 0.0001*	0.3075	0.2035
Ornamental * Weed species _density	< 0.0001*	0.0130	0.1194	0.6913
Container size	< 0.0001*	0.3802	0.0130*	< 0.0001*
Ornamental * Container size	< 0.0001*	0.4264	0.0974	0.0022*
Weed species _density *Container size	0.08763	0.0028*	0.2627	0.4390

*Significant ($P \leq 0.05$) main effects or interactions

Table 3.3: Mean weed fresh weights of interactions ornamental * weed species, weed species * density of weeds species, weed species * container size, and density of weeds * container size at 8 weeks after planting.

Interactions	Response Variable Weed Fresh Weight (g)
Ornamentals * Weed species	
Syringa * Smooth pigweed	114.17 C
Hydrangea * Smooth pigweed	98.56 C
Syringa * Large crabgrass	376.23 A
Weed species * Density	
Large crabgrass * 6	442.19 A
Large crabgrass * 3	299.97 B
Smooth pigweed * 6	159.83 C
Large crabgrass * 1	155.76 C
Smooth Pigweed * 3	123.09 C
Weed species * Container size	
Large crabgrass * 3 Gallon	495.78 A
Large crabgrass * 1.5 Gallon	288.25 B
Smooth pigweed * 3 Gallon	163.90 C
Smooth Pigweed * 1.5 Gallon	115.65 DC
Large crabgrass * 0.67 Gallon	113.90 DC
Density * Container size	
6 * 3 Gallon	474.23 A
3 * 3 Gallon	350.85 B
6 * 1.5 Gallon	302.00 CB
3 * 1.5 Gallon	202.77 CD
1 * 3 Gallon	164.44 ED
6 * 0.67 Gallon	126.80 EDF
1 * 1.5 Gallon	101.08 EDF
3 * 0.67 Gallon	80.96 EF
1 * 0.67 Gallon	22.41 F

* Weed fresh weights followed by the same letter are not significantly different from each other within a column. Mean separation by Tukey's HSD test.

Table 3.4: Mean ornamental fresh weights of interactions ornamental * weed species density, and ornamentals * container size at 8 weeks after planting.

Interactions	Response Variable Ornamental Fresh Weights (g)
Ornamentals * Weed species density	
Hydrangea * Smooth pigweed_ 6	146.86 A
Hydrangea * Smooth pigweed_ 1	124.64 BA
Hydrangea * Smooth pigweed_ 3	106.28 BC
Hydrangea * control_ 0	104.90 BC
Hydrangea * large crabgrass_ 3	96.89 BC
Hydrangea * large crabgrass_ 1	89.22 C
Hydrangea * large crabgrass_ 6	76.28 C
Syringa * large crabgrass_ 1	28.53 D
Syringa * control_ 0	28.14 D
Syringa * Smooth pigweed_ 3	26.30 D
Syringa * Smooth pigweed_ 1	25.36 D
Syringa * large crabgrass_ 3	4.92 D
Syringa * Smooth pigweed_ 6	23.83 D
Ornamental * Container size	
Hydrangea * 3Gallon	149.61 A
Hydrangea * 1.5Gallon	130.05 B
Hydrangea * 0.67Gallon	66.65 C
Syringa * 3Gallon	30.22 D
Syringa * 1.5Gallon	23.41 D
Syringa * 0.67Gallon	22.81 D

* Ornamental fresh weights followed by the same letter are not significantly different from each other within a column. Mean separation by Tukey's HSD test.

Table 3.5: Mean ornamental PAR of interactions ornamental * weed species density and weed species density * container size at 8 WAP.

	Response Variable
Interactions	Ornamental PAR (μmol m^{-2} s^{-1})
Ornamentals * Weed species density	
Hydrangea * Smooth pigweed_ 6	52.37 A
Hydrangea * Smooth pigweed_ 1	36.34 BAC
Hydrangea * Smooth pigweed_ 3	46.34 BA
Hydrangea * control_ 0	30.80 BC
Hydrangea * large crabgrass_ 3	27.85 BC
Hydrangea * large crabgrass_ 1	29.44 BC
Hydrangea * large crabgrass_ 6	27.35 BC
Syringa * large crabgrass_ 1	32.35 BC
Syringa * control_ 0	40.35 BAC
Syringa * Smooth pigweed_ 3	40.43 BAC
Syringa * Smooth pigweed_ 1	54.03 A
Syringa * large crabgrass_ 3	30.80 BC
Syringa * Smooth pigweed_ 6	44.31 BAC
Weed species density * Container size	
Smooth pigweed_ 6 * 0.67Gallon	55.97 A
Smooth pigweed_ 1 * 0.67Gallon	53.97 A
Smooth pigweed_ 3 * 0.67Gallon	52.94 BA
Smooth pigweed_ 6 * 3Gallon	48.46 BAC
Smooth pigweed_ 3 * 3Gallon	45.33 BDAC
Smooth pigweed_ 1 * 3Gallon	42.07 BDAC
Smooth pigweed_ 6 * 1.5Gallon	40.59 BDAC
control_ 0 * 3Gallon	40.42 BDAC
Smooth pigweed_ 1 * 1.5Gallon	39.53 BDAC
Large crabgrass_ 1 * 3Gallon	36.78 BDAC
Large crabgrass_ 3 * 1.5Gallon	36.64 BDAC
Large crabgrass_ 6 * 1.5Gallon	34.62 BDAC
control_ 0 * 1.5Gallon	34.31 BDAC
control_ 0 * 0.67Gallon	32.00 BDAC
Smooth pigweed_ 3 * 1.5Gallon	31.89 BDAC
Large crabgrass_ 3 * 3Gallon	28.79 BDC
Large crabgrass_ 1 * 1.5Gallon	28.24 DC
Large crabgrass_ 1 * 0.67Gallon	27.66 DC
Large crabgrass_ 6 * 3Gallon	23.58 D
Large crabgrass_ 6 * 0.67Gallon	23.3012 D
Large crabgrass_ 3 * 0.67Gallon	22.51 D

Table 3.5 (Cont'd)

* Ornamental PAR followed by the same letter are not significantly different from each other within a column. Mean separation by Tukey's HSD test.

