Organic Mulch and Halosulfuron Placement Affect Yellow Nutsedge Control and Ornamental Plant Quality in Landscape Beds[1]

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Abstract

Halosulfuron (SedgeHammer™) applied above or below pine nugget, pine straw, or shredded cypress mulch at 0, 0.038, or 0.075 kg ai·ha^{-1} (0.034 or 0.067 lb ai·A^{-1}) was evaluated for postemergence control of yellow nutsedge in two field experiments. Tolerance of 'Mystery' gardenia (*Gardenia jasminoides* Ellis), 'Stella de Oro' daylily (*Hemerocallis* x), and 'Big Blue' liriope (*Liriope muscari* L.H. Bailey) to overtop applications of halosulfuron was also evaluated. Without halosulfuron, mulching with pine nugget, pine straw, and shredded cypress provided about 51 to 62% yellow nutsedge control at 4 weeks after treatments (WAT) compared with non-sprayed bare soil plots. At the infestation level of 167 tubers per m^2 (15 tubers per ft^2) in both experiments, halosulfuron application at the lower rate resulted in similar control as the higher rate regardless of mulch type and herbicide placement. Applications prior to mulching provided equal or, in some cases, better control than applications after mulching. Overall, halosulfuron resulted in greater control in Experiment 2 than Experiment 1, possibly because of smaller yellow nutsedge shoots in the second trial. Over-the-top application of halosulfuron at the higher rate caused transient leaf injury and reduced aboveground biomass in liriope. However, mulching improved gardenia transplant quality as indicated by reduced leaf chlorosis and increased number of flowers.

Index words: weed management, pine nugget, pine straw, shredded cypress.

Species used in this study: gardenia (*Gardenia jasminoides* Ellis 'Mystery'); daylily (*Hemerocallis* x 'Stella de Oro'); and liriope (*Liriope muscari* L.H. Bailey 'Big Blue').

Chemicals used in this study: halosulfuron (SedgeHammer™), methyl5-{[(4, 6-dimethyl-2-pyrimidinyl) amino] carbonylaminosulfonyl}-3-chloro-1-methyl-1-H-pyrazole-4-carboxylate.

Significance to the Nursery Industry

Yellow nutsedge (*Cyperus esculentus* L.) is one of the most troublesome perennial weeds infesting landscape beds in the southeastern United States. Few selective herbicides are available for managing this weed. Mulching is a common practice in landscape installation and maintenance. Previous research indicated that mulching can enhance weed control and aesthetic quality of flower beds but its effects on ornamental plants may vary. In this study, when applying halosulfuron (SedgeHammer™, Gowan Company, 370 South Main Street,Yuma, AZ 85364) for postemergence control, applying it before mulching resulted in equal or, in some cases, greater control compared to treatment after mulch application. Lower light intensity and higher moisture under organic mulch may have increased herbicide longevity or the nutsedge-herbicide contact time may have been greater when placed under mulch. However, there might be other unknown factors involved because this placement effect was not significant for most treatment combinations. Overhead application of halosulfuron caused foliage injury in liriope, and reduced aboveground dry weight in daylily, but these adverse effects were transient. Mulch application reduced leaf chlorosis in gardenia compared to bare soil, perhaps through increased soil moisture. Mulching, however, reduced liriope shoot weight. Liriope may be sensitive to allelopathic chemicals from the mulch types tested. Based on these results, halosulfuron should be applied preferably before mulching as a directed spray around landscape ornamentals.

Introduction

Yellow nutsedge is a common and troublesome perennial weed in managed landscapes (14, 28, 30). It grows rapidly in irrigated landscape beds and tends to become established where other weeds are controlled by herbicides. Yellow nutsedge can be difficult to control due to its ability to produce numerous aerial shoots and carbohydrate-storing tubers. Ransom et al. (24) reported that a single yellow nutsedge plant is capable of producing 1,700 to 3,000 shoots and 19,000 to 22,000 tubers each year. Controls reducing shoot growth or limiting tuber production are critical for its efficient control (29).

