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Fertilizer placement effects on eclipta (*Eclipta prostrata*) growth and competition with container-grown ornamentals

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Research Article

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Abstract

The objective of this study was to determine the effect of fertilizer placement on the growth of eclipta [*Eclipta prostrata* (L.) L.] and evaluate its interference with container-grown ornamental plants, including Japanese boxwood (*Buxus microphylla* Siebold & Zucc.) and ligustrum (*Ligustrum lucidum* W.T. Aiton). Results indicated that subdressing reduced *E. prostrata* shoot weight by 28%, 42%, and 46% at depths of 2.5, 5.0, and 7.5 cm, respectively, in comparison with a topdressed fertilizer treatment (a standard industry practice). Presence of *E. prostrata* reduced the growth of both ornamental species. Ligustrum shoot weight decreased as subdressing depth increased, while boxwood growth was most notably reduced at the 7.5-cm depth in comparison with topdressed containers. Overall, results indicated that subdressing may be an effective weed management strategy, but subdressing depth needs to be based on initial liner size to prevent possibly delays in production time.

Introduction

While weeds can cause growth reductions in field-grown ornamentals, they have an even greater detrimental effect on container-grown plants, because nutrients and water are more limited in the confinement of a container compared with field crops. Previous research has shown that a single weed in a 3.8-L nursery pot can reduce ornamental plant growth by 40% to 60% over one season (Berchielli-Robertson et al. 1990). Even if competition were not a concern, container plants must be weed-free in order to be marketable; thus weed action thresholds are very low compared with some other agricultural systems.

There are no labeled POST herbicides available that can be applied safely over the top of ornamentals for broadleaf weed control, so growers depend heavily on PRE herbicides and hand weeding to manage weeds. While PRE herbicides are an effective and economical means of weed control, they may still be cost prohibitive for smaller operations when utilized as the sole control strategy. Most nursery growers situated in regions with mild winter temperatures apply between four and eight PRE herbicide applications per year (Judge 2001; Stewart et al. 2017). Stewart et al. (2017) estimated that a 10-ha nursery might spend \$41,400 yr^{-1} in PRE herbicides alone, without adding the cost of labor needed for applying or the supplemental hand weeding that will be needed for weed escapes. Case et al. (2005) reported that nursery crop producers lose an estimate of \$17,300 ha^{-1} due to weed infestations and an additional \$9,900 ha^{-1} on hand weeding. Further, many common ornamental plants produced in containers, such as herbaceous annuals and perennials, succulents, and tropical plants, are notoriously sensitive to PRE herbicides. Thus, many nursery crop producers are wary of herbicides, as they can lead to potential crop injury.

Due to the cost of hand weeding and the challenges associated with PRE herbicides, more integrated weed management strategies are needed for nursery production. Potting media used in container nursery production is composed of bark, sand, peat, perlite, and other materials. Bark and peat contain few available nutrients, and most other common amendments are largely inert, (Landis et al. 1990), so controlled-release fertilizers (CRFs) are added to the substrate for a continuous supply of nutrients. Due to the low nutrient availability in potting media, strategic placement of CRF could be a potential weed management strategy. Currently, most growers fertilize container crops by incorporating or topdressing fertilizer. To fertilize by topdressing, the entire allotment of CRF is added to the media surface after potting, while for incorporation, CRF is thoroughly mixed with potting substrate before potting (Bilderback et al. 2013). Two alternative or strategic approaches to fertilization include dibbling and subdressing fertilizer (Stewart et al. 2018). Dibbling is accomplished by placing CRF just below the rootball of the plant while potting. This method has been shown to be highly effective for weed control. In a study evaluating the effect of fertilizer placement on prostrate spurge [*Euphorbia prostrata* (Aiton) Small], topdressing caused an 888% growth increase when compared with spurge growth in dibbled containers (Fain et al. 2004). While dibbling is effective, it is less commonly used due to a high concentration of fertilizer around the plant roots, which may cause phytotoxicity in some crops (Bir and Zondag 1986).

Subdressing is another fertilization approach involving filling the pot approximately 50% or 75% with media, adding CRF in a single layer, and then filling the remainder of the pot with media (Stewart et al. 2018). This results in the fertilizer being placed in a single layer, approximately 3 to 5 cm below the substrate surface, depending upon initial liner size. Crop roots can access the nutrients, but germinating weed seedlings cannot, at least initially. This also offers an advantage over dibbling, because subdressing typically does not cause phytotoxicity issues associated with dibbling, as roots have less direct contact with CRF (Broschat and Moore 2003).

