



Article

Evaluating the Effect of Weed Placement on the Growth of Container-Grown Plants and Herbicide Application around Container Drain Holes and Root Pruning Containers

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Abstract: The objective of this study was to evaluate the effect of weed placement on the growth of container-grown ornamental plants. Additionally, it also assessed the safety of applying herbicides beneath and on the slits of air-pruning containers using four common container-grown ornamental plants. The study was divided into three experiments, with uniform liners of pentas (*Pentas lanceolata* (Forssk.) Deflers) and golden dewdrop (*Duranta erecta* L.) in the first experiment and pentas in the second. The weed seedlings, consisting of either ageratum (*Ageratum houstonianum* Mill.) or eclipta (*Eclipta prostrata* L.), were positioned in one of three locations within the container, either directly beside the rootball of the ornamental plant, 2.5 cm away from the rootball, or inside the drain hole of the container. The third experiment involved four ornamental species, which were utilized to assess the safety of herbicide application either beneath or on the slits of air-pruning containers. The overall results of the first two experiments revealed that weeds growing either at the center or the sides of the ornamental plant rootball had significant competitive effects on the growth of the ornamental species. In case of the third experiment, no herbicide injury was observed on the ornamental species, with a minor decrease in the growth of loropetalum (*Loropetalum chinensis* 'Ruby').



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Keywords: container plant production; container nursery; crop-weed interaction; nursery; weed competition; weed control; weed placement

1. Introduction

The nursery and floriculture agricultural sectors make a significant economic contribution to the United States, as evidenced by their substantial annual revenue of USD 10 billion in 2019 [1]. The majority of these crops are grown in nursery containers. However, one of the persistent challenges that container growers face in maximizing their profitability is the presence of weeds. It has been estimated that the annual expense of weed management in containers can surpass USD 25,000 per hectare per year [2,3]. Compared to field-grown crops, weeds cause a greater detrimental effect on container-grown plants due to the limited amount of nutrients, water, and space available in the confinement of a container. In addition, weed crop competition in the limited space of a container can adversely affect photosynthesis, leaf chlorophyll content, plant water relations, nutrient uptake, respiration, flowering, yield, and overall crop growth [4]. A single weed can reduce container-grown crop growth by 30% to 60% in just one season, increasing production time [5]. For instance, ref. [6] reported that a single redroot pigweed (*Amaranthus retroflexus* L.) or a single large crabgrass (*Digitaria sanguinalis* (L.) Scop.) caused decreases of 47% and 60%, respectively, in the dry weight of Japanese holly (*Ilex crenata* Thunb.) when grown in a 2.4 L container. Another study reported that the presence of one grass weed species consisting of either barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.), large crabgrass, or Chinese foxtail (*Setaria faberi* R.A.W. Herrm.) in a 7.6 L container reduced the shoot dry weight of bush cinquefoil (*Potentilla fruticosa* Gray. 'Gold Drop') by 52% in just 83 days [7].

An additional container weed–crop competition study was conducted to evaluate the growth of ligustrum (*Ligustrum lucidum* W.T. Aiton) and Japanese holly (*Ilex crenata*) in 3.8, 11.4, 26.5, and 56.8 L nursery containers with weed coverages of 50% and 100% consisting of eclipta (*eclipta prostrata* (L.) L.), 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.) [8]. The results of this study indicated that weed competition at both 50% and 100% weed levels was consistent across all container sizes with both species, highlighting the persistent competitiveness of weeds even in larger containers. In contrast to field crops, container-grown ornamentals are sold primarily for their visual appeal [9], and consumers expect weed-free containers when making a purchase [10]. Therefore, container producers have a more restrictive threshold for weeds to ensure the marketability and desirability of ornamental plants. Furthermore, the presence of weeds also leads to reduced leaf size, decreased vitality, a lower quantity of flowers, and overall compromised plant health, often leading to a decline in the marketability of the plant [11].

One of the most effective weed management methods involves eliminating weeds and preventing their spread through sanitation [12,13]. Growing plants in containers offers growers an advantage in controlling the environment around the crop and reducing the amount of weed seeds that can enter the nursery. Nevertheless, weed seeds have the potential to infiltrate a nursery area via various means such as wind, new plant material, potting substrate, tools, equipment, animals, and people [14].

Weed species commonly found in container plant production include eclipta (*Eclipta prostrata*), artilleryweed (*Pilea microphylla*), hairy bittercress (*Cardamine hirsuta* L.), bittercress (*Cardamine* spp.), bluemink (*Ageratum houstonianum*), spotted spurge (*Euphorbia maculata* Aiton), horseweed (*Conyza canadensis* (L.) Cronquist), garden spurge (*Euphorbia hirta*), oxalis (*Oxalis stricta* L.), phyllanthus (*Phyllanthus tenellus*), and liverwort (*Marchantia polymorpha* L.) [15,16], among many others. Many of these species readily establish in the pot drain holes or on the substrate that may spill under containers, leading to competition for water and nutrients [15]. The weed species mentioned above share several common characteristics that contribute to their frequent occurrence in container production systems. These traits include being annual plants capable of producing multiple generations in a single year, possessing seeds adapted for germination in shaded environments, or having mechanisms for seed dispersal within the nursery [16]. These weed species growing in the drain holes or under containers can be an immediate source of weed seeds. For example, bittercress can produce about 2000 seeds per plant within 7 weeks, whereas eclipta can produce more than 17,000 seeds per plant in optimum conditions [16,17]. Additionally, many weed species, once established, have the ability to disperse their seeds over considerable distances, potentially infesting neighboring containers [18].

