Effects of Three Fertilization Methods on Weed Growth and Herbicide Performance in Soilless Nursery Substrates[1]

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Abstract

Research objectives were to determine the effect of fertilization method (incorporation, subdress, and topdress) on weed growth and the performance of preemergence herbicides applied to soilless substrates. Nursery containers were filled with a pine bark:peat substrate and fertilized at two different rates [4.4 and 9.5 $kg \cdot m^{-3}$ (8.9 and 19.2 $lb \cdot yd^{-3}$)] via topdressing, subdressing, or incorporating. Containers were treated with either dimethenamid-P for spotted spurge (*Euphorbia maculata* L.), flumioxazin for eclipta (*Eclipta prostrata* L.) or prodiamine for large crabgrass (*Digitaria sanguinalis* L.). A control was established for each fertilizer rate/placement and weed species that was not treated. Incorporating or subdressing fertilizer resulted in reduced large crabgrass and spotted spurge growth in non-treated containers. Weeds grew larger at the higher fertility rates in both topdress and incorporated treatments but fertilizer rate did not affect growth of spotted spurge or large crabgrass when fertilizers were subdressed. Herbicides generally provided commercially acceptable weed control regardless of fertilizer treatment, but results varied with species. Results suggest that in the absence of herbicides, topdressing may result in greater weed growth compared with subdressing or incorporating fertilizers; however, fertilizer placement will have less impact on herbicide performance if proper herbicides are chosen and applied correctly.

Index words: topdress, subdress, incorporate, large crabgrass, eclipta, spotted spurge, preemergence.

Chemicals used in this study: Flumioxazin (SureGuard®); 2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole1,3(2H)-dione; Dimethenamid-P (Tower) 2-chloro-N-[(2,4-dimethyl-3-thienyl)-N-(2-methoxy-1-methylethyl)acetamide; Prodiamine (Barricade) 2,4-dinitro-N^3, N^3-dipropyl-6-(trifluoromethyl)-1,3-benzenediamine (Barricade®).

Species used in this study: Large crabgrass (*Digitaria sanguinalis* L.); Eclipta (*Eclipta prostrata* L.); Spotted spurge (*Euphorbia maculata* L.).

Significance to the Horticulture Industry

Container growers rely on preemergence herbicides and handweeding to control weeds but the impact of different production practices, such as fertilizer placement methods, needs further investigation. Results indicate that weed growth may increase where topdressing is used as the sole fertilization method compared with incorporation or subdressing fertilizer at similar rates. Based upon this data, subdressing fertilizer deserves further investigation as a possible means of non-chemical weed control in container-grown ornamental crops. Regardless of fertilization method, growers should expect acceptable control if proper herbicides are chosen for problematic weed species and applied correctly. However, results differed with individual species and thus additional research is needed to fully address how fertilizer placement affects weed growth and performance over a broader range of active ingredients and weed species.

Introduction

Weed management is critical in container-production of ornamental crops as weeds are highly competitive with ornamentals for water and nutrients. Even a single weed can negatively affect crop growth (Berchielli-Robertson et al., 1990; Fretz, 1972; Walker and Williams, 1989) due to the restricted rooting environment for container-grown plants. Berchielli-Robertson et al. (1990) demonstrated that one eclipta (*Eclipta prostrata* L.) reduced the growth of 'Fashion' azalea (*Rhododendron* x 'Fashion') by 43%. Similarly, Fretz (1972) reported a 47% and 60% reduction in the growth of 'Convexa' Japanese Holly (*Ilex crenata* 'Convexa') when one large redroot pigweed (*Amaranthus retroflexus* L.) or large crabgrass (*Digitaria sanguinalis* L.) was present, respectively. Studies conducted by Walker and Williams (1989) have reported similar results of one weed greatly reducing the growth of a variety of ornamental crops.