Although hand-weeding is commonly used to remove mature yellow nutsedge from landscape beds, it is time-consuming and inefficient because tubers often remain in the soil. When establishing new landscape beds in areas infested with yellow nutsedge, removing existing vegetation by pre-planting application of non-selective herbicide (i.e., glyphosate) is a common practice among landscape professionals, which may reduce yellow nutsedge populations if applied appropriately. In addition, studies have shown that applications of selective preemergence (PRE) herbicides, such as EPTC, and organic landscape mulches, including pine nuggets, can provide critical initial yellow nutsedge

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control (7). However, when these actions fail, postemergence (POST) treatment is recommended (29). Few selective POST herbicides are available for yellow nutsedge control in ornamentals.

Halosulfuron is registered for selective POST nutsedge control in established turf and landscapes (2). Halosulfuron is absorbed into leaf tissues within 24 to 48 hours after contact and translocated through the vascular system to underground tubers, interrupting amino acid production within the plant. Control is rate dependent and affected by application timing. Halosulfuron applied POST at 71.6 g ai·ha^{-1} (0.06 lb ai·A^{-1}) 35 days after sugarcane planting, when yellow nutsedge was 15 to 25 cm (6 to 10 in) in height, provided 77% yellow nutsedge control at 3 weeks after treatments (WAT) (12). In a nursery field study, halosulfuron applied POST when yellow nutsedge was 10 to 15 cm (4 to 6 in) tall at 0.07 to 0.28 kg ai·ha^{-1} (0.06 to 0.25 lb ai·A^{-1}) provided acceptable control (approximately 86%) at 4 WAT, but less control (approximately 78%) at 9 WAT (10).

Halosulfuron has also been reported to provide PRE control of yellow nutsedge in turf (18, 19), sugarcane (12), vegetables (20), and nursery crops (10). Etheredge et al. (12) reported that halosulfuron at 71.6 g ai·ha^{-1} (0.06 lb ai·A^{-1}) applied PRE at planting of sugarcane provided 43% yellow nutsedge control at 10 WAT. Derr et al. (10) reported that PRE treatments of halosulfuron at increasing rates from 0.03 to 0.28 kg ai·ha^{-1} (0.03 to 0.31 lb ai·A^{-1}) provided 68 to 95% and 16 to 73% controls at 4 and 9 WAT, respectively. Macrae et al. (20) reported that sequential PRE and POST applications of halosulfuron at 26 g ai·ha^{-1} (0.03 lb ai·A^{-1}) controlled yellow nutsedge 89 to 99%.

Halosulfuron is labeled for over-the-top application to established turfgrass and causes little injury to turfgrass (13). However, it needs to be directed around ornamental plants (2). Plant injuries from overhead application, especially at higher rates, were observed in field-grown ornamental plants, such as azalea, cotoneaster and crape myrtle (10). However, in a POST study on prostrate spurge, halosulfuron at 0.034 kg ai·ha^{-1} (0.3 lb ai·A^{-1}) caused no injury to single Big Blue liriope bibs (1).

Mulching is recommended as one of the Best Management Practices for improving weed control and overall aesthetics of landscape plantings (6, 27). Organic mulch may reduce weeds by inhibiting germination and suppressing growth (11). As reviewed by Chalker-Scott (6), mulching at an appropriate depth improved soil water retention, reduced weed competition, and enhanced root establishment, transplant survival, and overall plant growth. Pine bark, pine nuggets, and shredded cypress applied at depth over 10 cm (4 in) tended to inhibit growth of Japanese privet (*Ligustrum japonicum* Thunb.), although the optimum depth was dependent on the mulch material used (4). However, at appropriate depths, some mulch may adversely affect plant growth. For example, cypress, eucalyptus, melaleuca, pine bark, pine straw, and a utility mulch (mixture of pruning from oaks and cherry with a small amount of cedar and pine) inhibited germination of lettuce seeds, perhaps by hydroxylated aromatic compounds that were allelopathic (11). Cregg and Schutzki (8) reported that mulching with pine bark, hardwood fines, and ground pallets, but not cypress, improved growth of eight taxa, suggesting potential allelopathic effects from cypress mulch. In addition, mulches having high carbon to nitrogen ratio may cause nitrogen immobilization by soil microorganisms (23), or water interception when volume of irrigation was low, resulting in a drier root ball and greater transplant stress (15).