It is difficult to make general recommendations for fertilizer placement, as ornamental crop response has been shown to be species specific (Broschat and Moore 2003; Stewart et al. 2017), and thousands of taxa are produced across the United States. However, subdressing has resulted in similar or greater growth of many ornamental species when compared with topdressing or incorporation (Altland et al. 2004; Broschat and Moore 2003; Marble et al. 2012). In agronomic studies, banding fertilizer below the surface compared with broadcast surface application has also been shown to reduce weed growth (Chauhan and Abugho 2013; Kirkland and Beckie 1998). In container production, Saha et al. (2019) evaluated the growth of *E. prostrata*, spotted spurge [*Euphorbia maculata* (L.) Small], and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] in pots fertilized via topdressing, incorporation, dibbling, or subdressing. Results showed subdressing resulted in germination rates similar to the industry standards for incorporation or topdressing, but also resulted in biomass reductions of more than 80% for all three species over a 9-wk period due to reduced nutrient availability for germinating weed seedlings.

If subdressing consistently reduced weed growth, at least over the short term, it could be used as part of an overall weed management plan in container crops. Most previous research has focused on subdressing only in regard to its effects on weeds (Saha et al. 2019; Stewart et al. 2018) or crop growth (Broschat and Moore 2003), but generally not both. To effectively utilize subdressing in containers, more research is needed to understand weed growth and crop response, in addition to the competitive dynamics of weeds and crops under this fertilization method. The first objective of this experiment was to determine germination and growth of *E. prostrata* in containers that have been topdressed or subdressed at three different depths. Our second objective was to determine the competitive effects of *E. prostrata* on two common ornamental species fertilized via topdressing or subdressing at three different depths.

Materials and Methods

All experiments were conducted at the Mid-Florida Research and Education Center in Apopka, FL, in May 2019 and were repeated in time, with the second experimental run being initiated approximately 1 mo after the first. In all cases, the potting substrate was a pine bark:sand (8:1 by volume) that was amended with 3 kg m^{-3} dolomitic lime before use. In all cases, pots were fertilized using 35 g of CRF (Osmocote® Plus micronutrients 17-5-11 N-P-K [8 to 9 mo], ICL Specialty Fertilizers, Dublin, OH) based on the manufacturer's recommendations. Regardless of fertilizer placement, all pots were fertilized at the same rate. All trials were conducted on a nursery pad in full-sun outdoor conditions and received 1.3 cm of overhead irrigation per day with wobbler sprinklers (Xcel® wobblers, Senninger Irrigation, Clermont, FL).

Eclipta prostrata Germination and Growth

The objective of the first experiment was to determine whether *E. prostrata* germination or growth is affected by subdressing depth in relation to the industry standard of topdressing. Nursery pots (3.8 L, 18-cm height, 20-cm diameter) were filled with the potting substrate described previously and fertilized via topdressing or subdressing or contained no fertilizer. Pots that were topdressed were filled with pine bark substrate, and 35 g of fertilizer was placed on the media surface. For pots that were subdressed, the bottom portion of the pot was filled either 2.5, 5, or 7.5 cm from the top with pine bark substrate, 35 g of fertilizer was added in a single layer, and then the remaining portion of the pot was filled with substrate. This resulted in subdressed pots with fertilizer being placed at depths of 2.5, 5, or 7.5 cm from the media surface. Another set of pots were included that only contained the pine bark substrate and no fertilizer was added to serve as a nonfertilized control. After being filled, all pots were placed on a full-sun nursery pad, and 25 *E. prostrata* seeds were surface sown to each pot. Seeds were collected from natural populations of *E. prostrata* at the Mid-Florida Research and Education Center and were counted, stored for approximately 1 wk at 22 C in glass vials in a laboratory, and sown with no preconditioning. After 4 wk, weed counts were taken to assess germination between the different fertility placements.

A second study following the same procedures was installed at the same time, except that pots were thinned (hand weeded) so that only one *E. prostrata* plant was in each pot. The *E. prostrata* plant in each pot was allowed to grow for 12 wk to determine the effects of fertilizer placement on *E. prostrata* growth. After 12 wk, *E. prostrata* growth index [(height + width at widest point + perpendicular width) ÷ 3] was measured. At 12 wk after seeding (WAS), the trial was completed with final shoot and root dry weight recorded at trial conclusion. To collect shoot weight, plants were cut at the soil level, all aboveground plant tissues were placed in paper bags, and bags were placed in a forced-air oven at 60 C until reaching a constant weight. Root weight was determined after washing off all potting media with pressurized water and then drying in the same manner. Both experiments were completely randomized block designs with four single-pot replications per treatment and repeated in time using the same methodology. All data were subjected to ANOVA in SAS (v. 9.4, SAS Institute, Cary, NC), and means comparison was performed using Tukey's honest significance differences test at $\alpha = 0.05$ to compare the three subdressing depths to both the industry standard of topdressing and the nonfertilized control. Data were pooled over both experimental runs, because no experimental run by treatment interaction was detected.

