

Fertilizer placement affects growth and reproduction of three common weed species in pine bark-based soilless nursery substrates

Research Article

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Abstract

Weed management in container crops is primarily accomplished through frequent PRE herbicide applications and supplemental hand weeding. However, many ornamental species are sensitive to herbicides, and a significant number of tropical plants, ornamental grasses, and foliage crops have not been screened for herbicide tolerance. As nursery crops are produced in inert substrates that are largely composed of bark or peat, strategic fertilizer placement has the potential to significantly reduce weed growth in container-grown ornamentals. Growth and reproduction of three common container nursery weed species, eclipta [*Eclipta prostrata* (L.) L.], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and spotted spurge (*Euphorbia maculata* L.), were evaluated following fertilization via alternative methods, including subdressing or dibbling in comparison with industry standard practices of topdressing or incorporating a controlled-release fertilizer (17-5-11 [8 to 9 mo.]) to each 3.8-L container at 36.5 g per container. Fertilizer placement had little to no effect on germination of *Eclipta prostrata* or *D. sanguinalis*, but incorporation increased *E. maculata* germination by 77% to 183% compared with other placements or a nonfertilized control. Subdressing reduced seed production by 94%, 63%, and 92% for *Eclipta prostrata*, *D. sanguinalis*, and *E. maculata*, respectively, compared with the average number of seeds produced in the conventional placement methods (average of incorporation and topdressing). Dibbling fertilizer resulted in similar decreases in the case of *D. sanguinalis* and *E. maculata*, while *Eclipta prostrata* produced no seeds when fertilizer was dibbled. Similar to reductions observed in reproduction, subdressing fertilizer resulted in biomass decreases of 90%, 81%, and 85% compared with the average biomass of the incorporation and topdressed placements. Results suggest alternative fertilizer placements could be implemented as part of an integrated weed management program in container production to reduce weed growth.

Introduction

Weed management in container-grown ornamental crops is challenging and costly for producers. Nursery crop producers regularly report that hand-weeding costs can exceed \$9,900 ha⁻¹ while total economic losses due to weed infestations have been estimated at \$17,300 ha⁻¹ (Case et al. 2005) and are often the most expensive production input with the exception of labor (Mathers 2003). In container production, weeds may reduce the growth of ornamental crops by more than 50%, as they are more competitive with ornamental crops in restricted rooting environments (i.e., the container) (Berchielli-Robertson et al. 1990; Fretz 1972; Walker and Williams 1989). Weed competition in nursery crops reduces profit margins due to increased production time, but even if competition were not a concern, ornamental crops must be weed free, because consumers demand weed-free pots (Simpson et al. 2002).

In contrast to agronomic crops, no broadleaf POST herbicides are available that can be applied safely over the top of ornamentals, requiring growers to manage weeds through hand weeding and frequent PRE herbicide applications. PRE herbicides are the most effective and economical means of weed control, but may still be cost prohibitive for smaller operations. A 20-ha nursery may spend \$83,000 per year in for PRE herbicides, not including costs for labor required for application (Stewart et al. 2017). While approximately 25 different herbicidal products are labeled for use in ornamentals (Neal et al. 2017), only five mechanisms of action are commonly used; thus, it is difficult to develop effective rotations that provide a high degree of crop safety. In some situations, growers may be able to afford herbicides but may have a crop mix that does not allow for herbicide application due to potential crop injury. Common ornamental crops such as hydrangea (*Hydrangea* spp.), herbaceous perennials, succulents, and ornamental grasses are notoriously sensitive to PRE herbicide applications. Increasing

environmental regulations related to pesticide use and the tendency for PRE herbicides move off-target through leaching, runoff, or spray drift are also an increasing concern for nurseries (Case et al. 2005). Growers may also be wary of certain herbicides if they use containment ponds to irrigate, as phytotoxicity has been reported (Horowitz and Elmore 1991; Keese et al. 1994).

Due to the cost of hand weeding and challenges associated with PRE herbicides, growers and researchers have investigated use of various nonchemical tools for weed control, including organic mulch such as pine bark (Cochran et al. 2009; Richardson et al. 2008; Wilen et al. 1999), rice hulls (Case et al. 2005), and weed disks or similar products that are secured on the container medium surface (Amoroso et al. 2009; Chong 2003; Mathers 2003). All of these methods have been found to be as or more effective than a single herbicide application, but cost and availability often prohibit wide-scale adoption (Stewart et al. 2017). Other disadvantages associated with these materials, such as their being prone to blowing out of containers and being lost when pots blow over during high winds, further limit adoption.