The emergence of yellow nutsedge in early spring is synchronous with many landscaping activities and is often overlooked until they have grown into a size necessitates POST control. When establishing new plantings or replenishing existing landscape beds, POST herbicides can be applied before or after laying mulch. This herbicide placement may affect herbicide efficacy. However, information on this type of interaction is lacking. Therefore, the objective of this study was to evaluate yellow nutsedge control efficacy and responses of three ornamental plant species to POST halosulfuron application, either above or below organic mulch.

Materials and Methods

The field studies were conducted in Hammond, LA (U.S. Department of Agriculture Plant Hardiness Zone 8b) in 2006 (Experiment 1) and repeated in 2007 (Experiment 2) in an adjacent field. The native topsoil is a Cahaba sandy loam with 57% sand, 30% silt, and 13% clay, with 1% organic matter. Soil analysis indicated (in mg·liter^{-1}): 39 phosphorus, 58 potassium, 462 calcium, and 127 magnesium and soil pH of 5.2 (LSUAC Soil Testing and Plant Analysis Laboratory, Baton Rouge, LA). In both years, glyphosate (Roundup Pro, Monsanto Co., 800 N. Lindbergh Blvd., St. Louis, MO 63167) at 1.6% v/v was applied to eliminate existing vegetation prior to bed preparation.

General information. In each experiment, four raised beds were prepared by rototiller-incorporating a 10.2 cm (4 in) layer of bedding mix [mixture of green-waste compost, rice hulls, and top soil (Natural Resources Recovery, Inc. Baton Rouge, LA)] and 3360 kg·ha^{-1} (70 lb·1000 ft^{-2}) pulverized dolomitic limestone into the top 15.2 cm (6 in) of the native soil to raise the soil pH to 6.5. Then beds were each divided into 18 treatment plots. Each plot measured 1.2 m (4 ft) long by 1.5 m (5 ft) wide. A 0.6 m (2 ft) alleyway was left between individual plots, and weeds in these areas were controlled with glyphosate applications throughout the experiment.

Experimental design was an unbalanced, randomized complete block design with four replications (17). Treatment structure was 3-factor factorial consisted of two halosulfuron rates [0.038, or 0.075 kg·ha^{-1} (0.033, or 0.067 lb·A^{-1})] by three mulch types (pine nuggets, pine straw, or shredded cypress) by two herbicide placements (above or below mulch). A nonionic surfactant (Induce, Helena Chemical Co., Collierville, TN) was added at 0.3% v/v to treatment solutions. In addition, mulch-alone and bare soil plots were used as controls. Mulch-alone treatments were mulched with one of the three organic mulches but received no herbicide. Because the treatment factor, herbicide placement, was missing from these controls, the experimental design was unbalanced. The 16 treatment combinations were randomly arranged within each raised bed, which served as replications.

Three mulch products, pine nuggets (bark and some wood from *Pinus elliottii* and *P. taeda* L., Louisiana Soil Products, Ruston, LA), pine straw (needles from *P. elliottii* Engelm, Custom Pine Straw, Inc., Branford, FL), or shredded cypress (wood and some bark from *Taxodium distichum* L., Corbitt Manufacturing Co., Lake City, FL) were evaluated. A small trial was conducted prior to treatment to calculate the approximate amount of products needed to maintain a 7.62 cm

Table 1. **Particle size composition and bulk density of pine nugget, pine straw, and shredded cypress mulch averaged across two experiments.**

Mulch type	Particle size composition (%) < 2.54 cm (1 in)	2.54 to 5.08 cm (1 to 2 in)	> 5.08 cm (2 in)	Bulk density[z] g·L^{-1}
Pine nuggets	10.4	55.7	33.9	187.8
Pine straw	2.0	5.0	93.0	63.0
Shredded cypress	38.0	52.7	9.3	215.1

[z]Bulk density was determined following the method described by Bilderback and Fonteno (3).

(3 in) layer after four weeks of settling. Mulches were fresh and undyed. Size composition (by vol) of each mulch product was determined by separating particles < 2.54 cm (1 in), 2.54 to 5.08 cm (1 to 2 in), and > 5.08 cm (2 in). Bulk density (weight per volume) was determined using procedures described by Bilderback and Fonteno (3) (Table 1).