Influence of Fertilizer Placement on *Eclipta prostrata* Competition

The objective of this experiment was to assess the competitive effects of *E. prostrata* on two ornamental species fertilized via topdressing or subdressing at depths of 2.5, 5, or 7.5 cm. Pots were filled and fertilized as described earlier, except that a nonfertilized

Table 1. *Eclipta prostrata* germination and growth in response to fertilizer placement.[a]

		Growth[b]		
	Germination[c]	Growth index[d]	Shoot weight	Root weight
Placement[e]	no. pot^{-1}	—cm—	———g plant^{-1}———	
Topdress 0.0 cm	15.3 a	27.1 a	12.3 a	10.8 a
Subdress 2.5 cm	16.6 a	25.8 a	8.8 b	9.3 ab
Subdress 5.0 cm	14.0 a	20.1 ab	7.1 b	7.8 bc
Subdress 7.5 cm	16.1 a	13.0 b	6.7 b	5.9 c
No fertilizer	15.6 a	0.0* c	0.0* c	0.0* d

[a] Means followed by the same letter within a column are not significantly different according to Tukey's honest significance differences test $\alpha = 0.05$. Data were pooled over two experimental runs. An asterisk (*) indicates a mean growth index of less than 0.1 cm or mean shoot or root weight less than 0.1 g.

[b] Growth parameters were assessed separately from germination using pots containing one *E. prostrata* plant. All data were collected at 12 wk after sowing (WAS).

[c] Germination was assessed by surface sowing 25 *E. prostrata* seeds to each 3.8-L nursery pot. Data show mean count per pot at 3 WAS.

[d] Growth index = (height + width at widest point + perpendicular width) ÷ 3.

[e] Placement refers to the location of 35 g of 17-5-11 N-P-K (8- to 9-mo) controlled-release fertilizer in a 3.8-L nursery pot.

control was not included. Uniform liners of ligustrum (*Ligustrum lucidum* W.T. Aiton) and Japanese boxwood (*Buxus microphylla* Siebold & Zucc.) grown in 5-cm plug trays were transplanted into separate sets of nursery pots (as previously described) after filling. A separate set of pots were fertilized as described earlier but were left fallow and contained no ornamental plants. At 3 d after filling pots with substrate and planting ornamentals, *E. prostrata* seedlings that had been sown and germinated in a separate set of nursery pots were transplanted by hand into half of the pots containing ligustrum and half of the pots containing boxwood. One *E. prostrata* seedling was transplanted into each pot. *Eclipta prostrata* seedlings contained two true leaves, were approximately 1.3 cm in diameter, and had emerged 2 wk before transplanting. Ornamental liners typically contain at least a minute amount of fertilizer to maintain quality and growth of plants before transplanting (Carney and Whitcomb 1983). To prevent *E. prostrata* seedling roots from being in immediate contact with fertilizer present in the liner but to also place seedlings in proximity to the crop plants, *E. prostrata* seedlings were transplanted by hand 2.5 cm away from the ornamental plant's rootball. Use of transplanted seedlings in lieu of sowing seeds was done to ensure uniform *E. prostrata* size and location relative to the ornamental within each pot. In a separate set of fallow pots, one *E. prostrata* seedling was transplanted into the center. This resulted in boxwood and ligustrum being fertilized via topdressing (0-cm depth) or subdressing at three different depths (2.5, 5, or 7.5 cm) and either containing one *E. prostrata* seedling to assess competition or being hand weeded and having no weed competition. Similarly, pots with one *E. prostrata* plant were also hand weeded to prevent additional *E. prostrata* competition or growth of other weed species.

Growth index measurements were collected on ornamentals at 12 wk after planting (WAP) in addition to initial growth measurements taken at study initiation (2 WAP), and percent increase in growth index was calculated. At trial conclusion (12 WAP), root and shoot dry weights for ornamentals and *E. prostrata* were collected as described previously. Following shoot dry weight determination, a subsample of leaves from each plant (ornamentals and *E. prostrata*) was collected from three randomly selected replicates in each treatment, ground, homogenized, and analyzed for total nitrogen concentration by a commercial laboratory using a LECO total nitrogen analyzer. As an estimate of *E. prostrata* seed production, six mature flower heads containing seeds were randomly selected from each plant, and the total number of seeds were counted. The total number of seeds were then multiplied by the total number of mature flowers heads to get an approximation of number of seeds per plant (Saha et al. 2019).