Container nursery growers are expected to produce weed-free ornamentals, as most nursery crops are sold based on aesthetic value and consumers often demand weed-free containers (Simpson et al., 2002). As postmergence herbicides are limited, growers must rely on preemergence herbicides and handweeding for control. Darden and Neal (1999) reported that the cost to hand weed 1000 3 L (0.66 gal.) containers over a four-month period was $1367. In a similar study, Mathers (2003) reported that

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some nurseries spend up to $9900 per ha ($4000 per acre) on handweeding and still have economic losses of close to twice this amount due to weed infestations. In addition to the manual removal of weeds and the economic losses due to weed infestations, there are also large costs associated with applying herbicides. The average cost of a 23 kg (50 lb.) bag of granular-based herbicide is approximately $70, which would make treatment of 1 ha approximately $690 (Stewart et al., 2017). A 10 ha (24.7 acre) nursery that made six applications per year would expend $41,400 in chemicals alone. Labor needed for applying herbicides and/or handweeding is increasing in cost and becoming more difficult to find due to immigration reform and recent legislation passed in several states (Johnson, 2011; Martin, 2017; Taylor et al., 2012).

One method of weed management that has shown potential for increased efficacy, but deserves further investigation, is fertilizer placement (Altland et al., 2004). Currently, most growers apply fertilizer to their container stock through incorporation (thoroughly mixing fertilizer in the substrate prior to potting) or via topdressing (placing fertilizer on the substrate surface after potting). Topdressing may be used a sole means of fertilization or may be done as a supplemental application later in the season on crops that were potted using incorporated fertilizer.

Dibbling and subdressing are less commonly used to apply fertilizer. Although several different dibbling methods exist, most dibbling practices utilize placement of fertilizer in a planting hole underneath the rootball of the ornamental liner. Dibbling is not often employed due to positioning of a high concentration of fertilizer prills directly into contact with plant roots, which may result in plant phytotoxicity (Bir and Zondag, 1986). Subdressing (also called layering) another uncommon method of applying fertilizer, involves filling the container half-way or more with substrate, placing the fertilizer in a single layer, and then filling the rest of the container with substrate. Subdressing or layering fertilizer has been employed by some nurseries in an attempt to manage weeds and or prevent fertilizer losses when containers are knocked over.

Strategic nutrient placement has been previously investigated as a weed management tool in both container nursery production (Altland et al., 2004) and field cropping systems. In agronomic or field crops, strategic nutrient placement, such as banding, has been shown to reduce growth of multiple weed species by up to 50% compared with broadcast type applications (Blackshaw et al., 2004; Kirkland and Beckie, 1998; Rasmussen et al., 1996). Fain et al. (2003) reported an 888% increase in prostrate spotted spurge (*Euphorbia prostrata* L.) growth in containers that were topdressed compared to those dibbled. Similarly, Altland et al. (2004) conducted a study in which fertilizer was applied at the same rate to containers using topdressing, incorporation, and dibbling application methods. For common grounsel (*Senecio vulgaris* L.), prostrate spurge, and creeping woodsorrel (*Oxalis corniculata* L.), dibbling resulted in 85 to 97% weed control compared to 19 to 85% and 55 to 88% control observed in topdress and incorporation treatments, respectively, when no herbicides were applied. When fertilizer placement methods were combined with use of herbicides, (oryzalin + oxyfluorfen or pendimethalin + oxyfluorfen), dibbling resulted in 89 to 99% control compared with 82 to 90% and 81 to 98% for topdressing and incorporation methods, respectively.

While dibbling can lead to reduced weed growth, research has demonstrated that response of ornamental crops vary dependent upon fertilization placement and species (Alam et al., 2009; Cobb, 1985; Conover and Poole, 1985; Hicklenton, 1990; Klock-Moore and Broschat, 1999; Yeager and Ingram, 1987). For example, Fain et al. (2004) reported Japanese privet (*Ligustrum japonicum* Thunb.) growth decreased when fertilizers where dibbled compared to topdressed, whereas no differences were observed in growth of yaupon holly (*Ilex vomitoria* Aiton). Dibbling or subdressing fertilizer has resulted in similar or greater growth when compared to topdressing or incorporation in Chinese hibiscus (*Hibiscus rosa-sinensis* L.), bamboo palms (*Chamaedorea seifrizii* Burret), Areca palms (*Dypsis lutescens* H. Wendl.), Fishtail palms (*Caryota mitis* Lour.), Macarthur palms (*Ptychosperma macarthurii* H. Wendl.), downy jasmine (*Jasminum multiflorum* Burm. F.), plumbago (*Plumbago auriculata* Lam.) (Broschat and Moore, 2003), gumpo azaleas (*Azalea* × *hybrida* 'Gumpo White') (Marble et al., 2012) and several other species (Altland and Von Arx, 2004).

