Research Reports

Mulch Type and Depth Influences Control of Three Major Weed Species in Nursery Container Production

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SUMMARY. Two commonly used management practices for weed control in container plant production are hand pulling and herbicide applications. There are problems associated with these methods including crop phytotoxicity and environmental concerns associated with off-target movement of herbicides. Other nonchemical weed control methods could reduce herbicide-based environmental concerns, mitigate herbicide-resistance development, and improve the overall level of weed control in container nursery production. Readily available tree-mulch species, eastern red cedar (*Juniperus virginiana*), ground whole loblolly pine (*Pinus taeda*), chinese privet (*Ligustrum sinense*), and sweetgum (*Liquidambar styraciflua*) were harvested, chipped, and evaluated at multiple depths with and without the herbicide dimethenamid-p. Pine bark mini-nuggets were also evaluated. Mulches were applied at depths of 1, 2, and 4 inches and evaluated over three 30-day periods for their effectiveness in suppressing spotted spurge (*Chamaesyce maculata*), long-stalked phyllanthus (*Phyllanthus tenellus*), and eclipta (*Eclipta prostrata*). After 30 days, herbicide/mulch combinations, as well as mulch treatments alone, had reduced weed fresh weight 82% to 100% with 1 inch of mulch. By 168 days after treatment, dimethenamid-p had lost all efficacy, and mulch depth was the only factor that still had significant effects, reducing spotted spurge fresh weight by 90%, 99.5%, and 100% with depths of 1, 2, and 4 inches, respectively. The economics of mulch weed control will depend on variables such as available time, nursery layout, location, and availability of resources, equipment, among others. Regardless of variable economic parameters, data from this study reveals that any of these potential mulch species applied at a depth of at least 2 inches will provide long-term weed control in nursery container production.

Weeds are plants that compete with a crop for essential components for crop growth and development [i.e., light, water, space, or nutrients (Neal, 1999)]. These components are critical in container production because of the limited amount of space within a container. Although the competitive effect of

a weed is highly variable depending on the species of both the weed and ornamental, many researchers have documented the detrimental effects of weeds on container-grown ornamentals (Berchielli-Robertson et al., 1990; Fretz, 1972; Walker and Williams, 1989).

Two common management practices for weed control in container

plant production are hand weeding and herbicide applications. Hand weeding is an increasingly expensive option because of increasing labor cost (Darden and Neal, 1999; Gilliam et al., 1990; Mathers 2003). Through communications with Monrovia Nursery Co. (Azusa, CA), one of the largest wholesale nurseries in the United States, Mathers (2003) reported that nurseries spend an estimated \$500–\$4000/acre annually for hand weeding. This cost varies depending on the weed pressure and species. To reduce the need for hand weeding, nursery growers typically rely on multiple applications of preemergence herbicides to reduce weed pressure. Preemergence herbicides are commonly broadcast in a granular form using a cyclone or “belly-grinder”-type rotary spreader despite more recent research revealing the ineffectiveness of some granular applications when compared with liquid formulations and applications (Wehtje et al., 2015). There are numerous problems associated with current application methods of preemergence herbicides including improper handling of materials and application procedures, injury to nontarget plants, and nontarget loss (Wooten et al., 1999). Heavy reliance on preemergence herbicides has also led to herbicide resistance in some weed species.

Mulches have proven to be an effective nonchemical alternative for weed control in both the landscape and nursery container industries. Tree-derived mulches such as chipped eastern red cedar, pine bark mini-nuggets (*Pinus* sp.), and douglas fir (*Pseudotsuga menziesii*) have widespread availability, reasonable consistency, and are generally accepted by consumers (Llewellyn et al., 2003). In landscape studies conducted on tree-derived mulches, weed control was deemed acceptable and better when compared with nontreated control plots (Billeaud and Zajicek, 1989; Broschat, 2007; Greenly and Rakow, 1995). Tree-derived mulches have also been effective for weed control in nursery production, providing acceptable, long-term control of common weed species (Richardson et al., 2008; Wilen et al., 1999). In other container plant studies, combinations of herbicides and mulches were deemed most effective (Case