The experiment was designed as a factorial treatment structure with four fertilizer placements (topdressing and subdressing at three depths) and ornamentals with two competition levels, grown either with or without competition from one *E. prostrata* plant. *Eclipta prostrata* growth was analyzed in the same manner as ornamentals to determine significance of fertilizer placement and ornamental species (ligustrum or boxwood) on growth parameters. All data were subjected to a mixed model ANOVA in SAS (v. 9.4, SAS Institute, Cary, NC) reflecting the factorial treatment arrangement to determine the influence of main effects and interactions on individual growth parameters. Data were pooled over experimental runs, as there were no treatment by experimental run interactions. Replication was considered random, while all other experimental variables and interactions were considered fixed factors. Before analysis, all data were inspected to ensure the assumptions of normality were met, and data for percent increase in growth index were arcsine transformed before ANOVA. If only main effects were significant for fertilizer placement, polynomial contrasts were used to determine trends in *E. prostrata* or ornamental growth parameters over the four fertilizer placements (i.e., depths), and Pearson correlation coefficients (r) were calculated to determine whether there was a linear relationship between shoot weight and foliar nitrogen concentration using the PROC CORR procedure in SAS. Differences in plant growth parameters based on competition were determined using the main effect *F*-test or Tukey's honest significance differences test where appropriate. Where interactions between fertilizer placement and competition were detected, contrast analysis was used to determine the effect of *E. prostrata* competition on ornamental plant growth parameters at each of the four fertilizer placements to assess the fertilizer placement in which the competition effect differed. In all cases, effects were considered significant at $\alpha = 0.05$.

Results and Discussion

Eclipta prostrata Germination and Growth

At 3 WAS, *E. prostrata* germination was similar in all treatments regardless of fertilizer placement, ranging from 14 to 16.6 plants per pot (56% to 66% germination) (Table 1). While no differences were observed in germination, fertilizer placement did influence

Table 2. Competitive effects of *Eclipta prostrata* on container-grown boxwood as influenced by fertilizer placement.

	Shoot weight[a]			Growth index increase[b]			Root weight[c]		
Placement[d]	Weeded	w/*E. prostrata*	Mean	Weeded	w/*E. prostrata*	Mean	Weeded	w/*E. prostrata*	Mean
		g			%			g	
Topdress 0.0 cm	21.8	20.3	21.0	51	36	44	17.6	17.7	17.7
Subdress 2.5 cm	23.0	22.5	22.7	49	46	48	17.8	18.1	18.0
Subdress 5.0 cm	22.5	20.1	21.3	48	48	48	17.7	17.3	17.5
Subdress 7.5 cm	19.7	19.8	19.8	38	35	37	17.2	17.3	17.2
Trend[e]	NA	NA	Q**	NA	NA	Q**	NS	NS	NS
Mean[f]	21.8 a	20.7 b		47 a	41 b		17.6	17.6	
ANOVA[g]									
Competition (C)		0.0337			0.0401			0.7785	
Placement (P)		0.0011			0.0071			0.0649	
C × P		0.3479			0.1419			0.6113	

[a] Shoot dry weight taken at 12 wk after planting (WAP) when grown either weed-free (weeded) or in competition with one *E. prostrata* plant (w/*E. prostrata*).

[b] Determined by calculating percent increase in growth index [(height + width at widest point + perpendicular width) ÷ 3] from 2 to 12 WAP. Weeded shows growth increase in weed-free plants and w/*E. prostrata* shows growth increase in competition with one *E. prostrata* plant.

[c] Root dry weight taken at 12 WAP when grown either weed-free (weeded) or in competition with one *E. prostrata* plant (w/*E. prostrata*).

[d] Placement refers to the location (depth) of 35 g of 17-5-11 N-P-K (8- to 9-mo) controlled-release fertilizer in the container.

[e] Significant linear (L) or quadratic (Q) response trend at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***). NS = nonsignificant; NA = not analyzed due to no significant interaction.

[f] Means within a row and growth parameter followed by the same or no letter are not significantly different based on the main effect *F*-test at $\alpha = 0.05$.

[g] ANOVA was performed to test for significance of main effects and interactions. Effects are considered significant at $\alpha = 0.05$. Data were pooled over two experimental runs.

both shoot and root growth. *Eclipta prostrata* in pots that were subdressed at 7.5 cm were smaller than *E. prostrata* in pots that were topdressed or subdressed at only 2.5 cm based on growth index. Similarly, subdressing at any depth reduced *E. prostrata* shoot weight in comparison with topdressing by 28%, 42%, and 46% at the 2.5-, 5-, and 7.5-cm depths, respectively, in comparison with *E. prostrata* in topdressed pots. Differential responses between growth index and shoot weight were most likely a result of *E. prostrata* growth characteristics, as plants in subdressed pots were often similar in height and width to those topdressed pots but had noticeably thinner stems and more leggy growth. Previous reports on *E. prostrata* are lacking, but the morphology of several weed species has been reported to be affected by fertility levels (Berger et al. 2007; Bravo et al. 2018). Morphological differences in response to fertility placement were not evaluated in the present study, but would warrant further investigation, as changes in morphology could affect competition (Jiang et al. 2010). Similar to results with shoot growth, *E. prostrata* root growth was reduced when fertilizer was subdressed to a depth of at least 5 cm in comparison with topdressing. In nonfertilized containers, *E. prostrata* never grew past the 1- to 2-leaf stage, and shoot and root growth was minimal throughout the 12-wk experiment.