To manage weeds effectively, nursery growers use various methods such as hand weeding, sanitation, use of mulch, weed discs, and herbicide application [19]. These existing methods primarily concentrate on managing weeds on the surface of containers, while little to no attention has focused on weeds that may proliferate in the drain holes of containers and escape other forms of management (excluding manual removal). Proper drainage is essential for the growth of plants in containers. This drainage is provided through holes that are either present at the bottom of the containers or present along the wall of bottom corners. A variety of containers ranging in depth, width, shape, material, and drainage hole placement are used in container plant production. A survey on weed management strategies used by container nurseries revealed that growers use black plastic (44%), weed mat (9%), rock or shell (12%), and combinations of the above (23%) to control weed growth under the containers [20]. The survey also reported that larger nurseries applied herbicides under the containers to control weeds during spring or when new container beds are assembled. Although these methods can be effective for short-term weed control under containers, factors such as container design, soilless substrate, daily irrigation, and high fertilizer rates create an optimal environment for weed seed germination underneath the

containers. In most cases, container drain holes have moist and sandy soil along with nutrients leaching out, making them an ideal environment for a weed species to thrive.

There have been a handful of previous research studies focusing on the competitive effect of weeds on container-grown ornamental plants [5–8]. However, competition with ornamentals from weeds growing in container drain holes has received limited or no attention from researchers. Additionally, no research has been focused on the effect of weed placement on the growth of container-grown crops. Several field studies have investigated the effect of weed distance on crop plant size and yield [21,22]. For example, ref. [23] reported that soybean (*Glycine max* (L.) Merr.) growth was significantly reduced at 6 weeks after planting (WAP) when individual common cocklebur plants (*Xanthium strumarium* L.) were 10 cm away, whereas it required 12 WAP to affect soybean growth when the common cocklebur was 40 cm away. No studies have been conducted in container settings to assess the impact of weed–crop competition based on the placement of weeds within the container. While all or at least most weeds would need to be removed prior to sale and for sanitation purposes, understanding how competition is affected by weed placement could have important management implications, as weeds in drain holes are often difficult to see during scouting and are consequently the last to be removed.

Further, there is limited information on the safety of applying herbicides on the sides or underneath containers. Many container nurseries use air-pruning containers instead of smooth-sided containers to eliminate the issue of circling and girdling roots, root escape through drain holes, unevenly distributed root structure, and overall deformed root systems [24,25]. Air-pruning containers lead to the pruning of apical root meristems when the root tips are exposed to air, which in turn promotes the growth of finer roots and assists the development of a balanced and uniform root system [26,27]. Despite the extensive research conducted on the advantages of using air-pruning containers, there is currently no available data on the application of herbicides specifically on the sides of these containers. These innovative containers feature open slits that serve the purpose of root trimming, but they also provide an ideal habitat for weed seeds to enter and germinate. Similar to the drain holes found in smooth-sided nursery containers, these slits create optimal conditions for weed growth and spread (Figure 1).



Figure 1. An example of the root pruning containers used to evaluate herbicide safety.

Due to the literature gaps described above, the primary objective of this study was to evaluate the effect of weed placement on the growth of container-grown ornamental plants. The weed placement consisted of weed seedlings placed either directly beside the rootball of the ornamental plant, 2.5 cm away from the rootball, or inside the drain hole of the container. The goal was to investigate the weed–crop competitive effect in three different locations within a container, which can help recommend growers where to focus weed management efforts first. Additionally, our secondary objective was to evaluate the safety of applying herbicides beneath and on the slits of air-pruning containers using four common container-grown ornamental plants.

2. Materials and Methods

All the experiments were conducted at the Mid-Florida Research and Education center in Apopka, FL, USA. In all experiments, nursery containers were filled with a substrate consisting of pine bark, peat, and sand mix (80:10:10 v:v:v) amended with dolomitic lime to yield a pH of 5.5 and fertilized with a controlled release fertilizer (CRF) (Osmocote® Plus micronutrients 21-4-8 N-P-K (8–9 mo), ICL Specialty Fertilizers, Dublin, OH, USA) at 4.7 kg m^{-3} .

2.1. Experiment 1: Effect of Three Different Weed Placement Scenarios on the Growth of Container-Grown Pentas (*Pentas lanceolata*) and Golden Dewdrop (*Duranta erecta*)

Uniform liners of pentas (*Pentas lanceolata*) and golden dewdrop (*Duranta erecta*) grown in 5 cm plugs were transplanted into separate 3.8 L nursery containers (18 cm height, 20 cm diameter). Two commonly found weed species in container plant production were used for this study consisting of ageratum (*Ageratum houstonianum*) or eclipta (*Eclipta prostrata*). Two weeks before transplanting the ornamentals mentioned, separate sets of containers were seeded with either ageratum or eclipta. The seedlings emerged in two weeks and consisted of two true leaves and approximately 1.3 cm in diameter. One seedling of either ageratum or eclipta was selected for uniformity and transplanted by hand into the nursery containers with pentas and golden dewdrop. The weed seedlings were positioned in one of three locations within the container: either directly beside the rootball of the ornamental plant, 2.5 cm away from the rootball, or inside the drain hole of the container (Figure 2).