and Mathers, 2003; Richardson et al., 2008). Case and Mathers (2003) reported acceptable long-term weed control in containers mulched with douglas fir and pine bark nuggets in combinations with either acetochlor (Harness®; Monsanto, St. Louis, MO), flumioxazin (SureGuard®; Nufarm, Alsip, IL) or oryzalin (Surflan®; United Phosphorus, King of Prussia, PA). Neither oryzalin nor flumioxazin provided long-term control when applied alone. Likewise, pine bark nuggets and douglas fir mulches provided some control but did not meet commercial standards (≥ 7 on a scale of 0 to 10, 10 being perfect control). However, these mulches were applied at a depth of one mulch particle layer, not allowing the particles to overlap. Mulches, when applied for weed control, are most effective when applied at greater depths of 2–3 inches (Greenly and Rakow, 1995; Richardson et al., 2008).

Other readily available tree-derived mulches could be used in container production in lieu of commercialized pine bark mini-nuggets. The objective of this study was to evaluate four different types of mulch derived from readily available tree species at multiple depths for long-term weed control. The four species tested were eastern red cedar, ground whole loblolly pine, chinese privet, and sweetgum. These species were selected because of their relative abundance and low value in many southeastern areas of the United States. To assess these mulches in combination with conventional methods of weed control, mulch treatments were evaluated with and without dimethenamid-p herbicide (Tower®; BASF Corp., Research Triangle Park, NC).

Materials and methods

This study was conducted at the Paterson greenhouse complex at Auburn University in Auburn, AL. The experiment was initiated 19 Apr. 2014 and repeated on 17 Mar. 2015. Each year, eastern red cedar,

loblolly pine, chinese privet, and sweetgum trees that were 4–8 inches in trunk diameter (measured at 12 inches from the soil) were harvested. Only the trunk portions (bark included) of these trees were used to provide mulch. Tree trunks were chipped with a chipper (BC1400 XL; Vermeer Manufacturing Co., Pella, IA) 1 week after harvest. Chipped mulches were left on nursery pads for ≈ 1 month. Along with these four mulches, pine bark mini-nuggets were included (Pine Bark Mini-Nuggets Landscape; Garick, Cleveland, OH) to allow comparison with a commercially available mulch product.

Particle size distribution was determined for each mulch species. Samples were collected randomly from each mulch pile, mixed by hand in a drum, and dried for 1 week at 175 °F. Three 5-lb samples of each mulch species were hand shaken for 3 min through a series of 2 × 2-ft wire screens (2-, 1-, 0.5-, and 0.25-inch sieve sizes). The contents retained in each screen were weighed, and means of the percent total retained in each sieve for each mulch species were calculated (Fig. 1). Ideal mulches are those that provide an effective physical barrier, quickly dry out, and are void of nutrients. All chipped mulches had relatively consistent particle distributions with 70% to 90% of the weight of particles retained in a 0.25-inch sieve. The screening process involved in refining commercially available pine bark mini-nuggets resulted in a larger percentage of weight retained in the 0.5-inch sieve (69%) compared with the chipped mulches.

Treatments consisted of five mulches (eastern red cedar, loblolly pine, chinese privet, sweetgum, and pine bark mini-nuggets), three mulch depths (1, 2, and 4 inches), and two herbicidal treatments (with and without herbicide). Two additional treatments were a nontreated control (no

mulch with no herbicide) and a no mulch with herbicide for a total of 32 treatments. Three weed species (long-stalked phyllanthus, eclipta, and spotted spurge) were tested, each receiving all treatments. Each treatment was replicated five times for a total of 60 pots per weed species.