Table 3.6: Mean ornamental initial growth indices of interaction ornamental * container size at 8 weeks after planting.

Interactions	Response Variable
Ornamental * Container size	Ornamental Initial GI At 1 WAP (in.)
Hydrangea * 3 Gallon	17.45 A
Hydrangea * 1.5 Gallon	16.75 A
Hydrangea * 0.67 Gallon	14.76 B
Syringa * 3 Gallon	10.69 C
Syringa * 1.5 Gallon	9.27 D
Syringa * 0.67 Gallon	9.37 D

* Ornamental initial growth indices followed by the same letter are not significantly different from each other within a column. Mean separation by Tukey's HSD test.

* WAP represents weeks after planting.

Table 3.7: Mean ornamental final growth indices of treatments ornamentals and container sizes at 8 weeks after planting.

Treatments	Response Variable Ornamental Final GI At 8 WAP (in.)
Container sizes (gallons)	
3	16.02 A
1.5	15.72 BA
Ornamentals	
Hydrangea	18.11 A
Syringa	13.02 B

* Ornamental final growth indices followed by the same letter are not significantly different from each other within a column. Mean separation by Tukey’s HSD test.

* WAP represents weeks after planting.

LITERATURE CITED

1. ADAMS, D. (1990). Chemical weed control in containerized hardy ornamental nursery stock. *Professional Horticulture*, *4*(2), 70-75.

2. Bartley, P. C., Wehtje, G. R., Murphy, A.-M., Foshee, W. G., & Gilliam, C. H. (2017). Mulch type and depth influences control of three major weed species in nursery container production. *HortTechnology*, *27*(4), 465-471.

3. Berchielli-Robertson, D. L., Gilliam, C. H., & Fare, D. C. (1990). Competitive effects of weeds on the growth of container-grown plants. *HortScience*, *25*(1), 77-79.

4. Case, L., Mathers, H., & Senesac, A. (2005). A review of weed control practices in container nurseries. *HortTechnology*, *15*(3), 535-545.

5. Chong, C. (2003). Experiences with weed discs and other nonchemical alternatives for container weed control. *HortTechnology*, *13*(1), 23-27.

6. Criscione, K. S., Fields, J. S., Owen, J. S., Fultz, L., & Bush, E. (2022). Evaluating stratified substrates effect on containerized crop growth under varied irrigation strategies. *HortScience*, *57*(3), 400-413.

7. Fain, G. B., Knight, P. R., Gilliam, C. H., & Olive, J. W. (2003). Effect of fertilizer placement on prostrate spurge growth in container production. *Journal of Environmental Horticulture*, *21*(4), 177-180.

8. Fretz, T. A. (1972). Weed Competition in Container Grown Japanese holly1. *HortScience*, *7*(5), 485-486.

9. Gilliam, C. H., Foster, W. J., Adrain, J. L., & Shumack, R. L. (1990). A survey of weed control costs and strategies in container production nurseries. *Journal of Environmental Horticulture*, *8*(3), 133-135.

10. Khamare, Y., Marble, S. C., Altland, J. E., Pearson, B. J., Chen, J., & Devkota, P. (2022). Effect of substrate stratification on growth of common nursery weed species and container-grown ornamental species. *HortTechnology*, *32*(1), 74-83.

11. Khamare, Y., Marble, S. C., & Chandler, A. (2020). Fertilizer placement effects on eclipta (Eclipta prostrata) growth and competition with container-grown ornamentals. *Weed Science*, *68*(5), 496-502.

12. Khamare, Y., Marble, S. C., Pearson, B. J., Chen, J., & Devkota, P. (2023). Effect of Weed Competition on Growth of Container Grown Ornamentals Plants in Four Different Container Sizes. *Horticulturae*, *9*(3), 317.

13. Massa, D., Benvenuti, S., Cacini, S., Lazzereschi, S., & Burchi, G. (2019). Effect of hydro-compacting organic mulch on weed control and crop performance in the cultivation of three container-grown ornamental shrubs: Old solutions meet new insights. *Scientia Horticulturae*, *252*, 260-267.

14. Mathers, H. M. (2003). Novel methods of weed control in containers. *HortTechnology*, *13*(1), 28-34.

15. Saha, D., Marble, S. C., Torres, N., & Chandler, A. (2019). Fertilizer placement affects growth and reproduction of three common weed species in pine bark–based soilless nursery substrates. *Weed Science*, *67*(6), 682-688.

16. Stewart, C. J., Marble, S. C., Pearson, B. J., & Wilson, P. C. (2017). Impact of container nursery production practices on weed growth and herbicide performance. *HortScience*, *52*(11), 1593-1600.