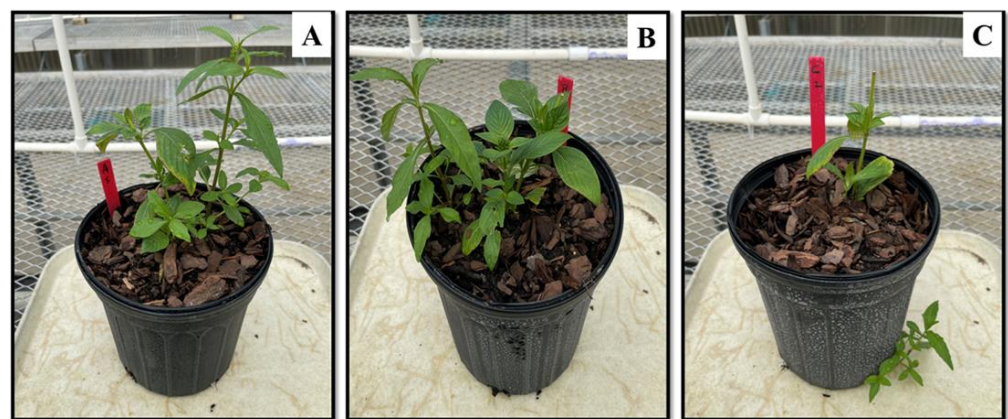


Figure 2. Eclipta seedlings were positioned in one of three locations within the container: either directly beside the rootball of the pentas plant (A), 2.5 cm away from the rootball (B), or inside the drain hole of the container (C).

The use of seedlings instead of seeds was implemented to ensure consistent size and growth of the weed species within all the treatments. In a separate group of containers, the seedlings were placed in one of the three locations mentioned above (center of the container's surface, 2.5 cm away from the center of the container's surface, or in the drain hole) but without any ornamental plants. As a result, the treatments consisted of containers containing either pentas and golden dewdrop plants with weeds positioned either next

to the rootball (center), 2.5 cm away from the rootball (side), or in the drain holes (drain holes). In addition, there were fallow containers that only contained weed seedlings placed at the same three positions. Furthermore, a separate treatment involved containers with either pentas or golden dewdrop plants, which were carefully maintained to be weed-free to serve as a control group. All the containers were placed inside a screened greenhouse and received 0.7 cm irrigation per day via overhead irrigation.

Data collection consisted of measuring the ornamental plant growth index (height + width at widest point + perpendicular width) 8 and 12 weeks after planting (WAP). The shoot and root dry weights were collected at trial conclusion (12 WAP) for both ornamental and weed species. The shoots were cut at the soil level, whereas the roots were washed and separated with pressurized water to rinse off all the substrates. The plant material was dried in a forced-air oven at 60 °C until reaching a constant weight. The experiment was a completely randomized design with six single-container replications for each treatment and each ornamental species. The first experiment run was initiated in June 2021 and repeated in September 2021.

2.2. Experiment 2: Effect of Two Different Weed Placements on the Growth of Container-Grown Pentas (*Pentas lanceolata*)

A second experiment was conducted to fine-tune and build upon the results obtained in Experiment 1. The ornamental plants consisted of uniform liners of pentas grown in 5 cm plugs. The liners were transplanted into separate 3.8 L nursery containers (18 cm height, 20 cm diameter). Two weeks prior to transplanting pentas liners, a separate set of containers were seeded with either ageratum or eclipta. The weed seedlings emerged in two weeks, consisted of two true leaves and were approximately 1.3 cm in diameter. One seedling of either ageratum or eclipta was transplanted by hand into the nursery containers with pentas. The weed seedlings were positioned either directly beside the rootball of the pentas or inside the drain hole of the container. In a separate group of containers, the seedlings were placed in either center of the container's surface or the drain hole without the presence of pentas. As a result, the treatments consisted of containers containing pentas with weeds positioned either next to the rootball (center), or in the drain holes (drain holes). In addition, there were fallow containers that only contained weed seedlings placed at the same two positions. Furthermore, a separate treatment involved containers with pentas plants as control, which were carefully maintained to be weed-free. All the containers were placed inside a screened greenhouse and received 0.7 cm irrigation per day via overhead irrigation.

Data collection consisted of measuring the ornamental plant growth index (height + width at widest point + perpendicular width) at 6 and 10 weeks after planting (WAP). The shoot and root dry weights were collected at trial conclusion (10 WAP) for both the ornamental and weed species. The shoots were cut at the soil level, and roots were washed and separated with pressurized water to rinse off all the substrates. The plant material was dried in a forced-air oven at 60 °C until reaching a constant weight. The experiment was a completely randomized design with six single-container replications for each treatment and each weed species. Both experimental runs were initiated in October 2023.