Experiment 1. Fifteen yellow nutsedge tubers (Azlin Seed Service, Leland, MS) were planted per 0.09 m^2 (1 ft^2) at 1.3 to 2.5 cm (½ to 1 in) deep on March 1, 2006. Three 'Mystery' gardenias from 2.8 liter pots, two 'Stella de Oro' daylily and two 'Big Blue' liriope from 0.6 liter pots, were transplanted to field plots On March 8. A controlled release fertilizer [Osmocote 18-6-12 (14N-4.2P-11.6K) (8 to 9-month southern), Scotts Co., 14111 Scottslawn Rd,. Marysville, OH 43041] was hand broadcast to each plot at 2.24 kg N·ha^{-1} (2 lb·1000 ft^{-2}) prior to planting the ornamentals. Micro-sprinklers (11 gal·h^{-1}, Vari-Jet; Antelco Corp., Longwood, FL) were set to deliver 10 liters (2.75 gal) of water to each plot at each watering, and irrigation was scheduled three times per week for the first four weeks after planting and then reduced to twice per week.

Field plots were left unmulched until treatment application at four weeks after tuber planting. Approximately 70% of the tubers had emerged and were at the 5 to 6-leaf stage, approximately 12 cm (3.9 in) in height. Halosulfuron was sprayed over the top of ornamental plants before or after covering plots with one of the mulches. Non-sprayed mulch-alone plots were mulched at the same time.

Soil temperature and moisture were recorded by soil moisture sensors (5TE; Decagon Devises, Pullman, WA). Sensors were buried 2.54 cm (1 in) below surface of bedding mix on the south side of gardenia in four plots: three plots were mulched for each mulch type and there was a non-sprayed bare soil plot. Data were recorded hourly from June 11 to June 18, 2006. Light intensity at the surface of bedding mix below mulch or at the surface of bare soil was recorded by a Decagon AccuPAR external quantum light sensor at 1200 HR from June 11 to 18, 2006 (Table 2).

Yellow nutsedge control efficacy was visually estimated by comparing treated plots with non-sprayed bare soil plots using a scale from 0% (no control) to 100% (complete control) in 10% increments at 4, 8, and 12 WAT. Leaf chlorosis was observed in gardenia at 2 and 4 WAT. Chlorosis ratings were made on a 0 to 5 score, where 0 was no yellowing, 1 was 1 to 10% yellowing, 2 was 11 to 20%, 3 = 21 to 30%, 4 was 31 to 40%, and 5 was 50% or more leaves turned yellow. Because no year by data interaction was found, data recorded at 4 WAT from both experiments were pooled before analysis. At 24 WAT, gardenia, daylily, and liriope plants were measured for height (H, measured from the soil surface to the tallest point of the plant excluding inflorescences), widest width (W_1), and the width perpendicular to the widest width (W_2). Size index was calculated as $SI = (H + W_1 + W_2) / 3$. Aboveground parts of daylily and liriope plants were then harvested for dry weight.

Experiment 2. Experiment 2 followed the same treatment regime except that yellow nutsedge tubers were planted a week earlier than 2006. Ornamental plants were transplanted at five weeks after tuber planting, and plots were treated with halosulfuron and mulched on March 26, 2007. Nutsedge plants were about 6 cm (2.3 inches) tall at the time of treatment application, shorter than that in Experiment 1. Number of yellow nutsedge shoots in each field plot was counted at 2, 4, 6, 8, and 12 weeks after halosulfuron treatment (WAT). Shoot density was then calculated by dividing this count by plot size (1.86 m^2). Yellow nutsedge shoots were too numerous to count in non-sprayed bare soil plots after 12 WAT, therefore, control efficacy was visually estimated and compared with non-sprayed bare soil plots at 14 WAT. A leaf chlorosis rating was recorded at 4 WAT. To evaluate herbicide and mulch effects on plant flowering, number of gardenia and daylily flowers were counted at 8 and 12 WAT. A daylily flower was counted when its outer three petals were partially reflexed. A gardenia flower was counted when its first layer of petals unfolded to reveal center petals. Daylily and gardenia flowers only last for a few days, therefore, flowers counted at 8 WAT are unlikely to be counted again at the later sample dates. The aboveground part of one of