Many studies have shown that fertilizers may benefit weeds more than crop plants (Blackshaw et al. 2004; DiTomasso 1995). Annual weed species are most prevalent in container-grown ornamental crops, and as nutrient resources are limited and confined inside the container, it may take only one or two weed plants to significantly reduce the growth of slower-growing perennial ornamentals (Berchielli-Robertson et al. 1990; Fretz 1972). One method of weed management uniquely afforded to producers of container-grown ornamentals is the ability to alter fertilizer placement inside the container. Container medium, or potting soil, is primarily comprised of bark, typically pine (*Pinus* spp.) or Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], peat, and various other components such as sand, perlite, vermiculite, or wood fibers (Bilderback et al. 2013; Buamscha et al. 2007). These materials are largely inert and contain few available nutrients (Landis 1990), requiring the addition of controlled-release fertilizers to allow and promote crop growth (Bilderback et al. 2013). Currently, fertilizers are typically topdressed at potting, and the entire allotment of fertilizer is placed on the container medium surface, or the fertilizer is incorporated and thoroughly mixed in the medium using large soil mixers before potting. Topdressing is often the only method of fertilization but may also be used in addition to incorporation for longer-term crops (12+ mo). Two less commonly used methods are dibbling and subdressing. Dibbling can be accomplished in several ways, but is usually performed by placing the entire fertilizer allotment directly below the root ball of the plant liner. Dibbling is not commonly practiced, as there is a chance of reduced crop growth or phytotoxicity resulting from crop roots remaining in direct contact with fertilizer prills (Hicklenton 1990). Similar to dibbling, subdressing is not commonly practiced, but this is primarily because information is lacking on how to implement this method, and depending upon nursery operations, it may be difficult or time-consuming to use this method in some cases. Subdressing involves filling a pot approximately 50% or more with inert potting medium, adding all the fertilizer in a single layer, and then placing the plant liner and more potting medium on top. This results in a 5- to 8+-cm top layer of potting medium containing no fertilizer, while the crop roots are placed in close proximity to the fertilizer, but only a small percentage of roots are in direct contact initially following potting. As root growth and nutritional requirements increase, a larger percentage of roots come into contact with the fertilized layer inside the container.

Ornamental crop response to fertilizer placement is highly species specific, and it is difficult to make broad recommendations (Yeager and Ingram 1987). Alternative methods such as dibbling or subdressing may result in either increased (Alam et al. 2009; Broschat and Moore 2003; Cobb 1985; Conover and Poole 1985) or decreased (Hicklenton 1990) ornamental crop growth or may have no influence at all (Cobb 1985; Klock-Moore and Broschat 1999). However, dibbling or subdressing fertilizer has been shown to result in similar or greater growth of many ornamental crops compared with standard incorporation or topdressing methods (Altland et al. 2004; Broschat and Moore 2003; Marble et al. 2012). While it is difficult to make broad generalizations concerning ornamental crop response, weed response to fertilizer placement is more straightforward. Banding fertilizer in agronomic cropping systems reduced growth of multiple weed species by up to 50% when compared with broadcast applications in studies by several authors (Blackshaw et al. 2004; Kirkland and Beckie 1998; Rasmussen et al. 1996). In a nursery container filled with inert potting medium, weed control potential of strategic fertilizer placement is often far more impactful. Dibbling or subdressing may not consistently reduce germination, but weeds often never grow beyond the cotyledon stage when they have no access to available nutrients (Altland et al. 2004; Wada 2005). Fain et al. (2003) reported that dibbling reduced prostrate spurge (*Euphorbia prostrata* Aiton) biomass by 40% to 90% in a pine bark:peat (3:1 v:v) potting medium containing ornamental crops. Similarly, Altland et al. (2004) reported reductions in common groundsel (*Senecio vulgaris* L.) biomass of 82% and 46%, reductions in *Euphorbia prostrata* growth of 56% and 61%, and an increase in creeping woodsorrel (*Oxalis corniculata* L.) control of 47% and 49% when comparing dibble placement to topdressing or incorporation placements, respectively. Subdressing has been less studied, but Broschat and Moore (2003) have reported significantly less total weed biomass when fertilizers were subdressed compared with incorporated or topdressed fertilizer applied at the same rate.