Our results are similar to those previously reported by Saha et. al. (2019), which also showed decreased *E. prostrata* growth when fertilizer is subdressed in comparison with standard nursery practices of topdressing or incorporation of fertilizer before potting. While Saha et al. (2019) only evaluated subdressing at a 5-cm depth, evaluation of multiple depths in the present study indicates that fertilizer may need to be placed at least 5 cm below the substrate surface based on growth index and root biomass at a 2.5-cm depth, which were similar to topdressed treatments. Similarly, previous research has shown that a depth of only 3.8 cm was ineffective at reducing *E. prostrata* growth in a smaller pot size (Stewart et al. 2018). *Eclipta prostrata* growth reduction is also most likely temporary, as Saha et al. (2019) reported a 90% reduction in *E. prostrata* biomass over 9 wk compared with only a 42% reduction at the 5-cm depth over 12 wk in the present study. While weed growth will most likely increase once roots reach the fertilized layer and subdressing benefits will be diminished, delayed growth resulting from a subdressed fertilizer would allow growers more time to hand weed or implement other control measures before *E. prostrata* reaches maturity and becomes more difficult to remove manually.

Ornamental Response to Fertilizer Placement and Eclipta prostrata Competition

In boxwoods, there was no interaction between competition and fertilizer placement, but main effects of competition ($\alpha = 0.0337$) and fertilizer placement ($\alpha = 0.0011$) were significant (Table 2). Averaged over all fertilizer treatments, the presence of *E. prostrata* caused a 5% reduction in boxwood shoot biomass and a 13% reduction in boxwood growth index over the 12-wk study. Across both competition levels, quadratic trends were observed in boxwood shoot weight and growth index, indicating a nonlinear relationship between boxwood shoot growth and fertilizer placement. This nonlinear trend most likely occurred due to reduced growth at the 7.5-cm depth treatment, in which fertilizer was placed entirely below boxwood roots. While differences were observed in shoot growth, root growth was similar among all treatments regardless of fertilizer placement. While a competition effect was observed, it is important to note that boxwood is considered to have a comparatively slow growth rate (Le Duc et al. 2000), and it is likely that the full effect of weed competition was not captured over a 12-wk experiment.

For ligustrum, the competition effect was significant for both shoot weight and growth index, and fertilizer placement was significant for shoot and root weight, but there was no significant competition by fertilizer placement interaction for any growth parameter (Table 3). Across all fertilizer placements, presence of *E. prostrata* reduced ligustrum shoot biomass by 16% and growth index by 14%. Averaged over both competition levels, ligustrum shoot weight and root weight decreased linearly as fertilizer depth increased. The faster growth rate of ligustrum compared with boxwood most likely contributed to the more pronounced linear decrease in growth resulting from less nutrient availability with greater subdressing depths.

In addition to reducing plant growth, *E. prostrata* significantly reduced foliar nitrogen concentration of both ornamental species (Table 4). In boxwood, there was a significant competition by fertilizer placement interaction, with the presence of *E. prostrata* resulting in lower nitrogen levels in boxwood shoots at all fertilizer

Table 3. Competitive effects of *Eclipta prostrata* on container-grown ligustrum as influenced by fertilizer placement.

Placement[d]	Shoot weight[a]			Growth index increase[b]			Root weight[c]		
	Weeded	w/*E. prostrata*	Mean	Weeded	w/*E. prostrata*	Mean	Weeded	w/*E. prostrata*	Mean
		g			%			g	
Topdress 0.0 cm	43.4	33.6	38.5	53	43	48	22.6	22.8	22.8
Subdress 2.5 cm	38.2	32.6	35.4	57	47	52	21.9	21.2	21.6
Subdress 5.0 cm	34.1	28.0	31.1	53	41	47	19.7	19.9	19.8
Subdress 7.5 cm	26.1	24.5	25.3	43	45	44	19.3	20.1	19.7
Trend[e]	NA	NA	L***	NS	NS	NS	NA	NA	L***
Mean[f]	35.4 a	29.7 b		51 a	44 b		20.9	21.0	
ANOVA[g]									
Competition (C)		0.0011			0.0024			0.8264	
Placement (P)		0.0001			0.1469			0.0001	
C × P		0.3924			0.1393			0.7516	

[a] Shoot dry weight taken at 12 wk after planting (WAP) when grown either weed-free (weeded) or in competition with one *E. prostrata* plant (w/*E. prostrata*).