2.3. Experiment 3: Evaluate the Safety of Herbicide Application on Root Pruning Containers Using Common Ornamental Plants

The ornamental species used in this study were loropetalum (*Loropetalum chinense* (R.Br.) Oliv. 'Ruby'), podocarpus (*Podocarpus macrophyllus* (Thunb.) Sweet), Japanese holly (*Ilex crenata* 'Compacta'), and Peach Drift® rose (*Rosa* 'Meiggili' PP 18,542). Loropetalum, podocarpus, and Japanese holly obtained in 2.8 L nursery containers (18.4 cm height, 16.2 cm diameter) were transplanted into 3.0 L root pruning containers (Figure 1; 15.2 cm height, 15.2 cm diameter; DL wholesale, Romulus, MI, USA). Peach Drift® roses obtained in 3.8 L containers (18.1 cm height, 19 cm diameter) were transplanted into 7.5 L root pruning containers (25.4 cm height, 25.4 cm diameter; DL wholesale, Romulus, MI, USA). After transplanting, all the plants were placed on a full sun nursery pad and received irrigation of 1.3 cm per day via overhead irrigation (Xcel-Wobbler; Senninger Irrigation, Clermont, FL,

USA). Herbicides were applied approximately 5 days after transplanting the ornamental plants in the root pruning containers.

On 22 July 2022 [28 C (84 F), 74% relative humidity, calm winds, clear skies], herbicides (Table 1) were applied around containers using a CO₂ backpack sprayer calibrated to deliver 234 L ha^{−1} via a TeeJet® 8008 flat-fan nozzle (TeeJet Technologies, Wheaton, IL, USA) at 30 PSI. The herbicide was applied as a directed application to the sides of the nursery containers, simulating an application that would be made to control weeds growing in the sides of root pruning containers. Plant foliage was not contacted with the spray during application.

Table 1. Herbicides evaluated for the ornamental safety on air-pruning containers.

Common Name	Trade Name	Rate (v/v) ^a	Manufacturer
Glyphosate	Roundup Pro®	2%	Bayer Environmental Science, Research Triangle Park, NC, USA
Diquat ^b	Reward®	0.58%	Syngenta Crop Protection, LLC; Greensboro, NC, USA
Pelargonic acid	Scythe®	5%	Gowan Company, Yuma, AZ, USA
Glufosinate	Finale®	3.12%	BASF Corporation, Research Triangle Park, NC, USA

^a Herbicides were applied based on spot-application rates on each label represented in v/v. ^b Diquat treatment was applied with the addition of 0.25% Capsil surfactant (Aquatrols, Paulsboro, NJ, USA).

An additional water-only treatment was also included as a control for comparison. At the time of application, all plant foliage was dry, and remained dry until irrigation was carried out the next morning. Data collection consisted of injury rating recorded visually on a scale of 0 to 100, where 0 indicated no injury and 100 indicated dead plants with no chance of recovery. Visual injury ratings were collected at 1, 2, 4, 6, 8, and 10 weeks after treatment (WAT). At the conclusion of the trial at 8 WAT, the growth indexes (height + width at widest point + perpendicular width) of all the plants were measured. The experiment was a completely randomized design with five single-container replications for each treatment and each ornamental species. The study was repeated in time using the same methodology.

2.4. Statistical Analysis

Data were subjected to analysis of variance using statistical software (JMP® Pro ver. 14, SAS Institute, Cary, NC, USA). Before analysis, all data were tested to ensure that the ANOVA assumptions were met. Post hoc means comparisons were performed using Tukey’s honestly significant difference test, with differences considered significant at $p \leq 0.05$. The data were pooled, since there was no interaction between the treatment and experimental runs.

3. Results and Discussion

3.1. Experiment 1: Effect of Three Different Weed Placement Scenarios on the Growth of Container-Grown Ornamental Plants

3.1.1. Effect of Eclipta Placement on Container-Grown Golden Dewdrop and Pentas

The presence of eclipta did not have a significant impact on the growth index of golden dewdrop plants at 8 or 12 WAP (Table 2).

However, when eclipta was positioned at the center or side of pentas, the growth index of pentas was noticeably reduced. At 8 WAP, the growth index of pentas with eclipta at the center decreased by 21%, while pentas with eclipta positioned at the side suffered a 28% decrease. Similarly, at 12 WAP, the growth of pentas was reduced by 29% and 28% for pentas with eclipta placed at the center and side, respectively (Table 2). Interestingly, the presence of eclipta growing in the drain hole did not have a significant effect on either pentas or golden dewdrop plants.

The shoot dry weight of golden dewdrop plants was predominantly affected when eclipta was growing at the center, resulting in a decrease of approximately 11% (Table 2). However, the root dry weight of golden dewdrop did not show any competitive effect, with similar growth observed across all treatments. On the other hand, both the shoot and

root dry weights of eclipta growing in the drain hole were significantly decreased in the absence of golden dewdrop plants compared to eclipta plants growing in the center in the absence of golden dewdrop (Figure 3A). Only the shoot dry weight of eclipta growing in the drain with the presence of golden dewdrop was decreased compared to eclipta growing in the center in the absence of golden dewdrop. Unlike golden dewdrop, both the shoot and root dry weights of pentas growing with eclipta at the center and side were negatively affected (Table 2). The shoot dry weight was approximately decreased by 38%, whereas the root dry weight decreased by nearly 13%. In the case of eclipta, the shoot and root dry weights of eclipta growing in drain hole were the lowest, with or without the presence of pentas (Figure 3B).