Dibbling, subdressing, and other strategic fertilizer placements reduce weed growth by limiting weeds' access to nutrients and/or providing crops with more direct access to nutrients and increasing their competitive ability (Nkebiwe et al. 2016). Although weed seed germination may not always be influenced (Sweeney et al. 2008), increased rates or access to nutrients, primarily nitrogen, has been shown to increase seed production in barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] (Chauhan and Abugho 2013), *S. vulgaris* (Harper and Ogden 1970), and several other weed species (Van Deldon et al., 2002; Whigham 1984). Reducing access to nutrients may significantly reduce weed biomass (Weaver and Cavers 1980). For most weed species, seed production is highly correlated to plant size (McLachlan et al. 1995; Senseman and Oliver 1993; Thompson et al. 1991); thus, limiting weed biomass is likely to limit seed production and reduce future weed pressure.

Little research has focused on weed seed introduction and dispersal in container-grown ornamentals; however, Williams and Sanders (1984) showed that dispersal by wind and irrigation and/or rainfall are primary contributors to seed spread when weeds are present in production areas. Cross and Skroch (1992) found that the majority of weed introductions in container nurseries were related to the weed presence in the immediate environment, similar to findings by Aldrich (1984) in field crops. Annual weed species most commonly infest container-grown ornamentals using copious seed production as their primary means of reproduction (Neal and Derr 2005). Thus, reducing weed biomass and seed

production could lead to significant cost savings for growers due to reduced hand weeding and to a lesser extent, reduced PRE herbicide applications per year. As many ornamental species are prone to injury from herbicide applications, strategic fertilizer placement may be a viable method of weed management in some ornamental crops. Although the influence of topdressing, incorporating, and dibbling fertilizer on weed growth have been investigated previously, subdressing has not been thoroughly investigated. Further, no reports, have been published identifying the influence fertilizer placement may play on weed reproduction in soilless container substrates. The objective of this research was to determine the influence of conventional (incorporation or topdressing) and alternative (subdressing or dibbling) fertilizer placement in soilless pine bark substrates on biomass, flowering, and seed production of three weed species that are commonly problematic in ornamental production. If subdressing or dibbling resulted in significant decreases in weed growth or seed production, nursery producers could begin implementing these alternative fertilizer placements as part of an integrated weed management program to reduce overall weed pressure in container-grown nursery crops.

Materials and Methods

Experiments were conducted at the Mid-Florida Research and Education Center in Apopka, FL, in 2018. On June 17, 3.8-L plastic nursery containers with a top surface area of 206 cm² were filled with a substrate composed of bagged pine bark (Elixson Wood Products, Starke, FL) mixed with sand at a 8:1 (pine bark:sand, v:v) ratio. Pine bark, especially when bagged, is largely initially weed free (Stewart et al. 2017). Dolomitic lime was incorporated into the pine bark:sand mixture at 3 kg m⁻³ in all cases, resulting in a pH of approximately 5.5 at the time of filling based on pour-through leachate analysis using methods described by Bilderback (2001). Fertilizer (Osmocote® Plus micronutrients 17-5-11 [8 to 9 mo.], ICL Specialty Fertilizers, Dublin, OH) was added to each container at 36.5 g (6.2 g N, 1.8 g P, 4.0 g K), representing the manufacturer's recommended high rate, via incorporation, topdressing, subdressing, or dibbling. Incorporation of fertilizer was done by thoroughly mixing fertilizer homogeneously throughout the substrate before potting. In order to ensure that each pot received the same amount of fertilizer, containers were first filled with 3.8 L of substrate consisting of pine bark and sand only at the aforementioned ratio. This substrate was then removed from the container and placed in a larger plastic container. Fertilizer (36.5 g) was then weighed out individually for each container and added to the substrate, and then thoroughly mixed before the substrate was placed back into the nursery container. Topdressing was accomplished by adding the entire allotment of fertilizer to the substrate surface after fully filling the container with the substrate. Subdressed containers were first filled with the pine bark:sand substrate up to 5.1 cm from the soil surface. Fertilizer was weighed individually for each container, and then the entire allotment of fertilizer was then applied evenly to the substrate surface in a single layer. After the addition of fertilizer, the remaining 5.1-cm depth of substrate was added so that the containers were completely filled. Fertilizer was dibbled by first fully filling the container with substrate. A plastic pipe was used to make small hole in the substrate surface that was 2.5-cm wide by 5-cm deep. The entire allotment of fertilizer was then added to this hole, and substrate was then placed on top. Regardless of fertilizer placement, each pot received 36.5 g of fertilizer. A separate set of pots filled with only the pine bark:sand substrate and containing no fertilizer were used for comparison