Previous research has focused mainly on comparing topdress, dibble, and incorporation methods of fertilization. Effects of subdressing fertilizer on weed growth has been subject to less investigation. There is also a need to determine what impact, if any, various fertilization placements have on preemergence herbicide performance. Many of the most commonly applied preemergence herbicides are degraded by soil microbes (Senseman, 2007). Authors have reported both increased (Gough and Seiler, 2004) and decreased (Thirukkumaran and Parkinson, 2000) microbial respiration rates following fertilizer applications in field soil and soilless nursery substrates (Jackson et al., 2009a). Increased heterotrophic respiration could indicate more rapid herbicide degradation and thus potentially reduced herbicide performance. Additional research is needed to determine the impact of common and alternative fertilization methods on both weed growth and herbicide performance. Therefore, the objective of this research was to determine the impact of fertilizer placement on growth of three common container nursery weed species and the performance of three widely used preemergence herbicides.

Materials and Methods

Experiments were conducted at the Mid-Florida Research and Education Center in Apopka, FL during the summer of 2017. On April 28, nursery containers [0.9 L (1 qt.)] were filled with a pine bark:peat substrate (70:30 v:v) amended with 3 kg (6.05 lbs.) dolomitic lime per m^{-3} (yd^{-3}) and fertilized with a controlled-release fertilizer (Osmocote® Pro (8-9 mo.) 17N-2.2P-9.1K (ICL Inc., Dublin, Ohio)) at 4.4 and 9.5 $kg \cdot m^{-3}$ (8.9 and 19.2 $lb \cdot yd^{-3}$), representing low and high manufacturer rate recommendations. Fertilizer was applied via either incorporation (mixed thoroughly in the substrate prior to potting), topdressing (the entire allotment of fertilizer applied to the substrate surface after potting), or by subdressing [containers filled 3.8 cm (1.5 in.)] from the top; fertilizer was applied evenly throughout the surface of the substrate, and then the remaining 3.8 cm (1.5 in.) of substrate applied on top so that the fertilizer was placed 3.8 cm (1.5 in.) below the substrate surface).

After filling, containers were moved to a full sun nursery container pad and received 1.3 cm (0.5 in.) total of overhead irrigation daily via two irrigation cycles. On April 30 [clear skies, 27°C, 56% relative humidity, winds 17 kph (10.6 mph)] herbicides including dimethenamid-P (Tower® 6.0EC, BASF Corp., Florham Park, New Jersey), flumioxazin (SureGuard® SC, Nufarm Inc., Alsip, IL) and prodiamine (Barricade® 4FL, Syngenta Crop Protection, Inc., Greensboro, North Carolina) were applied at their highest recommended label rate [1.7, 0.4, and 1.7 kg·ai ha^{-1}, (1.52, 0.36, 15.2 lb·ai A^{-1}) respectively] to separate sets of containers. Each herbicide was applied using a CO_2 backpack sprayer calibrated to deliver 281 L·ha^{-1} (30 gal·A^{-1}) using an 8004 TeeJet (TeeJet Technologies, Glendale Heights, IL) flat fan nozzle at 207 kpa (30 psi). All containers were irritated 1.3 cm (0.5 in) immediately following herbicide application. On May 1, approximately 30 seeds of spotted spurge (*Euphorbia maculata* L.), eclipta, and large crabgrass were measured out by volume and surface sown to containers treated with dimethenamid-P, flumioxazin, and prodiamine, respectively. Herbicide and weed species combinations were chosen in order to evaluate control of each weed species with an herbicide that has been established as having a high degree of efficacy on the chosen species. Controls used for comparison purposes included each fertilizer rate and placement combination without herbicide application.