On 26 May 2014 and on 13 Apr. 2015, no. 10 squat containers (C6900S; Nursery Supplies, Kissimmee, FL) were filled 5 inches short of the top with a 6:1 pine bark:sand (v/v) substrate amended with 5 lb/yard³ dolomitic lime, 14 lb/yard³ of 18N-2.6P-9.7K (Polyon®; Pursell Technologies, Sylacauga, AL), and 1.5 lb/yard³ micronutrient fertilizer (Micromax®; Scotts, Maryville, OH). Containers were placed on a nursery pad and irrigated twice daily with 0.5 inches of water for 3 d to allow for settling and accurate adjustment of substrate depth. A single application of dime-thenamid-p was then applied at 1.4 lb/acre a.i. to the herbicide designated pots as a liquid application (30 gal/acre) with a carbon dioxide (CO₂) backpack sprayer (model-T; R&D Sprayers, Opelousas, LA) at 40 psi using an 11,004 VS nozzle (TeeJet Spraying Systems, Springfield, IL). After the herbicide application, dividers were placed into each container. These dividers consisted of vertically installed, 5-inch-tall, corrugated polypropylene sheets held in place by a central dowel to divide the substrate surface into thirds. Each third of the substrate surface was then seeded with 10 seeds of long-stalked phyllanthus, eclipta, or spotted spurge on 31 May 2014 and 16 Apr. 2015 (Fig. 2). The three partitions of each container were designated one of the three mulch depths so that each contained 1, 2, and 4 inches of mulch (Fig. 3). Mulch was applied to the surface of the substrate immediately after seeding and irrigation resumed [two irrigation

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
0.5933	lb/yard ³	kg·m ⁻³	1.6856
28.3495	oz	g	0.0353
6.8948	psi	kPa	0.1450
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

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cycles (8 h apart) per d for a total of 1 inch applied] immediately after mulch applications.

Three evaluation periods were conducted to record treatment efficacy and longevity over the course of a growing season. The first evaluation period began when 10 seeds of the designated weed species were sown on the substrate surface before mulch applications. Weeds were allowed to grow for ≈ 30 d after seeding. At the end of each evaluation period, weeds, if any, were counted, clipped at the mulch or substrate surface, and fresh weights were taken. One week after weed harvest, the containers were sprayed with paraquat dichloride (Gramoxone Inteon[®]; Syngenta Crop Protection, Greensboro, NC) at a rate of 0.25 lb/acre a.i. to kill any non-target or reemerged weeds. One week after paraquat was applied, containers were reseeded on top of the mulch or substrate surface with 10 seeds of the designated weed species, initiating the second evaluation period. This process was repeated once more to initiate the third and final evaluation period.

An analysis of variance was performed on all responses using the GLIMMIX procedure of SAS (version 9.3; SAS Institute, Cary, NC). Weed species and experimental rounds were analyzed as separate experiments, and the experimental design was a split plot with mulch type and herbicide application in the main plot and mulch depth in the subplot. Where residual plots and a significant COVTEST statement with the HOMOGENEITY option indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity for weed fresh weight. Weed counts were analyzed using the Poisson distribution. Single-df orthogonal contrasts were used to test linear and quadratic trends over mulch depth. Differences between herbicide treatments were determined using the simulated method ($\alpha = 0.05$). All reported means are least squares means.

Results and discussion

A herbicide by mulch depth interaction influenced weed counts and fresh weights of each weed species in the first evaluation period taken on 30 June 2014 (Table 1). Least square means comparison within

Fig. 1. Particle size distribution of four chipped tree species [eastern red cedar (cedar), ground whole loblolly pine (pine), chinese privet (privet), and sweetgum] compared with commercial pine bark mini-nuggets; 1 inch = 2.54 cm.

Fig. 2. Corrugated polypropylene sheets held in place by a dowel to divide the substrate surface into thirds before mulching. Ten weed seeds of the designated weed species were scattered on the surface of the substrate before mulch applications in the first evaluation period.

each weed species showed differences in weed count and fresh weight in nonmulched containers treated with or without dimethenamid-p. Non-mulched containers with long-stalked phyllanthus had higher mean weed counts in non-herbicide-treated containers (mean of 4 weeds) than containers that receive herbicide (mean of 2 weeds). Long-stalked phyllanthus fresh weights were also higher in non-herbicide-treated containers (9.28 g) than in those that received herbicide (0.04 g). Similar results were recorded for eclipta and spotted spurge. There were fewer weeds in containers with herbicide than in containers without herbicide when 1 inch of mulch was applied over spotted spurge.