Table 2. Competitive effects of eclipta (*Eclipta prostrata*) and ageratum (*Ageratum houstonianum*) on the growth of container-grown golden dewdrop (*Duranta erecta*) and pentas (*Pentas lanceolata*).

Treatments ^c	Golden Dewdrop				Pentas				
	Growth Index ^a		Biomass ^b		Growth Index		Biomass		
	Eclipta Placement	8 WAP	12 WAP	Shoot wt. (g)	Root wt. (g)	8 WAP	12 WAP	Shoot wt. (g)	Root wt. (g)
Ageratum placement	Center	15.1 a ^d	17.4 a	18.0 b	16.5 a	28.4 ab	31.8 b	25.4 b	17.2 b
	Side	16.8 a	21.8 a	18.7 ab	17.2 a	26.1 b	32.1 b	26.1 b	17.6 b
	Drain hole	19.5 a	22.5 a	19.5 ab	17.6 a	35.9 a	44.5 a	38.6 a	19.0 a
	Control	18.4 a	18.7 a	20.3 a	17.3 a	36.1 a	44.6 a	41.2 a	19.7 a
Eclipta placement	Center	16.0 ab	19.6 ab	18.0 a	16.3 a	18.6 b	21.8 c	14.4 a	5.5 a
	Side	14.4 b	16.4 b	18.0 a	16.8 a	23.8 b	24.8 bc	17.7 a	4.7 a
	Drain hole	21.6 a	23.2 a	20.6 a	17.3 a	27.7 ab	35.0 ab	19.9 a	6.4 a
	Control	18.7 ab	24.4 a	20.2 a	17.2 a	34.9 a	44.6 a	22.2 a	5.4 a

^a Growth index was determined by calculating [(height + width at widest point + perpendicular width) ÷ 3] at 8 and 12 weeks after planting (WAP). ^b Shoot and root dry weights of golden dewdrop and pentas were measured at 12 weeks after planting (WAP). ^c Treatment consisted of either eclipta or ageratum seedling planted either at center of the ornamentals rootball (Center), 2.5 cm away from the ornamental rootball (Side), or inside the drain hole. Control consisted of ornamental growing without eclipta or ageratum seedling. ^d Means followed by the same letter within a column are not significantly different according to Tukey's HSD test, $\alpha = 0.05$.