Table 2. **Maximum, minimum, and daily average temperatures, and soil moisture (volumetric water content) at 2.54 cm (1 in) below bedding mix surface in plots mulched with pine nuggets, pine straw, shredded cypress, or bare soil; and light intensity at soil surface under each mulch or at the surface of bare soil. Temperatures and soil moisture were recorded hourly from June 11 to June 18, 2006. Light intensities were measured at 1200HR from June 11 to 18, 2006.**

Mulch	Temperature[z] (C) Maximum	Minimum	Average	Light intensity µmol photons m^{-2}s^{-1}	Volume water content Mpa
Cypress	25.5	24.8	25.2	136	–0.073
Pine nugget	25.0	24.5	24.8	189	–0.049
Pine straw	25.6	24.5	25.1	239	–0.041
Bare soil	25.4	22.8	24.1	1521	–0.001

[z]F = C × 9/5 + 32.

Table 3. Yellow nutsedge control effect in Experiment 1 estimated at 4, 8, and 12 weeks after mulching and halosulfuron application.

Treatment[z]			Control[y,x] (%)		
			Weeks after treatment		
Mulch	Halosulfuron rate kg a.i·ha^{-1}	Placement	4	8	12
Pine nuggets	0.038	Above	88ab	76ab	66ab
	0.038	Under	90a	82a	71a
	0.075	Above	91a	80a	76a
	0.075	Under	96a	79ab	80a
Pine straw	0.038	Above	85ab	78ab	75a
	0.038	Under	92a	80a	71a
	0.075	Above	88ab	76ab	69ab
	0.075	Under	95a	83a	80a
Shredded cypress	0.038	Above	76b	60b	52b
	0.038	Under	75bc	67b	55b
	0.075	Above	89ab	76ab	66ab
	0.075	Under	82ab	75ab	60ab
Pine nugget	0	—	64c	52bc	40c
Pine straw	0	—	59cd	49c	34c
Shredded cypress	0	—	52d	45c	37c

[z]Herbicide by mulch by placement interactions were significant at 4 and 8 weeks after treatment. Therefore treatment combinations were compared using PROC GLIMMIX, and lsmeans were grouped using PDIFF (22) and additional software (26).

[y]Non-sprayed bare soil plots were used as a reference (0 control) to estimate treatment effects in non-sprayed mulch-alone plots and halosulfuron plus mulching plots using a scale from 0% (no control) to 100% (complete control) in 10% increments.

[x]Means within a column followed by the same letter are not significantly different at $\alpha \leq 0.05$.

the two plants of daylily and liriope were harvested for dry weight at 16 WAT and the other plant was measured for SI at 24 WAT.

Data from two experiments were analyzed separately and first subjected to normality tests. Non-normal data were transformed using appropriate means to improve normality based on suggestions from Hartwig and Dearing (17). LSMEANS were back-transformed after analysis. Because of interactions between treatments and sample dates, repeated measurements such as shoot density were analyzed by each sample date rather than using repeated measurement analysis.

All treatment factors were included when data were first analyzed (ANOVA) using PROC GLIMMIX (SAS version 9.3; SAS Institute, Cary, NC). In this model, treatment factors [mulch type (four levels), herbicide rate (three levels), and placement (two levels)] and their interactions were considered fixed effects. Block, block by mulch by rate, and block by mulch by rate by placement were considered random effects. Means were compared using LSMEAN PDIFF (22). Additional SAS program was performed after each PDIFF command to assist the grouping of lsmeans (26). The value of alpha in the original coding of this software was changed to 0.05. When interactions between placement and other factors were not significant, data were re-analyzed with PROC MIXED and LSMEAN statements. LSMEANS were then separated using Tukey's honest significant difference test.

Results and Discussions

Yellow nutsedge control. In Experiment 1, mulching alone provided 52 to 64% yellow nutsedge control compared with non-sprayed bare soil at 4 WAT (Table 3). This control decreased to 34 to 40% by 12 WAT. These results suggest that mulching plays an important role in suppressing yellow nutsedge but the effect decreases over time. The three mulch types were similar in terms of their abilities for suppressing yellow nutsedge in non-sprayed plots, except one occasion in which cypress mulch was less effective than pine nuggets at 4 WAT (Table 3).