Fig. 3. The three partitions of each container were filled with a single mulch species and contained all three mulch depths, 1 inch (bottom right), 2 inches (bottom left), and 4 inches (top); 1 inch = 2.54 cm.

Quadratic trends in weed counts and fresh weights were significant for all weed species in containers without herbicide. Spotted spurge fresh weights had means of 27.02 g in containers without mulch, 2.26 g at 1 inch, and 0 g in both 2-inch and 4-inch depths. Results from the first evaluation period in 2014 and 2015 (data not shown) showed similar results.

In the first evaluation period of 2014 and 2015, mulch species was observed to be insignificant. However, dimethenamid-p and mulch treatments decreased weed growth by 82% or greater over a span of 30 d. All treatments showed complete control of eclipta in the first evaluation period of 2014 and 2015, something not observed in any other evaluation period. Duryea et al. (1999) attributed the effectiveness of freshly applied mulches to higher concentrations of hydroxylated aromatic compounds believed to inhibit seed germination. Weed seed placement below mulch treatments for the first evaluation period could have also attributed to the effectiveness of mulches. It is also important to note that herbicide did not change the efficacy of mulches to control weeds other than spotted spurge weed counts in 2014 at a depth of 1 inch.

The second evaluation period (seeds placed on top of the mulch/substrate surface) did not yield results consistent with the first evaluation period or between years. In 2014, evaluation period two had significant interactions between herbicide and mulch depth (Table 2). Unlike the first period, containers treated with herbicide and without mulch had higher weed counts than containers with no herbicide and no mulch across all weed species. For example, eclipta had a mean of three weeds in containers treated with herbicide and no mulch and one in nonmulched, no herbicide containers. Long-stalked phyllanthus also had greater fresh weights in containers treated with herbicide and no mulch (2.66 g) than those without herbicide and mulch (0.62 g). Eclipta and spotted spurge fresh weights were affected by mulch depth only. Spotted spurge had decreasing fresh weights with increasing mulch depth, 3.87 g in containers without mulch, 0.24 g at

Table 1. Effect of herbicide and mulch depth on weed counts and fresh weights of long-stalked phyllanthus, eclipta, and spotted spurge during the first evaluation period in 2014.^z

		Mulch depth (inches) ^x				
		0	1	2	4	
Weed species	Herbicide ^y	Weed count (no./pot)				Trend ^w
Long-stalked phyllanthus	No	4 a ^v	1	0	0	Q***
	Yes	2 b	1	0	0	Q***
Eclipta	No	4 a	0	0	0	Q***
	Yes	0 b	0	0	0	NS
Spotted spurge	No	6 a	1 a	0	0	Q***
	Yes	0 b	0 b	0	0	NS
Fresh wt (g/pot) ^x						
Long-stalked phyllanthus	No	9.28 a	1.68	0.09	0.00	Q***
	Yes	0.04 b	0.02	0.00	0.00	NS
Eclipta	No	34.46 a	0.00	0.00	0.00	Q***
	Yes	0.00 b	0.00	0.00	0.00	NS
Spotted spurge	No	27.02 a	2.26	0.00	0.00	Q***
	Yes	0.00 b	0.00	0.00	0.00	NS

^zTreated on 31 May 2014; data recorded 30 June 2014, 30 d after treatment. Each weed species was analyzed separately.

^yDimethenamid-p was broadcast applied before seed (10 seeds/replication) and mulch applications at 1.4 lb/acre (1.57 kg·ha⁻¹) a.i.

^x1 inch = 2.54 cm, 1 g = 0.0353 oz.

^wNonsignificant (NS) or quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.001$ (***) over mulch depth.

^vSignificant herbicide by mulch depth interactions were detected for all species and both responses at $\alpha = 0.05$. Least square means comparisons between no herbicide and herbicide (in columns) for the herbicide by mulch depth interactions using the simulated method at $\alpha = 0.05$.