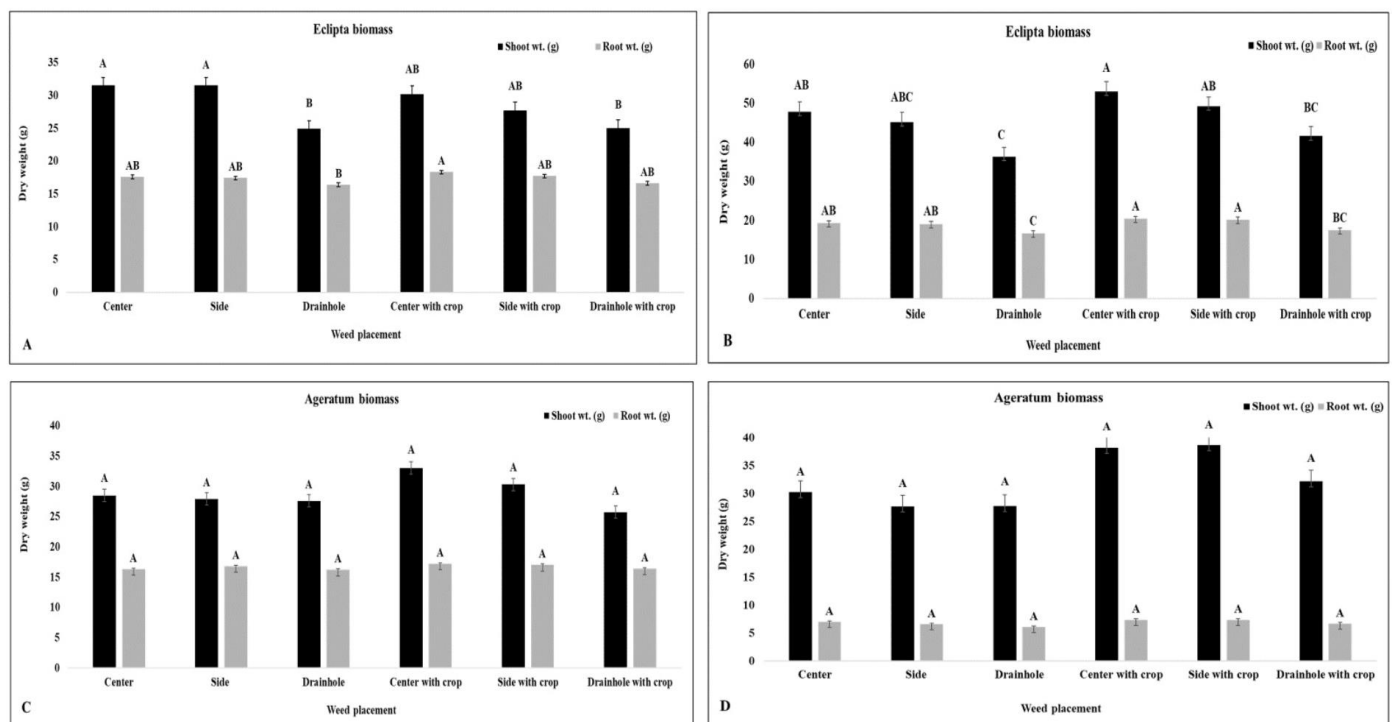


Figure 3. Shoot and root dry weights of eclipta (*Eclipta prostrata*) and ageratum (*Ageratum houstonianum*). Graph (A) consists of eclipta planted either at center, side, or in the drain hole of the container. Additional treatments consist of eclipta placed next to the golden dewdrop (*Duranta erecta*) rootball

(Center with crop), 2.5 cm away from the golden dewdrop rootball (Side with crop), or inside the drain hole (Drainhole with crop). (B) consists of eclipa planted either at center, side, or in the drain hole of the container. Additional treatments consist of eclipa placed next to the pentas (*Pentas lanceolata*) rootball (Center with crop), 2.5 cm away from the pentas rootball (Side with crop), or inside the drain hole (Drainhole with crop). (C) consists of ageratum planted either at center, side, or in the drain hole of the container. Additional treatments consist of ageratum placed next to the golden dewdrop rootball (Center with crop), 2.5 cm away from the golden dewdrop rootball (Side with crop), or inside the drain hole (Drainhole with crop). (D) consists of ageratum planted either at center, side, or in the drain hole of the container. Additional treatments consist of ageratum placed next to the pentas rootball (Center with crop), 2.5 cm away from the pentas rootball (Side with crop), or inside the drain hole (Drainhole with crop). Control consists of either eclipa or ageratum growing at the center in absence of ornamental plants. Error bars represent standard errors. Bars with same letters are not significantly different according to Tukey's HSD test, $\alpha = 0.05$.

3.1.2. Effect of Ageratum Placement on Container-Grown Golden Dewdrop and Pentas

At both 8 and 12 WAP, ageratum placed at the side of the container reduced the growth index of golden dewdrop, resulting in decreases of 23% and 33%, respectively (Table 2). However, the growth index of pentas at 8 WAP was significantly affected when ageratum was placed at the center and side. By 12 WAP, ageratum placed at the center of the container reduced the growth index of pentas by 51%, whereas ageratum at the side reduced the growth index of pentas by 44%. Like eclipa, ageratum growing in the drain holes did not affect the growth of either golden dewdrop or pentas (Table 2).

The shoot and root dry weights of golden dewdrop were not affected by ageratum in any of the treatments (Table 2). Similar results were observed with the shoot and root dry weights of pentas, with no significant difference in the biomass of pentas in any of the treatments. Unlike eclipa, the shoot and root dry weights of ageratum were not affected by the placement or presence of ornamental plants (Figure 3). Though not a significant difference, the biomass of ageratum in the presence of either golden dewdrop or pentas was higher than ageratum growing in the absence of ornamental plants. This could be due to the greater ability of ageratum to compete for nutrients, light, and water compared to the ornamental species in this study.

3.2. Experiment 2: Effect of Two Different Weed Placements on the Growth of Container-Grown Pentas (*Pentas lanceolata*)

3.2.1. Competitive Effect of Ageratum and Eclipa Placement on Container-Grown Pentas

The presence of ageratum at the center reduced both the growth index and the biomass of pentas. By the trial's conclusion, the growth index of pentas with ageratum growing in the center decreased by 29% in just 10 weeks compared to the control (Table 3).

Interestingly, the ageratum growing in the drain hole did not have an effect on the pentas growth index. Similar results were observed with the shoot and root weights of pentas. The shoot and root dry weights of pentas growing with ageratum in the center compared to the control were reduced by 37% and 5%, respectively (Table 3). However, ageratum growing in the drain hole did not affect the shoot or root dry weight of pentas.

At both 6 and 10 WAP, eclipa had no effect on the growth index of pentas (Table 3). However, by the trial's conclusion, the shoot and root dry weights of pentas growing with eclipa in the center were reduced by 18% and 5%, respectively (Table 3). Similar to the results observed with ageratum, the presence of eclipa in the drain hole had no significant impact on either the growth index or the biomass of pentas.

Table 3. Growth of pentas (*Pentas lanceolata*) in response to competition with ageratum (*Ageratum houstonianum*) and eclipta (*Eclipta prostrata*).