to determine growth of each species in the absence of fertilizer. After being filled, all containers were placed in an open-sided screened greenhouse maintained between 21 and 35 C immediately after filling and received 0.7-cm irrigation d⁻¹ for the remainder of the experiment. On June 18, 25 seeds of eclipta [*Eclipta prostrata* (L.) L.], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and spotted spurge (*Euphorbia maculata* L.) were surface sown to separate sets of containers fertilized using one of the methods described previously (incorporated, topdressed, subdressed, dibbled, or no fertilizer). The experiment was completely randomized with four single-pot replications per treatment, and each weed species was grouped and analyzed separately. The study was repeated following the same methodology and timeline on August 22, 2018.

Weed counts in each pot were recorded at 3 and 8 wk after seeding (WAS). Studies were terminated at 9 WAS to coincide with typical PRE herbicide application schedules in Florida nurseries, which often occur at 8- to 10-wk intervals during the summer months. This allowed estimation of seed production that could occur from weed escapes in between hand weeding and herbicide applications, as growers typically hand weed containers before making a sequential PRE application. Weed counts were recorded for each pot by first counting the total number of emerged plants (mature and cotyledon stage) and then separately counting plants in the cotyledon to 2-leaf stage of growth (two or fewer fully formed leaves). At 9 WAS, shoot and root biomass was recorded by dry-weight determination. Plants were cut at soil level, and roots were washed with pressurized water to remove all substrate. Roots and shoots were separated and placed in a forced-air oven at 60 C for 7 d, reaching a constant weight. Immediately before shoot and root dry-weight determination at 8 WAS, inflorescence counts were recorded and seed production was estimated for each species. For *D. sanguinalis*, the total number of inflorescences was recorded in addition to recording the total number of racemes on each plant. Six racemes were then chosen randomly on each plant, and the total number of seeds (caryopsis) was counted for each raceme. Total seed number per plant and per pot was then estimated by multiplying the mean seed number per raceme by total raceme number per plant and per pot. The total number of compound flower heads (i.e., compound heads containing ray and disk florets) was recorded for *Eclipta prostrata* plants. Counts for both mature (containing seeds) and immature (containing no mature seeds) flower heads were recorded. In each mature flower head containing seeds (achenes), the total number of seeds was counted for six randomly selected mature flower heads and then multiplied by the total number of mature flower heads to estimate seed number per plant and per pot. *Euphorbia maculata* flowers (cyanthium) were recorded on a subsample of each plant and then totals were estimated for each pot and for each plant. *Euphorbia maculata* flowers are self-compatible with high fruit and seed set (>90%) being observed during summer months in previous studies (Suzuki and Ohnishi 2006; Suzuki and Teranishi 2005). Each fruit is a three-celled capsule containing three seeds. Seed production for *E. maculata* was estimated using fruit counts observed following the different fertilization treatments and based upon previously described fruit and seed set for this weed (Suzuki and Ohnishi 2006; Suzuki and Teranishi 2005).

Data Analysis

Each weed species was analyzed separately. Weed counts, total flowers and seeds per pot and per plant, and shoot and root dry-weight data were combined over both experimental runs

Table 1. Effect of fertilizer placement on biomass and reproduction of *Eclipta prostrata*, *Digitaria sanguinalis*, and *Euphorbia maculata* in soilless nursery substrates.^a