Table 2. Effect of herbicide and mulch depth on weed counts and fresh weights of long-stalked phyllanthus, eclipta, and spotted spurge during the second evaluation period in 2014.^z

		Mulch depth (inches) ^x				
		0	1	2	4	
Weed species	Herbicide ^y	Weed count (no./pot)				Trend ^w
Long-stalked phyllanthus	No	2 b ^v	2	1	0	L***
	Yes	3 a	1	1	0	Q***
Eclipta	No	1 a	0	0	0	Q***
	Yes	3 b	0	0	0	Q***
Spotted spurge	No	4 b	1	0	0	Q***
	Yes	5 a	1	1	0	Q***
Fresh wt (g/pot) ^x						
Long-stalked phyllanthus	No	0.62 b	0.88	0.08	0.00	L***
	Yes	2.66 a	0.50	0.30	0.00	Q***
Eclipta	n/a ^u	1.19	0.20	0.09	0.00	Q***
Spotted spurge	n/a	3.87	0.24	0.00	0.00	Q***

^zTreated on 31 May 2014; data recorded 19 Aug. 2014, 80 d after treatment. Each weed species was analyzed separately.

^yDimethenamid-p was broadcast applied before seed (10 seeds/replication) and mulch applications at 1.4 lb/acre (1.57 kg·ha⁻¹) a.i.

^x1 inch = 2.54 cm, 1 g = 0.04353 oz.

^wLinear (L) or quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.001$ (***) over mulch depth.

^vSignificant herbicide by mulch depth interactions were detected for all species for weed counts and long-stalked phyllanthus for fresh weights at $\alpha = 0.05$. Least square means comparisons between no herbicide and herbicide (in columns) for the herbicide by mulch depth interactions using the simulated method at $\alpha = 0.05$.

^uOnly the mulch depth main effect was significant at $\alpha = 0.05$.

1 inch, and 0 g in both 2-inch and 4-inch depths. Linear or quadratic trends in weed counts and fresh weight were significant. Weed counts and fresh weights decreased with increasing mulch depth.

In 2015, evaluation period two exhibited significant herbicide by mulch depth interactions, which indicated that dimethenamid-p was still active (Table 3). Long-stalked phyllanthus, eclipta, and spotted spurge

Table 3. Effect of herbicide and mulch depth on weed counts and fresh weights of long-stalked phyllanthus, eclipta, and spotted spurge during the second evaluation period in 2015.^z

Weed species	Herbicide ^y	Mulch depth (inches) ^x				Trend ^w
		0	1	2	4	
		Weed count (no./pot)				
Long-stalked phyllanthus	n/a ^{w,v}	2 ^u	1	1	0	Q*
Eclipta	n/a	4	2	1	1	Q***
Spotted spurge	No	8 a	3	2	0	Q***
	Yes	6 b	3	2	0	Q***
Fresh wt (g/pot) ^x						
Long-stalked phyllanthus	No	9.66 a	2.90	3.15	0.00	Q*
	Yes	0.64 b	1.00	0.01	0.00	NS
Eclipta	No	63.14 a	21.91	18.74	8.50	L**
	Yes	13.99 b	13.56	4.56	0.47	Q***
Spotted spurge	No	99.02 a	15.35	5.47	0.37	Q***
	Yes	35.16 b	10.98	3.23	0.22	Q**

^zTreated on 16 Apr. 2015; data recorded 30 June 2015, 75 d after treatment. Each weed species was analyzed separately.

^yDimethenamid-p was broadcast applied before seed (10 seeds/replication) and mulch applications at 1.4 lb/acre (1.57 kg·ha⁻¹) a.i.

^x1 inch = 2.54 cm, 1 g = 0.0353 oz.

^wNonsignificant (NS), linear (L), or quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***) over mulch depth.

^vOnly the mulch depth main effect was significant for weed count in long-stalked phyllanthus and eclipta at $\alpha = 0.05$.

^uSignificant herbicide by mulch depth interactions were detected for all species for fresh weights and spotted spurge for weed counts at $\alpha = 0.05$. Least square means comparisons between no herbicide and herbicide (in columns) for the herbicide by mulch depth interactions using the simulated method at $\alpha = 0.05$.