Treatments ^c	Pentas			
	Growth Index ^a		Biomass ^b	
	6 WAP	10 WAP	Shoot wt. (g)	Root wt. (g)
<i>Ageratum Placement</i>				
Center	25.8 b ^d	31.7 b	24.9 b	17.6 b
Drain hole	29.8 ab	39.2 a	36.4 a	18.3 a
Control	33.9 a	44.9 a	39.8 a	18.5 a
<i>Eclipta placement</i>				
Center	31.8 a	44.1 a	39.5 b	17.9 b
Drain hole	33.1 a	47.2 a	45.0 ab	18.6 ab
Control	35.7 a	47.8 a	48.6 a	18.8 a

^a Growth index was determined by calculating [(height + width at widest point + perpendicular width) ÷ 3] at 6 and 10 weeks after planting (WAP). ^b Shoot and root dry weights of pentas were measured at 12 weeks after planting (WAP). ^c Treatment consisted of either ageratum or eclipta seedling planted either at center of the pentas rootball (Center) or in the drain hole. Control consisted of pentas growing without eclipta or ageratum seedling. Additional treatments consisted of either ageratum or eclipta growing at the above-mentioned placement in absence of pentas. ^d Means followed by the same letter within a column are not significantly different according to Tukey's HSD test, $\alpha = 0.05$.

3.2.2. The Competitive Effect of Container-Grown Pentas on Eclipta and Ageratum

The shoot dry weight of eclipta was consistently reduced when placed in the presence of pentas (Figure 4A).

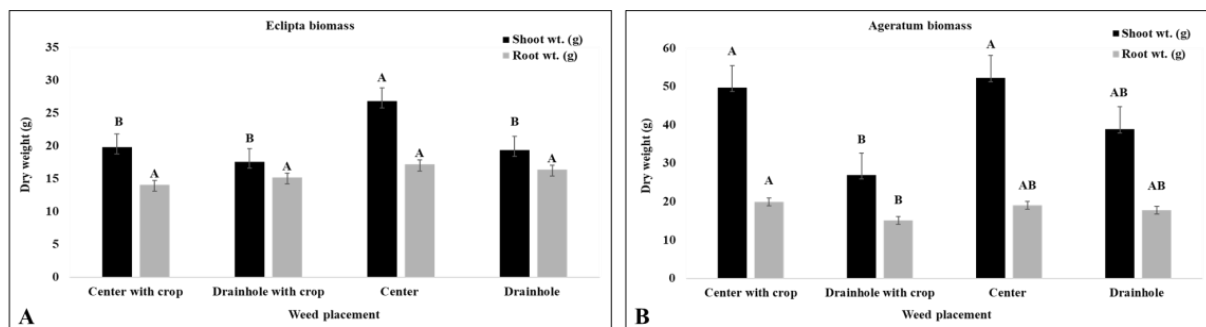


Figure 4. Shoot and root dry weights of eclipta (*Eclipta prostrata*) and ageratum (*Ageratum houstonianum*). Graph (A) consists of eclipta placed next to the pentas rootball (Center with crop) or inside the drain hole (Drainhole with crop). Additional treatments consist of eclipta planted either at center (Control), or in the drain hole of the container. Graph (B) consists of ageratum placed next to the pentas rootball (Center with crop), or inside the drain hole (Drainhole with crop). Additional treatments consist of ageratum planted either at center (Control), or in the drain hole of the container. Error bars represent standard errors. Means followed by the same letter within a bar are not significantly different according to Tukey's HSD test $\alpha = 0.05$.

Specifically, the shoot dry weight of eclipta growing in the center with pentas decreased by 26%, while the shoot dry weight of eclipta placed in the drain hole with pentas in the center of the container experienced a more significant reduction of 34% compared to the control (eclipta growing in the center without pentas). Additionally, the shoot dry weight of eclipta growing in drain hole without the presence of pentas was also reduced by 28% compared to the control. There was no effect on the root dry weight of eclipta in any of the treatments.

The shoot and root dry weights of ageratum growing in drain hole with the presence of pentas were reduced by 49% and 21%, respectively (Figure 4B). Unlike eclipta, the growth of ageratum growing in the center with pentas was not affected with similar growth to the control. Overall, the growth of both weed species in the drain hole was less prolific.

The results of experiments 1 and 2 indicate that the competitive effect of weeds and ornamental plants is species-specific. Overall, the weeds growing on the surface at either the center (closer to the ornamental rootball) or at the side had the most competitive effect on the ornamental plants. This result was consistent in both experiments with major reductions in ornamental plant growth. Similar results were reported by [28], which showed that eclipta placed 2.5 cm away from the ornamental plant reduced the shoot biomass of ligustrum (*Ligustrum lucidum*) by 16% and root dry weight by 14% in just 12 weeks. The results also indicated that, overall, eclipta was more competitive compared to ageratum. There have been several studies showing the problematic and competitive nature of eclipta in container plant production. One eclipta plant over a 12-week study resulted in an average decrease of 14% in the growth rate of boxwood (*Buxus microphylla*) and ligustrum [28]. Another study reported that one eclipta plant decreased the growth of fashion azalea (*Rhododendron eriocarpum* var. *tawadae* Ohwi (Hayata) Nakai × 'Fashion') by 49% over a period of 6 months [5].