The trial was designed as a 3 by 2 factorial with three fertilization placements and two fertilization rates in a completely randomized design with 8 single container replications per treatment. Each weed species was grouped separately and considered a separate experiment. Data collected included bi-weekly weed counts and shoot fresh weights at trial conclusion [10 weeks after treatment (WAT)]. This trial was repeated using similar methodology later in the summer with containers being filled on Aug. 10 and treated with herbicides on Aug. 13 [clear skies, 32 C, 63% relative humidity, winds 7.4 kph (4.6 mph)] and overseeded on Aug. 14.

In addition to weed control data, substrate CO_2 efflux was sampled each week as an indicator of microbial activity on each of the fertilizer placement and rate combinations. Nursery containers [3.8 L (0.84 gal.)] were filled with substrate and fertilized on the dates and using the methods described previously but were not treated with herbicides. After filling containers and applying fertilizer, PVC collars with a diameter of 10 cm (3.9 in.) and a height of 8.9 cm (3.5 in.) were placed into each container until only 1.0 cm (0.39 in.) of the collar was exposed above the substrate surface. Soil CO_2 efflux was measured weekly on 4 replications of each fertilizer placement and rate combination using a LI-COR 8100A infrared gas analyzer (Li-Cor Biosciences, Lincoln, NE) equipped with a 10 cm survey chamber (Xu et al., 2006) which measured efflux from the substrate within the PVC collars. Similar methods have been implemented previously to provide accurate estimates of microbial activity in soils (Wang et al., 2003) and soilless substrates (Jackson et al., 2009b). Survey measurements were taken at approximately the same time each day approximately 4 hours following an irrigation cycle. Containers used for efflux measurement were not seeded and were kept fallow by handweeding weekly to ensure that only heterotrophic respiration was measured and were not confounded with autotrophic respiration of plant (weed) roots. This trial was repeated on the dates described previously; however, during the second experimental run, 11.4 L (2.51 gal.) nursery containers were used to facilitate CO_2 efflux data collection. In all cases, fertilizer rates were modified based upon container size.

Prior to statistical analysis, weed shoot fresh weight data from herbicide treated containers were first converted to percent control. Shoot fresh weights from non-treated containers that were fertilized similarly (placement and rate) were used as the reference to calculate percent control of each herbicide treated container using the formula [(shoot weight of nontreated – shoot weight of treated)/ shoot weight nontreated] $\times$ 100. Shoot fresh weights and weed counts from non-treated containers were analyzed as is to determine effect of fertilizer placement and rate on weed growth in absence of herbicide. Soil respiration flux rates were computed using SoilFluxPro™ (Li-Cor Biosciences) software to calculate CO_2 efflux (μmol·m^{-2} s^{-1}). All data were subjected to a mixed model analysis of variance in JMP Pro Software (Ver. 12, SAS, Cary, NC). Experimental run and replication were considered random factors while fertilizer placement and rate were considered fixed factors. Means of significant main effects (fertilizer placement or rate) and interactions between these effects were compared using pre-planned contrasts at the $p < 0.05$ significance level. Due to a lack of experimental run by treatment interaction, data from both experimental runs were pooled for analysis.

Results and Discussion

Large crabgrass. In control containers (not treated with prodiamine), fertilizer rate significantly affected large crabgrass weed counts while the main effects of placement and interaction of placement by rate were not significant (Table 1). In the topdress treatment, there were more large crabgrass plants (14.8) in containers fertilized with the 9.5 kg·m^{-3} (19.2 lb·yd^{-3}) rate (high rate) compared with containers fertilized at the 4.4 kg·m^{-3} (8.9 yd^{-3}) rate (low rate). Fertilizer rate had no effect on large crabgrass weed counts in containers with incorporated or subdressed fertilizer. Placement, rate, and the interaction of these two factors was significant for large crabgrass fresh weights. Large crabgrass fresh weights were 25 and 35% greater in containers that were topdressed compared with containers where fertilizer was incorporated or subdressed, respectively. Large crabgrass fresh weights were also greater at the high fertilizer rate in containers that were

Table 1. **Influence of fertilizer[z] placement and rate on count and shoot fresh weight (g) of three container nursery weed species when no herbicides are utilized, averaged over two trials.**