Because of the interactions among halosulfuron rate by mulch by placement at 4 and 8 WAT, individual treatment combinations were compared and presented (Table 3). The interactions at both sample dates were similar in that halosulfuron applied at the lower rate under shredded cypress was less effective (75 to 76% at 4 WAT, 60 to 67% at 8 WAT) compared with halosulfuron applied at the lower rate under pine nugget (90 and 82% at 4 and 8 WAT, respectively) and pine straw (92 and 80% at 4 and 8 WAT, respectively, Table 3). This effect was not significant at the higher rate. Despite these interactions, there was neither a significant rate effect nor mulch type or herbicide placement effect. Most treatment combinations provided effective yellow nutsedge control at 4 WAT, which decreased over time from 82 to 96% at 4 WAT to 60 to 80% at 12 WAT.

In Experiment 2, yellow nutsedge shoot density in non-sprayed bare soil plots was the highest at all sample dates and increased over time (Table 4). Shoot densities in non-sprayed but mulched plots were 50 to 60% less than non-sprayed bare soil. There was no difference among the three mulch types except that at 4 WAT, nutsedge density in shredded cypress plots was slightly higher than in pine nugget plots (Table 4). This is consistent with Experiment 1, indicating that shredded cypress is less effective in suppressing yellow nutsedge compared with pine nuggets. A possible cause is

Table 4. Yellow nutsedge shoot density in Experiment 2 at 2, 4, 6, 8, and 12 weeks after plots were sprayed with halosulfuron either before or after being covered with mulches (WAT); and control effects estimated at 14 WAT. 10.7639 shoots·m^{-2} = 1 shoot·ft^{-2}.

Mulch[z]	Halosulfuron a.i. kg·ha^{-1}	Placement[y]	Shoot density (shoot/m^2)[x]					Control (%)[w] 14 WAT
			2 WAT[v]	4 WAT	6 WAT	8 WAT	12 WAT	
Pine nugget	0.038	Above	0.7e[u]	3.4d	8.2d	12.6c	37.0c	86b
	0.038	Under	0.2e	0.2d	0.9d	1.8d	3.8d	96a
	0.075	Above	2.3de	0.4d	3.6d	3.8cd	22.9cd	88ab
	0.075	Under	0.0e	0.0d	0.0d	0.3d	5.8d	95ab
Pine straw	0.038	Above	0.2e	1.6d	4.3d	9.5cd	32.1c	75c
	0.038	Under	0.0e	0.0d	0.2d	1.6d	6.5d	97a
	0.075	Above	0.2e	0.4d	1.3d	1.8d	10.9cd	95ab
	0.075	Under	0.0e	0.0d	0.9d	0.3d	5.6d	91ab
Shredded cypress	0.038	Above	7.7c	12.6bcd	7.6d	5.6cd	7.0d	94ab
	0.038	Under	0.0e	0.4d	1.6d	2.0cd	7.5d	94ab
	0.075	Above	5.4cd	5.4cd	5.2d	1.8d	13.8cd	95ab
	0.075	Under	0.0e	0.2d	0.9d	3.6cd	13.9cd	95ab
Bare soil[t]	0	—	20.2a	31.5a	63.4a	101.2a	120.2a	0d
Pine nugget	0	—	5.4cd	5.4cd	20.7c	43.9b	66.0b	71c
Pine straw	0	—	7.7c	11.1bc	29.1c	49.0b	69.8b	65c
Shredded cypress	0	—	14.1bc	18.1b	46.3b	59.5b	77.5b	63c

[z]Placement by mulch type interactions were found at 2, 8, and 12 WAT. Therefore, means of treatment combinations are presented.

[y]Above = herbicide applied after mulching. Under = herbicide before mulching.

[x]Shoot density = (number of yellow nutsedge shoots per plot) / plot area (1.39 m^2 or 15 ft^2).

[w]Control was estimated by comparing treated plots with non-sprayed bare soil plots using a scale from 0% (no control) to 100% (complete control) in 10% increments.

[v]Weeks after treatment

[u]Means within a column were compared using LSMEAN PDIFF (22) and grouped by using Saxton, A.M.'s SAS program (26).