Interestingly, both the weed species growing in drain holes did not affect the growth of ornamental plants in both experiments. In all cases, the growth of ornamental plants with weed species in the drain hole was similar to the growth of weed-free ornamental plants (control). The absence of competitiveness through the drain hole could be due to the spatial distance between weeds and ornamental plants. We hypothesize that the weeds growing in the drain hole are receiving the nutrients and water that are already leached through the ornamental plant roots and will not be utilized. Additionally, since the weed is growing in the drain hole, it does not compete for light or space during its initial growing phase. Although we did not notice any competitive effect of weeds growing in the drain hole, both the weed species were still able to flower and produce seeds. The first and most important step of a weed management plan for container plant production is sanitation and preventing weed seeds from entering the growing area [13]. The cost of preventing a weed from growing in the drain hole is significantly lower than the cost of managing a weed infestation. For example, one eclipta plant can produce an average of 3000 seeds, with a potential of 17,000 seeds under optimal conditions, with no dormancy [17,29]. Several commonly found weed species in nurseries share similar weed biology and exhibit germination periods ranging from 5 to 12 days [16].

3.3. Experiment 3: Evaluate the Safety of Herbicide Application on Root Pruning Containers Using Common Ornamental Plants

No signs of herbicide injury were observed during the visual injury rating. The ornamental plants examined at 1, 2, 4, 6, 8, and 10 WAT did not exhibit any visible injury or symptoms related to herbicide application. With the exception of loropetalum, there were no discernible differences in the growth index among the various treatment groups for the other ornamental species. Out of all the treatments, only glyphosate demonstrated a significant impact on the growth index of loropetalum. When compared to the control group, the application of glyphosate resulted in a notable decrease of nearly 11% (Table 4).

Glyphosate, diquat, pelargonic acid, and glufosinate are commonly used as post-emergence herbicides in and around container grown ornamentals [15,30,31]. These are non-selective herbicides that are safe to use in production spaces and around containers to control weeds, as long as foliage or other plant parts are not contacted during application. All the mentioned herbicides were applied as a directed spray on the weeds and are typically used to target the above-ground portions of the weed. Glyphosate is a systemic herbicide that translocates throughout the plant via both symplastic and apoplastic pathways. Several crop species, including rapeseed (*Brassica napus* L.), barley (*Hordeum vulgare* L.), cotton (*Gossypium hirsutum* L.), and maize (*Zea mays* L.) have demonstrated the absorption of glyphosate through their roots [32–35]. In the case of our study, no symptoms were observed on the ornamental plants with a minor decrease in the growth of loropetalum, which is likely due to root contact and absorption, as it is possible that roots were contacted through the holes in the root pruning container. It is important to note that while no

injury was observed in this study, it is possible and even likely that plant roots were not directly contacted via the application, as no roots were visible through the slits in the container and plants had been relatively recently potted. Use of directed applications of post-emergence herbicides, especially contact action herbicides, would likely cause little to no injury to most ornamentals if foliage is not contacted; however, further research is needed before wide ranging recommendations can be made. Further, since loropetalum growth decreased, glyphosate would not be a recommended option for spot treating weeds in root pruning containers.

Table 4. Effects of herbicide applications on air-pruning containers using common ornamental species.

Herbicide ^b	Growth Index ^a			
	Loropetalum	Podocarpus	Japanese Holly	Drift Roses
Glyphosate (RoundUp Pro)	49.4 b ^e	46.3 a	41.8 a	26.2 a
Diquat (Reward) ^c	51.5 ab	42.2 a	41.9 a	26.3 a
Pelargonic acid (Scythe)	53.4 ab	42.4 a	44.2 a	25.1 a
Glufosinate (Finale)	53.6 ab	44.9 a	42.4 a	25.7 a
Check ^d	55.5 a	43.7 a	43.5 a	26.9 a

^a Growth index was determined by calculating [(height + width at widest point + perpendicular width) ÷ 3] at 8 weeks after treatment (WAT). ^b Herbicides were applied based on spot-application rates on each label represented in v/v. ^c Diquat treatment was applied with the addition of 0.25% Capsil surfactant (Aquatrols, Paulsboro, NJ, USA). ^d Check consisted of water-only treatment (Control). ^e Means followed by the same letter within a column are not significantly different according to Tukey's HSD test, $\alpha = 0.05$.

4. Conclusions

The results of this study revealed that competition of eclipta and ageratum can significantly hinder the growth of container-grown golden dewdrop and pentas plants. Interestingly, the weed growing in the drain hole had no competitive effect on the growth of the container-grown plant. The weed species growing in the drain hole, whether with or without ornamental crops, exhibited similar shoot and root weights. Although the weed species growing in drain holes did not cause any competitive effects, it is still important to manage them as they serve as a source of weed seeds. These seeds are in close proximity to the production area and can introduce seeds through various means, with some having the ability to disperse seeds over several meters away. An effective weed management plan consists of diminishing or eliminating the spread of weed seeds. Sanitation with preventative measures to control weeds will substantially reduce the cost of weed control. This study also indicates that growers could most likely safely apply contact herbicides to root pruning containers without compromising the growth and quality of the crops within the container. However, future studies should explore additional options for post-emergence herbicides and investigate their effects on commonly used plants in air-pruning containers.

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