[b] Determined by calculating percent increase in growth index [(height + width at widest point + perpendicular width) ÷ 3] from 2 to 12 WAP. Weeded shows growth index increase in weed-free plants and w/*E. prostrata* shows growth index increase in competition with one *E. prostrata* plant.

[c] Root dry weight taken at 12 WAP when grown either weed-free (weeded) or in competition with one *E. prostrata* plant (w/*E. prostrata*).

[d] Placement refers to the location (depth) of 35 g of 17-5-11 N-P-K (8- to 9-mo) controlled-release fertilizer in the container.

[e] Significant linear (L) or quadratic (Q) response trend at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***). NS = nonsignificant; NA = not analyzed due to no significant interaction.

[f] Means within a row and growth parameter followed by the same or no letter are not significantly different based on the main effect *F*-test at $\alpha = 0.05$.

[g] ANOVA was performed to test for significance of main effects and interactions. Effects are considered significant at $\alpha = 0.05$. Data were pooled over two experimental runs.

Table 4. Foliar nitrogen concentration in container-grown boxwood and ligustrum as affected by fertilizer placement and *Eclipta prostrata* competition.

	Boxwood			Ligustrum		
	Weeded	w/*E. prostrata*	Mean	Weeded	w/*E. prostrata*	Mean
	Shoot N[a]					
Placement[b]				%		
Topdress 0.0 cm[c]	3.1 a	2.3 b	2.7	1.9	1.2	1.6
Subdress 2.5 cm[c]	2.9 a	2.3 b	2.6	1.8	1.2	1.5
Subdress 5.0 cm[c]	3.0 a	2.4 b	2.7	1.8	1.2	1.5
Subdress 7.5 cm[c]	2.1 a	2.2 a	2.2	1.8	1.3	1.6
Trend[d]	NA	NA	NA	NS	NS	NS
Mean[e]	2.8	2.3		1.8 a	1.2 b	
ANOVA[f]						
Competition (C)		0.0001			0.0002	
Placement (P)		0.0001			0.9974	
C × P		0.0005			0.8259	

[a] Shoot N was determined at 12 wk after potting in plants that were either weeded or grown in competition with one *E. prostrata* plant (w/*E. prostrata*).

[b] Placement refers to the location (depth) of 35 g of 17-5-11 N-P-K (8- to 9-mo) controlled-release fertilizer in the container.

[c] Means followed by the same letter within a row in each species are not significantly different based on contrast analysis at $\alpha = 0.05$.

[d] Orthogonal contrasts were not significant (NS) or not analyzed (NA) due to significant interactions.

[e] Means within a row followed by the same letter are not significant different based on the main effect *F*-test at $\alpha = 0.05$.

[f] ANOVA was performed to test for significance of main effects and interactions. Effects are considered significant at $\alpha = 0.05$. Data were pooled over two experimental runs.

placements with the exception of the 7.5-cm depth. Boxwoods that were topdressed or subdressed at 2.5 or 5 cm had 26%, 21%, and 20% reduction in foliar nitrogen, respectively, when grown in competition with *E. prostrata* compared with plants that were hand weeded with no *E. prostrata* competition. No difference in foliar nitrogen was observed at the 7.5-cm depth, but this was most likely because both boxwood and *E. prostrata* growth was reduced at this level, and in general, lower nitrogen levels were observed regardless of competition. Competition was the only significant effect in ligustrum growth variables, with *E. prostrata* causing a 33% reduction in ligustrum foliar nitrogen concentration across all fertilizer placements.

These results are similar to previous reports of *E. prostrata* being highly competitive with container-grown woody ornamental species. Berchielli-Robertson et al. (1990) reported that one *E. prostrata* plant resulted in a 49% decrease in growth of fashion azalea (*Rhododendron eriocarpum* (Hayata) Nakai × 'Fashion') and a 14% reduction in growth of crimson pigmy barberry (*Berberis thunbergii* DC. var. *atropurpurea* 'Crimson Pigmy') over 6 mo. In the same study, other common weed species such as *E. maculata* and yellow woodsorrel (*Oxalis stricta* L.) caused either minimal or less than a 10% reduction in growth of either ornamental species.