Placement ^c	Weed counts			Reproduction				Biomass	
	3 WAS ^d	8 WAS ^b		Per pot ^c		Per plant		Dry weight	
		Cotyledon ^e	Mature ^f	Inflorescence	Seeds	Inflorescence	Seeds	Shoots	Roots
<i>Eclipta prostrata</i>									
Incorporation	11.1 (44) a	1.6	11.6 a	108.1 a	14,285 a	10.0 a	1,122 b	19.9 a	2.3 a
Topdressing	6.4 (26) ab	3.6	5.9 b	70.9 a	11,414 a	12.2 a	1,915 a	16.1 a	2.2 a
Subdressing	4.4 (18) b	8.8	4.3 bc	8.9 b	456 b	1.7 b	95 c	1.9 b	0.2 b
Dibbling	4.8 (19) b	3.1	0.3 c	0 b	0 b	0 b	0 c	0* b	0* b
No fertilizer	8.5 (34) ab	11.5	0.1 c	0 b	0 b	0 b	0 c	0* b	0* b
<i>Digitaria sanguinalis</i>									
Incorporation	6.3 (25)	0.1	8.5 a	63.5 a	37,751 a	7.8 a	4,737 a	71.2 a	7.4 a
Topdressing	4.3 (17)	0.1	7.8 a	42.3 a	26,617 b	5.9 ab	3,490 a	56.7 a	5.8 a
Subdressing	4.9 (20)	0.4	4.1 b	13.3 b	6,266 c	3.0 bc	1,507 b	11.4 b	1.8 b
Dibbling	5.8 (23)	0.8	2.9 bc	2.8 b	1,130 c	1.3 c	511 bc	2.7 b	0.6 b
No fertilizer	3.3 (13)	0.8	0.9 c	0 b	0 c	0 c	0 c	0* b	0.1 b
<i>Euphorbia maculata</i>									
Incorporation	11.3 (45) a	22.5	12.8 a	15,412 a	37,451 a	1,287 a	3,676 a	19.2 a	1.3 a
Topdressing	5.8 (23) b	11.0	6.0 bc	8,111 b	19,710 b	1,513 a	3,128 a	11.3 b	0.6 b
Subdressing	6.4 (26) b	23.6	8.3 ab	1,253 c	3,043 c	164 b	398 b	2.2 c	0.2 bc
Dibbling	5.5 (22) b	27.6	5.8 bc	261 c	634 c	53 b	130 b	0.3 c	0.1 c
No fertilizer	4.0 (16) b	34.1	0 c	0 c	0 c	0 b	0 b	0* c	0* c

^aMeans followed by the same letter or no letter within a column for each species are not significantly different based on Tukey's honest significance difference test ($P \leq 0.05$). An asterisk (*) indicates a mean of less than 0.01 g.

^bWAS, weeks after seeding. Weed counts were conducted at 3 and 8 WAS, while reproduction and biomass data were collected at 9 WAS. The experiment was initiated on June 18, 2018, and repeated on August 22, 2018. Values are averaged over both experimental runs.

^cSurface area of each pot was 206 cm² and pot volume was 3.8 L.

^dMean counts of all emerged seedlings of each species at 3 WAS. 25 seeds of each species were initially surface sown in each pot. Count data were analyzed; germination percentages for each fertilizer placement are shown parenthetically.

^eCotyledon to 2-leaf stage weeds counted at 8 WAS.

^fMature weeds shows counts of each species growing past a 2-leaf stage of growth.

and subjected to a mixed-model ANOVA in SAS v. 9.4 (SAS Institute, Cary, NC) with fertilizer placement as a fixed effect and trial run and replication as random effects. All data were analyzed for normality to ensure the assumptions of ANOVA were met. Means were separated using Tukey's honest significance difference test at 0.05 significance level.

Results and Discussion

Across all fertilization placements, germination averaged 20% to 28% for all three weed species. *Eclipta prostrata* counts were similar in pots that were fertilized via the two conventional methods (incorporation or topdressing). Pots that were subdressed or dibbled contained a similar number of *Eclipta prostrata* plants as pots that were topdressed or contained no fertilizer (Table 1). Fertilizer placement had no influence on *D. sanguinalis* counts at 3 WAS. It is unclear why *D. sanguinalis* germination was not affected, but it may relate to this species' ability to germinate across a wide range of nutritional and pH levels (Pierce et al. 1999). At 3 WAS, incorporation of fertilizer resulted in increases of 95%, 77%, 105%, and 183% in *E. maculata* counts compared with topdress, subdress, dibble, or no-fertilizer treatments, respectively. Higher *E. maculata* counts at 3 WAS for the incorporation treatment could be related to availability of nutrients to germinating seedlings. While topdressed and incorporation pots received fertilization at the same rate, incorporating fertilizer can result in more rapid release of controlled-release fertilizers compared with topdressing (Hoskins et al. 2014). When incorporated, fertilizer prills have greater surface-area contact with the substrate, and thus moisture, resulting in a more rapid release in the top portion of the container,