Placement	Rate (kg·m^{-3})	Large crabgrass Count[y]	Large crabgrass F.W.[x]	Eclipta Count	Eclipta F.W.	Spotted spurge Count	Spotted spurge F.W.
Topdress	4.4	10.7 b[w]	38.9 b	13.5 a	29.0 b	9.2	20.0 b
	9.5	14.8 a	55.5 a	13.1 a	43.3 a	8.9	28.7 a
	Mean	12.8	47.2 A[v]	13.4	36.1 A	9.1	24.3 A
Incorporate	4.4	11.1 a	27.4 b	12.2 a	24.8 b	8.4	16.0 b
	9.5	12.1 a	37.7 a	15.6 a	33.5 a	8.4	22.3 a
	Mean	11.6	32.5 B	13.9	29.2 B	8.4	19.1 B
Subdress	4.4	10.9 a	30.6 a	12.2 a	29.0 b	8.5	16.1 a
	9.5	13.5 a	30.3 a	16.1 b	40.0 a	7.4	18.7 a
	Mean	12.2	30.5 B	14.5	34.4 A	8.0	17.4 B
ANOVA[u]							
Placement		NS	0.0001	NS	0.0019	NS	0.0052
Rate		0.0039	0.0001	0.0238	0.0001	NS	0.0013
Placement × rate		NS	0.0102	NS	NS	NS	NS

[z]Fertilizer used was Osmocote® Pro (8-9 mo.) 17N-2.2P-9.1K (ICL Specialty Fertilizers, Geldermalsen, The Netherlands).

[y]Counts show mean number of weeds counted per container at 6 weeks after seeding.

[x]F.W. show mean shoot fresh weights per container recorded at 10 weeks after seeding.

[w]Fertilizer rate means within each placement and followed by the same lower-case letter are equivalent based on contrast statements ($p < 0.05$).

[v]Mean effect means of placement within a column and followed by the same upper-case letter are equivalent based on contrast analysis ($p < 0.05$).

[u]Analysis of variance performed using a mixed model in JMP to test for significance of main effects and interactions. Effects are considered significant at $p < 0.05$.

fertilized via topdressing or incorporating, while fertilizer rate did not affect fresh weights in containers that were fertilized via subdressing.

In containers treated with prodiamine, the only factor that significantly affected weed counts was fertilizer rate (Table 2). Containers fertilized at the low rate had a slightly higher weed count than containers fertilized at the high rate across all three placement methods. While rate was significant, mean weed counts were less than one plant per container in all cases. When evaluating percent control, fertilizer placement or rate had no effect on prodiamine efficacy. Prodiamine provided 100% control in all treatments.

Eclipta. In control containers, fertilizer placement did not affect weed counts (Table 1). Eclipta counts were

Table 2. **Influence of fertilizer[z] placement and rate on efficacy of three preemergence herbicides and three container nursery weed species, averaged over two trials.**

Placement	Rate (kg·m^{-3})	Large crabgrass[y] Count[v]	Large crabgrass[y] % Control[u]	Eclipta[x] Count	Eclipta[x] % Control	Spotted spurge[w] Count	Spotted spurge[w] % Control
Topdress	4.4	0.9	100	1.6	97	1.4	89 a[t]
	9.5	0.4	100	1.7	97	2.0	76 b
	Mean	0.6	100	1.6	97 A[s]	1.7 B	83 B
Incorporate	4.4	0.8	100	1.0	90	2.0	92 a
	9.5	0.4	100	2.4	82	3.4	67 b
	Mean	0.6	100	1.7	86 B	2.7 A	79 B
Subdress	4.4	0.5	100	2.3	80	1.0	90 a
	9.5	0.1	100	1.1	91	0.3	90 a
	Mean	0.3	100	1.6	86 B	0.7 C	90 A
ANOVA[r]							
Placement		NS	NS	NS	0.0061	0.0004	0.0001
Rate		0.0101	NS	NS	NS	NS	0.0075
Placement × rate		NS	NS	NS	NS	NS	0.0020

[z]Fertilizer used was Osmocote® Pro (8-9 mo.) 17N-2.2P-9.1K (ICL Specialty Fertilizers, Geldermalsen, The Netherlands).