In both ornamental species, shoot growth tended to decrease as fertilizer depth increased. Boxwood and ligustrum liners had root balls approximately 3.8-cm wide by 5-cm deep. Thus, at the 7.5-cm depth, plant roots initially had no contact with fertilizer after potting. Although ornamental roots were in contact with fertilizer at all depths except 7.5 cm, fewer roots will have access to nutrients as they leach into the container substrate. In a production setting, this reduced access to nutrients may result in a decreased growth rate, as was observed with ligustrum. Subdressing or "layering" fertilizers has been shown to cause either increased or no differences in growth of many different ornamental species (Altland et al. 2004; Broschat and Moore, 2003; Marble et al. 2012), but responses are often species specific (Stewart et al. 2017). Based on results in this trial, subdressing may result in an initial reduction in growth in comparison with topdressing,

Table 5. *Eclipta prostrata* growth, reproduction, and foliar nitrogen concentration when grown in competition with ligustrum or boxwood at four different fertilizer placements.

	Growth			Shoot N			
	Shoot weight[a]	Root weight[b]	Reproduction	None	w/Boxwood	w/Ligustrum	Mean
Placement[c]	g		Seed no.[d]	%			
Topdress 0.0 cm	44.9	22.9	12,921	2.4	2.9	2.4	2.5
Subdress 2.5 cm	42.6	21.7	11,899	3.1	3.0	2.5	2.9
Subdress 5.0 cm	44.7	22.8	13,228	3.3	3.4	3.0	3.2
Subdress 7.5 cm	37.0	19.3	12,813	3.0	3.2	3.1	3.1
Trend[e]	L*	L**	NS	NA	NA	NA	L**
Mean[f]	42.3	21.7		3.0 ab	3.1 a	2.8 b	
ANOVA[g]							
Species (S)	0.5243	0.7954	0.0704	0.0226			
Placement (P)	0.0166	0.0019	0.9475	0.0001			
S × P	0.2732	0.9234	0.3988	0.3194			

[a] Mean *E. prostrata* shoot dry weight (g) either grown alone or in containers with ligustrum or boxwood for 12 wk.

[b] Mean root dry weight of one *E. prostrata* plant either grown alone or in containers with ligustrum or boxwood for 12 wk.

[c] Placement refers to the location (depth) of 35 g of 17-5-11 N-P-K (8- to 9-mo) controlled-release fertilizer in the container.

[d] Estimated seed number of one *E. prostrata* plant either grown alone or in containers with ligustrum or boxwood for 12 wk.

[e] Significant linear (L) or quadratic (Q) response trend at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***). NS = nonsignificant; NA = not analyzed due to no significant interaction.

[f] Means followed by the same letter within a row are not significantly different according to Tukey's honest significance differences test $\alpha = 0.05$.

[g] ANOVA was performed to test for significance of main effects and interactions. The test for species includes *E. prostrata* grown alone and in containers with ligustrum or boxwood. Effects are considered significant at $\alpha = 0.05$. Data were pooled over two experimental runs.

especially in cases where plant roots are not initially in contact with fertilizer. Longer-term studies would be needed to determine whether the effects of these fertility treatments were consistent over an entire growing season and to evaluate the economic implications of potentially slower ornamental growth with an improvement in weed control or reduction in herbicide use.

Ornamental Species Effects on Eclipta prostrata Growth

There were no species by placement interactions for any *E. prostrata* growth parameter (Table 5). Species effects (boxwood, ligustrum, or no ornamental) were not significant for any *E. prostrata* growth parameter, indicating that *E. prostrata* (shoot and root weight) grew similarly regardless of presence of an ornamental in the pot. Fertilizer placement was significant for both shoot and root growth for *E. prostrata*, with both parameters decreasing linearly as subdressing depth increased, similar to results in the first experiment (summarized in Table 1). While *E. prostrata* growth decreased when fertilizer was subdressed, neither fertilizer placement nor competition had any effect on seed production, as all *E. prostrata* plants produced approximately 12,000 seeds regardless of fertilizer placement or ornamental species.

Although ornamental species had no effect on *E. prostrata* growth, shoot nitrogen concentration was lower in *E. prostrata* plants grown in competition with ligustrum when compared with *E. prostrata* grown in competition with boxwood (Table 5). The faster growth rate and higher root biomass of ligustrum may have contributed to this decrease in comparison with the slower-growing boxwood. While there was a difference in *E. prostrata* foliar nitrogen concentration, it was minimal (0.3%) and had no effect on *E. prostrata* growth or reproductive capability compared with *E. prostrata* growing in pots alone. Further, *E. prostrata* grown alone (without an ornamental) had shoot nitrogen concentrations similar to *E. prostrata* grown in pots planted with either boxwood or ligustrum.