which is the area accessible to germinating seedlings. Early in the trial at 3 WAS, it is possible that the release rate from the topdressed treatment was lower, and nutrients were therefore limited, similar to dibble or subdress fertilization methods, and germinating seedlings may have been nutrient depleted. Seeds of certain weed species require different levels of available nutrients for germination (Davis 2007). In field studies, Jornsgrard et al. (1996) reported that increased nitrogen had no effect on germination in natural weed populations in spring barley (*Hordeum vulgare* L.). Germination of species such as common lambsquarters (*Chenopodium album* L.), ladythumb (*Persicaria maculosa* Gray.), and giant foxtail (*Setaria faberi* Herrm.) has been reported to increase with increasing soil nutrition (Sweeney et al. 2008). In contrast, other species such as velvetleaf (*Abutilon theophrasti* Medik.), redroot pigweed (*Amaranthus retroflexus* L.), and jimsonweed (*Datura stramonium* L.) are unaffected (Fawcett and Slife 1978; Sweeney et al. 2008). Similar to our results, Fain et al. (2003) reported a 44% reduction in *Euphorbia prostrata* germination in pots that were dibbled compared with pots that were fertilized via topdressing; this reduction was attributed to limited availability of nutrients. Previous reports on the response of *D. sanguinalis*, *Euphorbia prostrata*, or *E. maculata* to soil nutrition are lacking, but it is possible that *E. maculata* has a higher nitrogen or nutritional requirement for germination. While other factors such as soil pH influence germination (Nandula et al. 2006), it is unlikely that any changes in substrate pH or electrical conductivity (EC) levels resulting from the various placements had any influence on germination. While fertilizer placement can influence substrate pH and EC levels throughout the substrate profile (Torres et al. 2010), all three species can germinate over a wide range of pH levels (Altom and Murray 2017; Asgarpour et al. 2015; Pierce et al. 1999).

At 8WAS, no differences were observed in counts of cotyledon-stage plants for any of the three species. As all three species had reached a reproductive stage of growth, cotyledon-stage weeds at 8WAS most likely resulted from seeds that were introduced to the containers after the initial seeding. The growth habit of each species also likely influenced the total number of cotyledon-stage weeds. Pots seeded with *Eclipta prostrata* had fewer than 12 plants in the cotyledon stage, while *D. sanguinalis* pots had less than 1 plant. The sprawling and upright growth habit of both *D. sanguinalis* and *Eclipta prostrata* likely resulted in more seeds falling in between pots. In contrast, *E. maculata* has a prostrate growth habit, and thus a higher number of seeds likely fell inside the containers and began to germinate.

In *Eclipta prostrata*, incorporated fertilizer resulted in the highest number of mature plants at 8 WAS (those growing past a true 2-leaf stage of growth), followed by topdressing and subdressing, which were similar. Pots that were subdressed also contained a similar number of *Eclipta prostrata* plants as pots that were dibbled or contained no fertilizer. For *D. sanguinalis*, both conventional fertilization placements had the highest number of mature plants. For *E. maculata*, no differences were observed between topdressing, subdressing, and dibbling. For all three species, the average number of mature plants in the nonfertilized control was 0.9 or less. This shows that these species will not reach maturity in the absence of fertilizer. Interestingly, there were 11.6 *Eclipta prostrata* and 34.1 *E. maculata* in the cotyledon stage of growth on the same evaluation date (8 WAS). The high number of germinating seedlings in these pots was due to the pots not containing any mature weeds throughout the trial, as the plants never matured, and these pots received a high seed load from adjacent pots. From a management perspective, this illustrates that if fertilizer is not accessible, weed numbers may be high but competitive effects and further spread would be minimal.

Inflorescence and seed counts followed the same general trend for all three weed species, both when examining total seed produced in each pot and seed produced per plant. In most cases, either incorporating or topdressing fertilizer resulted in greater flowering and seed production compared with subdressing or dibbling. *Eclipta prostrata* inflorescence and seed counts were consistently highest in either topdressing or incorporation treatments compared with dibbling or subdressing, which were similar to the nonfertilized treatment. Similar results were observed with *D. sanguinalis*, with the exception of inflorescence counts per plant in topdressed pots, which were similar to those of subdressed pots. *Euphorbia maculata* inflorescence counts were consistently highest in incorporation treatments or topdressing treatments compared with subdressing, dibbling, or nonfertilized treatments. Overall, subdressing reduced seed production per plant by 94%, 63%, and 92% for *Eclipta prostrata*, *D. sanguinalis*, and *E. maculata*, respectively, compared with the average seed production observed with conventional placements (average of incorporation and topdressing treatments). Dibbling was similar to subdressing for all three weed species in terms of inflorescence and seed counts and resulted in no seed production in the case of *Eclipta prostrata*.