[y]Prodiamine (Barricade®4FL, Syngenta Crop Protection, LLC., Greensboro, NC) was applied at 1.7 kg· ai ha^{-1} to evaluate large crabgrass efficacy.

[x]Flumioxazin (SureGuard®SC, Nufarm Inc. Alsip, IL.) was applied at 0.4 kg· ai ha^{-1} to evaluate eclipta efficacy.

[w]Dimethenamid-P (Tower®6.0EC, BASF Corp. Research Triangle Park, NC) was applied at 1.7 kg· ai ha^{-1} to evaluate spotted spotted spurge efficacy.

[v]Counts show mean number of weeds counted per container at 6 weeks after seeding.

[u]Shoot fresh weights from non-treated containers that were fertilized similarly (placement and rate) were used to calculate percent control of each herbicide using the formula [(shoot weight of nontreated – shoot weight of treated)/ shoot weight nontreated] × 100.

[t]Mean effect means of placement within a column and followed by the same upper-case letter are equivalent based on contrast analysis ($p < 0.05$).

[s]Mean effect means of placement within a column and followed by the same upper-case letter are equivalent based on contrast analysis ($p < 0.05$).

[r]Analysis of variance performed using a mixed model in JMP to test for significance of main effects and interactions. Effects are considered significant at $p < 0.05$.

higher in containers that were subdressed at the high rate compared to those subdressed at the low rate but fertilizer rate had no effect on weed counts in the other two fertilizer placement methods. Fertilizer placement and rate were significant main effects for eclipta fresh weights but there was no interaction between these factors. In all three placement methods, eclipta fresh weights were greater when fertilized at the high rate. In contrast to results observed with large crabgrass, fresh weights were also greater in containers that were either topdressed or subdressed than containers where fertilizer was incorporated.

In flumioxazin treated containers, fertilizer rate or placement had no effect on eclipta counts. When evaluating fresh weights, fertilizer placement was the only significant main effect (Table 2). Eclipta control was highest in containers that were topdressed (97%) compared to containers where fertilizer was incorporated or subdressed (86%). Fertilizer rate was not significant when flumioxazin was applied prior to seeding.

Spotted spurge. In non-treated containers, there was no difference in spotted spurge weed counts in any fertilizer treatment (Table 1). Spotted spurge fresh weights were higher in containers that were fertilized via topdressing or incorporating fertilizer at the high rate while fertilizer rate had no effect on spotted spurge growth when fertilizer was subdressed. Across both fertilizer rates, spotted spurge grew larger in containers where fertilizer was topdressed compared to containers where fertilizer was either incorporated or subdressed.

In dimethenamid-P treated containers, spotted spurge counts were higher in containers where fertilizer was incorporated (mean 2.7) followed by containers where fertilizer was topdressed (1.7) (Table 2). Subdressing fertilizer resulted in fewer spotted spurge counts than the other two placements (0.7). Spotted spurge control was similar to the trend observed in spotted spurge fresh weights. In containers that were fertilized either topdressed or incorporated, spotted spurge control was lower at the higher fertilizer rate whereas fertilizer rate did not affect spotted spurge control in containers where fertilizer was subdressed. Spotted spurge control was also higher in containers that were subdressed (90%) compared to containers where fertilizer was topdressed (83%) or incorporated (79%).

Substrate CO_2 efflux. Fertilizer placement and rate were significant main effects and there was no interaction between these two factors across all sampling dates and two experimental runs (Table 3). The highest average efflux was measured in containers where fertilizer was incorporated while subdressed and topdressed treatments had similar efflux. The main effect of fertilizer rate was significant with a higher flux observed at the low fertilizer rate.