[t]These non-sprayed plots were designed to evaluate effects of mulching on yellow nutsedge growth.

that cypress mulch contained more small particles than pine nuggets, allowing for easier emergence of yellow nutsedge (Table 1). Difference in their allelopathic traits can be another attribute; however, ranking of allelopathic strength of these two mulches was inconsistent in prior studies (8, 11).

Interactions were found between halosulfuron placement by mulch at 2, 8, and 12 WAT. At 2 WAT, applying halosulfuron under shredded cypress resulted in less shoot density compared with applying above this mulch (Table 4). However, this placement effect was not significant in pine nuggets or pine straw mulched plots. Similar placement effects were significant at the lower rate with pine nuggets at 8 and 12 WAT, and with pine straw at 12 WAT, but not with cypress mulch (Table 4). In all other occasions, applying halosulfuron under mulch resulted in similar control as applying above.

Longevity of halosulfuron on soil surfaces is not well documented. In general, herbicides dissipate via several pathways including: photodegradation, chemical degradation, microbial degradation, leaching, and volatilization. Herbicide persistence is dependent on several factors including light, temperature, and soil moisture. Photodegradation occurs when ultraviolet (UV) light breaks chemical bonds of the herbicide's active ingredient. Secondary molecules resulting from the cleavage of the parent molecule are generally less effective in providing weed control. Grey et al. (16) reported that halosulfuron dissipation was more rapid on bare soil than on soil under low-density polyethylene mulch, possibly because of lower light intensity. In this study, light intensity was dramatically reduced by all mulch types compared to bare soil (Table 2), thus potentially reducing UV degradation of halosulfuron. In addition, although no previous studies have evaluated effects of moisture on herbicide efficacy, higher moisture under mulch layers may also increase yellow nutsedge-herbicide contact time. In spite of these possibilities, in most cases, applying under mulch resulted in similar control as applying above mulch.

Halosulfuron applied at the higher rate resulted in similar yellow nutsedge shoot density as the lower rate in most cases throughout 14 weeks of evaluation except that, at 12 WAT, when applied above pine straw, the higher rate resulted in a lower shoot density than the lower rate (Table 4). This is consistent with Experiment 1. Yellow nutsedge control at 14 WAT ranged from 86 to 97% in herbicide plus mulch plots (Table 4), which were higher than the control effects estimated at 12 WAT in Experiment 1. Yellow nutsedge plants at the time of treatment were smaller in Experiment 2 than Experiment 1, which may have contributed to these greater control effects.

Responses of ornamental plants to treatments. Responses of ornamental plants to halosulfuron and mulching were species specific.

Daylily. At 24 WAT in both experiments, daylily plant size was not affected by herbicide application or mulching (data

Table 5. **Plant responses to halosulfuron and mulch treatments in Experiments 1 and 2, including dry weight of 'Stella de Oro' daylily at 16 weeks after treatment (WAT) in Experiment 2; leaf chlorosis ratings of 'Mystery' gardenia at 4 WAT averaged over two experiments and number of flowers at 8 WAT in Experiment 2; and dry weight of 'Big Blue' liriope in Experiment 2.**

Treatment[z]	Daylily	Gardenia		Liriope
	Dry weight g	Leaf chlorosis[y]	Flower no.[x]	Dry weight g
Rate (kg·ha^{-1})	**16 WAT**	**4 WAT**	**8 WAT**	**16 WAT**
0	1.83a[w]	3.4	8.5	8.07
0.038	0.96b	4.0	8.3	7.68
0.075	0.99b	3.8	10.0	7.16
$LSD_{0.05}$	0.9	NS	NS	NS
Mulch				
Bare soil	1.9	4.2a	1.5b	12.48a
Pine nugget	1.34	2.6b	7.3a	6.42b
Pine straw	1.11	2.2b	7.3a	7.75b
Shredded cypress	1.15	2.0b	9.4a	7.42b
$LSD_{0.05}$	NS	1.5	5.6	4.7

[z]No interactions were found among treatment factors, and placement had no effect on plant responses. Therefore, means under halosulfuron rates were averaged over mulch type and placement. Means under mulch type were averaged over rate and placement.