Across all species (boxwood, ligustrum, or none), *E. prostrata* shoot nitrogen concentration increased linearly as fertilizer depth increased (Table 5). Lower shoot nitrogen concentration in larger plants has been previously reported for multiple weed species. Blackshaw et al. (2003) found that while responses to nitrogen fertilization varied significantly by weed species, common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), wild mustard [*Sinapis arvensis* L.], and wild oat (*Avena fatua* L.) had very high increases in biomass when subjected to higher nitrogen levels, but also had lower shoot nitrogen concentrations, which was attributed to the greater biomass having a "dilution" effect on foliar nitrogen concentration. Correlation analysis revealed a significant but weak linear relationship between *E. prostrata* shoot weight and foliar nitrogen concentration ($\alpha = 0.008$, $r = -0.42$; data not shown). Although variable, results indicate *E. prostrata* tended to follow the same trend, as plants with greater biomass generally had lower shoot nitrogen concentrations.

Data indicate that subdressing may be an effective strategy for *E. prostrata* control in container-grown ornamentals but would need to be used along with other management strategies such as use of PRE herbicides and hand weeding. While germination was not reduced, subdressing reduced *E. prostrata* shoot biomass by 28%, 42%, and 46% at the 2.5-, 5-, and 7.5-cm depths in comparison with the industry standard of topdressing. Subdressing and other strategic nutrient placements have been shown to reduce growth of several common container nursery weed species, including *E. maculata*, *E. prostrata*, common groundsel (*Senecio vulgaris* L.), creeping woodsorrel (*Oxalis corniculata* L.), and *D. sanguinalis* (Altland et al. 2004 ; Saha et al. 2019). Although subdressing may not be an effective strategy as a singular approach to weed management, any reduction in weed growth would allow growers more time to hand weed before seed production and help prevent further spread of weeds throughout production areas. Reductions in weed growth and delayed seed production could also potentially reduce PRE herbicide applications and allow growers to implement other strategies, such as applying PRE herbicides that provide early POST control (Judge and Neal 2006).

In previous research evaluating topdressing, incorporation, and dibbling fertilizer, up to a 90% reduction in *E. prostrata* growth was observed over 9 wk following subdressing at a 5-cm depth (Saha et al. 2019). Only a 42% reduction was observed here at a similar depth over 12 wk, indicating that *E. prostrata* may be able to establish over time, and the benefits of subdressing may diminish if weeds are able to access nutrients as they mature. Although fertility rates are typically low (Carney and Whitcomb 1983), liner root balls will contain nutrients, and the ability of transplanted *E. prostrata* to access these nutrients resulted in there being no competitive advantage to boxwood or ligustrum by subdressing, as evidenced by biomass increases over 12 wk. In cases in which the competition effect was minimal, such as boxwood subdressed at 7.5-cm depth, slower overall ornamental growth was observed, resulting in less competition by *E. prostrata* interference.

Results from these experiments indicate more research is needed to determine optimal subdressing depth based on initial liner size and root length to prevent delayed or reduced ornamental growth. Shallow subdressing depths may not be effective at reducing growth of some weed species such as *E. prostrata*, as a depth of 7.5 cm was required to reduce *E. prostrata* growth. However, at this depth, a reduction in growth of both boxwood and ligustrum was observed. While subdressing may not be an effective approach for *E. prostrata* in this scenario, it is important to note that *E. prostrata* is especially problematic and competitive with container-grown ornamentals (Berchielli-Robertson et al. 1990). Over this 12-wk study, one *E. prostrata* plant reduced the growth rate of boxwood and ligustrum by approximately 14% and foliar nitrogen concentrations by 18% to 33%, indicating *E. prostrata* strongly competed for nitrogen. While water use was not assessed, *E. prostrata* is known to favor moist environments, requires relatively high soil moisture levels for germination, and can outcompete field crops for water (Chauhan and Johnson 2008; Lee and Moody 1989). As *E. prostrata* is one of the more competitive and troublesome weeds in container nurseries, it is possible that subdressing may be more effective on other common nursery species (Saha et al. 2019; Stewart et al. 2017, 2018) and should be investigated in future research. Nurseries produce plants in container sizes ranging from less than 3 L to more than 300 L, and different container sizes will be used as the initial liner depending upon the desired final marketable size. As liner size increases, the probability of being able to utilize subdressing without any negative growth effects may increase; however, as liners will inevitably contain nutrients and nursery pots are often greater or equal in diameter compared with height, the media surface area of the pot containing nutrients available to germinating weed seedlings would also increase. Future research should focus on evaluating whether ornamental liners produced in deeper but not wider pots, such as Treepots (Stuewe and Sons Inc., Tangent, OR), could provide growers with the ability to subdress at more effective depths for weed management by limiting nutrient availability on the media surface and without resulting in negative growth consequences for ornamental plants.

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