When no herbicide was applied, large crabgrass and spotted spurge shoot fresh weights significantly increased in containers fertilized via topdressing or incorporating methods at the high rate compared with the low rate (Table 1). These results were expected and similar to previous findings where weed growth increased with increasing N levels and was species specific (Blackshaw et al., 2003). However, for containers that were subdressed, fertilizer rate had no effect on growth of large crabgrass or spotted spurge. In previous research by Fain et al. (2004), prostrate spotted spurge growth was 31 to over 800% greater in containers where fertilizer was topdressed compared to containers fertilized via dibble. Authors concluded that dibble placement limited available N, P, and K near the substrate surface and spotted spurge seedlings could not access these nutrients, leading to reduced growth and/or survival. In our study, it is likely that the subdress treatment also provided this benefit and if access to the fertilizer was limited in the subdress treatment, the rate at which the fertilizer was applied has less influence on weed growth.

Table 3. Main effects of fertilizer[z] placement and rate on average CO_2 efflux in a pine bark:peat substrate, averaged over two trials.

Placement	Efflux[y]
Topdress	9.8 b[x]
Incorporate	11.8 a
Subdress	9.4 b
Rate ($kg\ m^{-3}$)	
4.4	11.0 a
9.5	9.7 b
ANOVA	
Placement	0.0001
Rate	0.0114
Placement × rate	NS

[z]Fertilizer used was Osmocote® Pro (8-9 mo.) 17N-2.2P-9.1K (ICL Specialty Fertilizers, Geldermalsen, The Netherlands).

[y]CO_2 efflux ($\mu mol\cdot m^{-2}\ s^{-1}$) was assessed using a Li-Cor 8100 A (Li-Cor Biosciences, Lincoln, NE) as an estimate of microbial activity.

[x]Means within each fertilizer placement or within each rate followed by the same lower-case letter are equivalent based on contrast statements ($p < 0.05$).

Results for eclipta differed from those observed in large crabgrass and spotted spurge. Eclipta shoot weights were similar in pots that were topdressed and subdressed whereas the incorporation treatment slightly (∼17%) reduced shoot fresh weight compared to the other two placements (Table 1). Additionally, eclipta had greater shoot weights in pots fertilized at the high rate in all three placements. In contrast, fertilizer rate had no effect on shoot weights of large crabgrass or spotted spurge when fertilizers were subdressed. While incorporating resulted in a slight decrease in eclipta shoot weight compared to topdressing or subdressing, topdressing significantly increased shoot weight of both large crabgrass and spotted spurge. Broschat and Moore (2003) reported similar findings to our results with spotted spurge and large crabgrass. In their study, layering fertilizer (similar to our subdressing method) resulted in less weed growth compared to incorporation or topdressing fertilizers in 2 of the 6 ornamental species evaluated. In 4 of the ornamental species, there was either minor or no weed growth overall or no difference in weed growth among the different fertilizer placements. They concluded that some of the weed species in their study were able to grow enough root biomass to reach the fertilized layer, which resulted in similar weed growth among the treatments. Depth of the fertilizer layer was not reported in Broschat and Moore (2003) but was 3.8 cm (1.5 in.) in our study. It is unknown why eclipta shoot fresh weights were less in the incorporation placement compared with subdress or topdress. It is possible that eclipta, a deep-rooted weed species, was able to grow roots to this depth, reducing the effect of the subdress placement. Once roots reached the subdressed fertilizer, the fertilizer would be present in a higher concentration than would be expected in an incorporation treatment, which may have led to decreased eclipta growth in the incorporation treatment compared to the other two placement methods. Alam et al. (2009) reported greater and more rapid nitrate leaching early in the production cycle (3 weeks after potting) in container grown forsythia (*Forsythia* × *intermedia* Zab. 'Spring Glory') when fertilizer was incorporated compared to when it was topdressed. Nutrient leaching was not assessed in this study, but if higher leaching occurred early in these experiments in the incorporation treatment, this may explain reduced growth compared with topdressing that was observed for all three species. These experiments were also shorter (10 weeks) than would be expected for a woody ornamental, thus, roots of these weed species could not utilize fertilizer in the lower depths of the containers until later weeks, also possibly reducing growth over a 10 week time span.