Table 4. Mulch species and depth influence weed counts of spotted spurge during the second evaluation period in 2015.^z

Mulch species	Mulch depth (inches) ^y				Trend ^x
	0	1	2	4	
Eastern red cedar	7 NS ^w	3 a	2 a	0 NS	Q***
Loblolly pine	7	3 a	3 a	1	Q***
Chinese privet	7	3 a	2 a	1	Q***
Sweetgum	7	4 a	2 a	0	Q***
Pine bark mini-nuggets	7	1 b	0 b	0	Q***

^zTreated on 16 Apr. 2015; data recorded 30 June 2015, 75 d after treatment.

^y1 inch = 2.54 cm.

^xQuadratic (Q) trends using orthogonal polynomials at $\alpha = 0.001$ (***) for mulch depth.

^wSignificant mulch species by mulch depth interaction were detected at $\alpha = 0.05$. Least square means comparisons among mulch species at each mulch depth (in columns) using the simulated method at $\alpha = 0.05$.

fresh weights, as well as spotted spurge weed counts, were greater in containers without mulch or herbicide than those containers with herbicide and no mulch. Long-stalked phyllanthus, eclipta, and spotted spurge fresh weights in herbicide-treated containers without mulch were reduced by 93%, 78%, and 65%, respectively, when compared with containers without herbicide or mulch. Long-stalked phyllanthus and eclipta weed counts were affected by mulch depth only. With the exception of long-stalked phyllanthus containers treated with herbicide, linear or quadratic trends in weed counts and fresh weight were significant.

Weed counts and fresh weights decreased with increasing mulch depth. Weed counts of eclipta and spotted spurge were also affected by mulch species (Table 4). Pine bark mini-nuggets controlled spotted spurge and eclipta better than eastern red cedar, loblolly pine, chinese privet, or sweetgum at 2 and 4 inches. No other differences between mulch species and depth were observed.

The second evaluation period revealed widely different results between 2014 and 2015. In 2014, dimethenamid-p treatments had higher weed counts and fresh weights compared with the non-herbicide-treated containers. Germination tests

were conducted in paper towels on all weed species before each evaluation period to ensure $\approx 90\%$ germination rates were met. These test indicated that all weed species had a germination rate greater than the target 90%. However, results throughout the study revealed inconsistent germination rates in the pine bark/sand substrates. A random event of inconsistent germination could have caused herbicide-treated containers to show greater weed counts and fresh weights than non-herbicide-treated containers. Dimethenamid-p has a short half-life of ≈ 21 d (Senseman, 2007). Microbial activity coupled with the herbicide's high adsorption to organic matter in container substrates presumably rendered the herbicide ineffective by the second evaluation period of the experiment (about 45 d after treatment). However, in 2015, dimethenamid-p had not lost efficacy and reduced the growth of all weed species and weed counts of spotted spurge. Cooler weather decreases microbial activity and can increase the longevity of a herbicide's half-life. It is possible that the earlier, cooler start in 2015 (16 Apr. as opposed to 31 May) allowed the herbicide's efficacy to be extended up to or beyond 45 d.

Differences among mulch species were only observed in 2015 during the second evaluation period. Pine bark mini-nuggets at a depth of 1 and 2 inches had fewer eclipta and spotted spurge than other mulch species. A weather recording station on Auburn University's campus recorded rainfall for each evaluation period. In 2014, 3.37, 3.05, and 2.30 inches of rain were received during the first, second, and third evaluation period, respectively. In 2015, 2.23, 5.72, and 1.60 inches of rain were received during the first, second, and third evaluation period, respectively. Throughout the second evaluation period in 2015, 13 d were overcast. It is our hypothesis that the amount of rain received during this evaluation period attributed the difference recorded in mulch species. Pine bark mini-nugget's larger particle size distribution and hydrophobic properties lent it an advantage during this wet period to best maintain its weed control efficacy.