[y]Leaf chlorosis was rated with a scale from 0 to 5, where 0 was no yellowing, 1 was 1 to 10% yellowing, 2 was 11 to 20%, 3 = 21 to 30%, 4 was 31 to 40%, and 5 was 50% or more leaves turned yellow. Because no year by data interaction was found, data recorded at 4 WAT from Experiments 1 and 2 were pooled before analysis.

[x]A gardenia flower was counted when the first layer of the petals unfolded to reveal center petals.

[w]Means separation within columns for herbicide rates across mulch type and herbicide placement, or for mulch type across herbicide rate and placement by using Tukey's Honestly Significant Difference test at $\alpha \leq 0.05$. NS indicates no significant difference among treatments were found.

not shown). However, overhead application of halosulfuron at both rates decreased aboveground dry weight of daylily plants at 16 WAT (Table 5). However, dry weights among treated and non-sprayed plants at 24 WAT were similar (data not shown). Adverse effect of halosulfuron on daylily growth in container production has been reported by McDaniel et al. (21). The growth reduction was rate dependent and occurred during the first 8 weeks after application in that study. The effect found in this study was similarly transient.

Gardenia. Leaf chlorosis in gardenia was observed prior to halosulfuron application, which was possibly caused by transplant stresses (data not shown). Leaf chlorosis estimated at 2 WAT in Experiment 1 was neither affected by herbicide nor mulching (data not shown). However, at 4 WAT, averaged over two experiments, mulching reduced the level of leaf chorosis compared to plants in bare soil (Table 5). By 8 WAT in Experiment 2, gardenias in mulched plots had more flowers than those in bare soil plots. As measured in Experiment 1 over 8 days in June, pine nugget mulch decreased daily maximum soil temperatures and all mulch types increased daily minimum soil temperatures (Table 2). Soil moisture was also higher in mulched plots compared to non-sprayed bare soil. These changes by mulching may have alleviated transplant stress in gardenia. Richardson et al. (25) reported similar results for 'August Beauty' gardenia, as growth was slightly improved when mulched with pine bark nuggets.

Overhead application of halosulfuron had no effect on gardenia plant size in both experiments and on flower numbers in Experiment 2. Gardenia has been reported to tolerate several herbicides registered for nursery or landscape use, such as flumioxazin, oxyfluorfen, oxadiazon, and metolachlor (9, 25).

Liriope. Minor injury was observed in liriope at both rates as bleached foliage, which was transient and gradually disappeared by 8 WAT (data not shown). Plant size in both experiments and dry weight in Experiment 2 were not affected by halosulfuron. Similar leaf injury in container-grown liriope was reported by McDaniel et al. (21) and Altland et al. (1) and the degree of injury was rate dependent. Liriope dry weight at 16 WAT in Experiment 2 was negatively affected by mulching regardless of mulch type (Table 5). This effect was still significant at 24 WAT (data not shown). As reported by other studies, allelopathic chemicals in fresh mulch may cause negative response in ornamental plants. Pine bark nuggets were reported to reduce Japanese privet growth (5). However, allelopathic effects to liriope from organic mulches have not been reported.

Halosulfuron applied at 0.038 kg ai·ha^{-1} (0.034 lb ai·A^{-1}) provided similar POST nutsedge control as 0.075 kg ai·ha^{-1} (0.067 lb ai·A^{-1}). Most combinations of organic mulch and halosulfuron provided > 80% control for up to 8 weeks in Experiment 1 when yellow nutsedge was about 12 cm (5 in) tall, and up to 14 weeks in Experiment 2 when yellow nutsedge was about 6 cm (2 in) tall. In most cases, applying halosulfuron before mulching resulted in similar yellow nutsedge control as applying after mulching. In a few occasions, though, applying halosulfuron before mulching did improve control efficacy. Applying halosulfuron before mulching is preferred as this should reduce losses by photodecomposition or volatility. Overhead application of halosulfuron caused foliage injury in liriope, and reduced aboveground dry weight in daylily, but these adverse effects were transient. If temporary injury can be tolerated, halosulfuron can be applied around daylily and liriope plants. Mulch application improved gardenia transplant quality as indicated by reduced leaf chlorosis and increased flower number. However, liriope may be sensitive to the allelopathic chemicals from the mulches tested types as its dry weight was significantly reduced although plant size was not affected.

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