For all three weed species, fertilizer placement had no effect on weed counts when herbicides were not applied (Table 1). In our short-term studies (10 weeks), it appears that fertilizer placement will have a minimum influence on weed germination. In previous studies where placement was shown to have an effect on weed counts (Fain et al., 2003), weed counts were similar at earlier ratings periods (60 days after sowing) and less in dibbled treatments at later evaluation dates, possibly due to weed seedling death as a result of nutritional deficiency. In research by Altland et al. (2004), weed counts of common groundsel and prostrate spurge were greater in topdressed treatments compared to dibble treatments even at early evaluation dates, but no differences were observed with creeping woodsorrel. Differing results are likely because the influence of fertility on weed emergence is often dependent on the weed species and environmental conditions (Sweeney et al., 2008). Additionally, dibbling fertilizer would theoretically limit nutritional availability to weed seedlings to a greater degree than a subdress treatment, but could also potentially cause a higher chance of ornamental phytotoxicity.

Weed counts and growth were minimally affected when labeled rates of efficacious herbicides were used for each weed species (Table 2). Prodiamine provided 100% control of large crabgrass regardless of fertilizer placement or rate. Dimethenamid-P, however, provided greater control when fertilizers were subdressed compared with the other two methods. Control of spotted spurge was also greater in the topdress and incorporation placements at the low fertility rate compared with the high rate while no difference in control was observed between fertility rates for the subdressed treatment. In contrast, flumioxazin provided the best control of eclipta when fertilizers were topdressed. It is unclear why flumioxazin performance increased when fertilizers were topdressed compared with when they were subdressed or incorporated. No previous studies have evaluated flumioxazin performance across different fertilization practices in soilless substrates. Flumioxazin is primarily degraded by soil microbes (Senseman, 2007), but it is unlikely that topdressing significantly decreased microbial degradation of flumioxazin as similar CO_2 efflux was observed in both topdress and subdress treatments, but increased efficacy was only observed in topdress treatments. More research is needed to determine why this occurred but overall, commercially acceptable weed control was achieved with flumioxazin across all three fertilizer placements.

Soil CO_2 efflux measured in this study showed that overall efflux was higher in containers with incorporated fertilizer as opposed to containers where fertilizer was topdressed or subdressed. Marble et al. (2012) reported higher CO_2 efflux in topdressed fallow containers compared with containers where fertilizer had been dibbled or incorporated. Similarly, in the present study, topdressing resulted in higher efflux than the other two methods on 3 evaluation dates in experiment 1 and two evaluation dates in experiment 2 (data not shown) but on most sampling dates, incorporation resulted in higher efflux. Differing results could be attributable to different substrate composition (pine bark:peat vs. pine bark:sand), different fertilizer formulations, and/or different time frames in which measurements were recorded and environmental conditions experienced. Similar to previous reports (Jackson et al., 2009a; 2009b), CO_2 efflux was higher at the lower fertility rate across all three placement methods, possibly indicating higher microbial activity. While this study was not designed to investigate correlation between microbial activity and herbicide performance, the influence of CO_2 efflux as an indicator microbial activity does not appear to predict herbicide performance (i.e. degradation rate), or at least not to a high enough level to significantly reduce herbicide efficacy. While efflux was often higher at the lower fertility rate, weed control resulting from herbicide application was also often higher in these treatments.

Results from this study suggest that weed growth may increase in containers where fertilizer is topdressed compared to containers where fertilizer is subdressed or incorporated, but this effect is likely to be species dependent based upon data observed with eclipta. Results also suggest that weed growth will likely increase at higher fertility rates, but subdressing fertilizer may limit the effect of higher fertility rates on weed growth of some weed species. In general, growers should expect to see similar and commercially acceptable (>80% for 10 wks) efficacy regardless of fertilizer placement if proper herbicides are chosen for weed species at the site. However, spotted spurge control was not commercially acceptable with dimethenamid-P in containers that were fertilized via either topdressed or incorporated at the high fertility rate. Overall, herbicide performance appears to be minimally affected by fertilizer placement or rate, but due to the large spectrum of problematic weeds in container nurseries, this is likely to be species dependent. It should also be noted that in the present study, a subdressing depth of only 3.8 cm (1.5 in.) was used. In most cases, fertilizers will be subdressed at the same depth of the rootball and depending upon liner size, could range from 5 to 12 cm or more. Further research is needed to determine response of multiple weed species to various fertilizer placements and different subdressing depths.

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