The third evaluation period in 2014 and 2015 revealed mulch depth

Table 5. Mulch depth affects weed counts and fresh weights of long-stalked phyllanthus, eclipta, and spotted spurge during the third evaluation period in 2015.^z

Weed species	Mulch depth (inches) ^y				Trend ^x
	0	1	2	4	
	Weed count (no./pot)				
Long-stalked phyllanthus	4 ^v	1	0	0	Q***
Eclipta	4	0	0	0	Q***
Spotted spurge	6	2	0	0	Q***
	Fresh wt (g/pot) ^y				
Long-stalked phyllanthus	5.77	0.27	0.05	0.00	Q**
Eclipta	6.42	0.28	0.01	0.00	Q***
Spotted spurge	4.63	0.48	0.02	0.00	Q***

^zTreated on 16 Apr. 2015; data recorded 1 Oct. 2015, 168 d after treatment. Each weed species was analyzed separately. Only mulch depth was significant for both responses at $\alpha = 0.05$.

^y1 inch = 2.54 cm, 1 g = 0.0353 oz.

^xQuadratic (Q) trends using orthogonal polynomials at $\alpha = 0.01$ (**) or 0.001 (***) over mulch depth.

was the only significant main effect on weed counts and fresh weights of all weed species. Significant quadratic trends were recorded across mulch depths. In all weed species, weed counts, and fresh weights decreased with increasing mulch depth. In containers without mulch, eclipta fresh weights averaged 12.51 g in the final evaluation period of 2014 (data not shown). In 2015, mulch depths of 1, 2, and 4 inches reduced eclipta fresh weight by 98%, 99.5%, and 100%, respectively. Spotted spurge fresh weight was reduced 90%, 99.5%, and 100% by 1, 2, and 4 inches of mulch, respectively, when compared with containers without mulch (Table 5).

These results demonstrate that tree-derived mulches are an effective, nonchemical alternative method of weed control. These data also indicate that a depth of 2 inches with any of these readily available, tree-derived mulches will provide effective weed control of the evaluated weed species in container plant production. This recommendation lends the practice of mulching to be more suitable for large container production rather than small container production (less than no. 3 containers) for two reasons. First, the longer a plant is grown in a container, the better economic value a slow-degrading mulch will have. Plants grown in larger containers typically require more time as opposed to plants grown in no. 1 container. Second, 2 inches of mulch in a trade gallon container (C300; Nursery Supplies) could decrease the volume of substrate in the container by 27.6% whereas only decreasing the

volume of the substrate in a no. 7 (C2800; Nursery Supplies) by 17.4%. The assumption could be made that a decrease in substrate of 27%, when having so little to start in a trade gallon container, could cause reduced growth over time whereas the same effect would be less noticeable, if at all, in a larger container. However, there is no research to support these assumptions. Deep mulch depths have been associated with decreased plant growth or increased exposure to pathogens. However, mulch depths of 2 and 4 inches showed no injury or decreased in growth of wax-leaf ligustrum (*Ligustrum japonicum*) or snowball viburnum (*Viburnum macrocephalum*) grown in no. 7 containers (Bartley et al., 2016).

Cost analysis research must be conducted to help support the practice of weed control with mulches from an economic perspective. The practicality of weed control with mulches will greatly vary from grower to grower. The economics of the practice will depend on many variables (i.e., available time, nursery layout, location, and availability of resources, equipment). Ideal conditions (i.e., proper equipment, nearby resources, available time) may support the mulch weed control practices over conventional methods. Similarly, detrimental conditions for conventional methods of weed control may force alternative practices to be used; for instance, the nursery is located in close proximity to a water supply source or the need for weed control in herbicide-sensitive ornamentals such as hydrangea. Currently,

the cost for pine bark mini-nuggets is $\approx \$16/\text{yard}^3$. At this price, it would cost \$0.11 (not including labor) to apply 2 inches of mulch in a no. 7 (14-inch diameter) container or \$0.18 in a no. 15 container. The total price for mulch weed control may be relatively comparable with the cost of conventional practices. Amoroso et al. (2007) reported that an application of preemergence herbicides to a no. 1 (trade gallon) container combined with a hand-weeding regiment cost \$0.05/year. In addition, further research must be conducted to analyze specific decomposition rates as noticeable decomposition differences were observed between mulch species. This information would be vital in determining application procedures in larger container production where plants are grown up to 18 months or longer. If this process can be made economical, the use of mulches in container plant production can alleviate many of the problems associated with common weed control methods such as non-target loss, high labor cost, and damage to crops.

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