Shoot and root biomass of *Eclipta prostrata* and *D. sanguinalis* was significantly greater when fertilizer was applied by conventional placements, while subdressing and dibbling fertilizer resulted in plants of similar size compared with the no-fertilizer treatment. In *E. maculata*, incorporation resulted in the highest root and shoot growth, followed by topdressing, while there was no difference in root and shoot growth in pots that were subdressed,

dibbled, or contained no fertilizer. Similar to reductions observed in reproduction, subdressing fertilizer resulting in total biomass decreases (dry matter production/weight) of 90%, 81%, and 85% for *Eclipta prostrata*, *D. sanguinalis*, and *E. maculata*, respectively, compared with the average biomass of the conventional fertilizer placements (average of topdress and incorporation).

Similar to results observed in field studies, strategic fertilizer placement (subdressing or dibbling) consistently reduced weed biomass and reproduction in container culture by 63% to 94% in comparison with conventional fertilization methods. It is also important to note weed growth and reproduction may be reduced or mitigated in the presence of crop plants that have the ability to compete with certain weed species for resources (Zimdahl 2004). Our studies were conducted in the absence of crop plants, so overall growth and reproduction of weed species could potentially be lower in a typical nursery environment depending on the ornamental species being grown. Due to the tremendous crop diversity in the ornamentals sector, it would be difficult to establish competition and reproduction models to estimate effects as has been done in monoculture systems such as wheat (*Triticum aestivum* L.), as reported by Wilson et al. (1995). Many weed species, including *D. sanguinalis* (Fretz 1972) and *Eclipta prostrata* (Berchielli-Robertson et al. 1990), have been shown to reduce growth of container-grown ornamental plants by up to 60%, but weed growth and/or reproduction in the presence or absence of crop plants has not been investigated in container production systems. While a crop plant could possibly reduce weed growth, strategically placing fertilizer where it is available to the crop but not available to weeds could further improve crops' competitive ability (Blackshaw et al. 2004; Kirkland and Beckie 1998; Rasmussen et al. 1996).

In studies with ornamental crops, dibbling may improve the growth of several ornamentals, including azaleas (*Rhododendron* L. × 'Stewartsonian'), holly (*Ilex crenata* 'Compacta' Thunb.), lavender (*Lavandula* L. × *intermedia* 'Grosso'), and wintercreeper euonymus [*Euonymus fortunei* (Turcz) Hand.-Maz. 'Emerald Gaiety'] (Altland et al. 2004). Similarly, subdressing can improve or have no detrimental effect on growth of Chinese hibiscus (*Hibiscus rosa-sinensis* L.), bamboo palms (*Chamaedorea seifrizii* Burret), Areca palms [*Dypsis lutescens* (H. Wendl.) Beentje & Dransf.], Burmese fishtail palms (*Caryota mitis* Lour.), Macarthur palms [*Ptychosperma macarthurii* (H. Wendl. ex H.J. Veitch) H. Wendl. ex Hook. f.], star jasmine [*Jasminum multiflorum* (Burm. f.) Andrews], plumbago (*Plumbago auriculata* Lam.) (Broschat and Moore 2003), and gumpo azaleas (*Azalea* × hybrid 'Gumpo White') (Marble et al. 2012). These alternative fertilizer placements are not associated with any sort of detrimental effect on PRE herbicide efficacy (Stewart et al. 2019) and in fact may improve PRE control in some instances (Altland et al. 2004). Both dibbling and subdressing can improve ornamental crop growth in many instances while eliminating or mitigating weed competition; however, more research is needed to fully understand these dynamics, as crop growth and weed management benefits have previously been investigated independently. Further, these alternative fertilization placements may provide other benefits such as improved nutrient efficacy, uptake, and reduction in leaching (Hoskins et al. 2014). While more research is needed, it is likely that subdressing, which has not been associated with phytotoxicity as has dibbling, could both increase crop growth and limit weed growth and could serve as part of integrated an integrated weed management program in container-grown nursery crops.

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