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Selective Herbicides for Bald Cypress Restoration and Cultivation

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Studies were conducted in 2007 and 2008 to evaluate herbicides having both PRE and POST activity for selective weed control in bald cypress plantings. Five herbicides were applied at two or three rates at two different timings. The first timing was to dormant seedlings without foliage and prior to weed emergence (i.e., PRE). The second timing was to foliated seedlings with established weed seedlings present (i.e., POST). Herbicide treatments included aminopyralid at 70 and 120 g ae ha^{-1}, hexazinone at 420 and 560 g ai ha^{-1}, imazapyr at 140 and 210 g ae ha^{-1}, sulfometuron methyl at 110, 160, and 210 g ai ha^{-1}, and flumioxazin at 290 and 430 g ai ha^{-1}. Herbicide rate had little effect on vegetation control. PRE-applied sulfometuron methyl was most effective, providing nearly complete control of graminoids and broadleaves at 60 d after treatment (DAT). POST-applied treatments were generally less effective, though in the 2008 study imazapyr and sulfometuron methyl resulted in approximately 60% bare ground at 60 DAT. Growth of bald cypress seedlings was enhanced by both PRE- and POST-applied sulfometuron methyl, flumioxazin, or hexazinone and by PRE imazapyr. The best bald cypress growth response followed POST-applied sulfometuron methyl at 210 g ha^{-1}, which resulted in 63 cm^3 mean volume index, more than fivefold greater than the nontreated check. Aminopyralid caused severe and lasting seedling injury. POST-applied imazapyr resulted in fasciculation and no growth benefit, despite providing the most efficacious weed control among POST treatments. Survival and growth of bald cypress can be greatly enhanced with a single selective herbicide treatment using sulfometuron methyl, flumioxazin, or hexazinone applied before or following foliation in the spring.

Nomenclature: Aminopyralid; flumioxazin; hexazinone; imazapyr; sulfometuron methyl; bald cypress, *Taxodium distichum* (L.) Rich var. *distichum*.

Key words: Afforestation, herbicide injury, postemergence, preemergence, reforestation, vegetation control, weed control.

En 2007 y 2008, se realizaron estudios para evaluar herbicidas con actividad PRE y POST para el control selectivo de malezas en plantaciones de *Taxodium distichum*. Cinco herbicidas fueron aplicados a dos o tres dosis y en dos momentos diferentes. El primer momento fue cuando las plántulas estaban latentes sin follaje y antes de la emergencia de malezas (i.e. PRE). El segundo momento fue cuando las plántulas tenían follaje y había plántulas de malezas establecidas (i.e. POST). Los tratamientos de herbicidas incluyeron aminopyralid a 70 y 120 g ae ha^{-1}, hexazinone a 420 y 560 g ai ha^{-1}, imazapyr a 140 y 210 g ae ha^{-1}, sulfometuron methyl a 110, 160 y 210 h ai ha^{-1}, y flumioxazin a 290 y 430 g ai ha^{-1}. La dosis de herbicida tuvo poco efecto sobre el control de la vegetación. Sulfometuron methyl aplicado PRE fue el más efectivo alcanzando cerca de un control completo de graminoides y hojas anchas a 60 días después del tratamiento (DAT). Tratamientos aplicados POST fueron generalmente menos efectivos, aunque en el experimento del 2008, imazapyr y sulfometuron methyl resultaron en aproximadamente 60% de suelo desnudo a 60 DAT. El crecimiento de *T. distichum* fue mejorado por las aplicaciones de sulfometuron methyl, flumioxazin o hexazinone en aplicaciones PRE y POST y de imazapyr PRE. La mejor respuesta en crecimiento de *T. distichum* se dio después de la aplicación POST de sulfometuron methyl a 210 g ha^{-1}, la cual resultó en un índice de volumen promedio de 64 cm^3, el cual fue más de cinco veces mayor que el tratamiento testigo no tratado. El aminopyralid causó daños severos y prolongados en las plántulas. Imazapyr aplicado POST resultó en crecimiento limitado y anormal (entrenudos cortos y ramificación) a pesar de proveer el control de malezas más eficaz entre los tratamientos POST. El crecimiento y supervivencia de *T. distichum* puede ser ampliamente mejorado con aplicaciones individuales de herbicidas usando sulfometuron methyl, flumioxazin o hexazinone antes o inmediatamente después de la producción de follaje en la primavera.

Bald cypress is a deciduous coniferous tree belonging to the *Cupressaceae* (cypress) family (USDA-NRCS 2011a), appreciated for its size, beauty, and longevity. Its native range extends along the Atlantic and Gulf Coastal Plains from southern Delaware to southeastern Texas and in the Mississippi Valley to southern Illinois and southwestern Indiana (Wilhite and Toliver 1990). The volume of cypress growing stock on commercial forest land totaled 155.7 million m^3 in 1980, with more than half growing in Florida and Louisiana. An estimate of the total area in cypress ranged from 1.2 to 2.0 million ha (Williston et al. 1980).

Cypress swamps are of great ecological importance for flood control, groundwater recharge, and enhancing water quality by nutrient removal in dendroremediation (Duryea and Hermansen 2006). According to Brandt and Ewel (1989), the use of cypress swamps for additional treatment of secondary treated municipal waste water appears compatible with forest utilization. Additionally, cypress swamps provide habitat for many wildlife species, as well as recreational and educational opportunities for a public that is increasingly interested in ecotourism (Duryea and Hermansen 2006).

Bald cypress heartwood has long been known for durability, resistance to decay, attractive appearance, and workability

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(Ewel et al. 1989). Most of the old-growth bald cypress trees were harvested during the first half of the 20th century (Duryea and Hermansen 2006). Harvesting of second-growth cypress has increased since the early 1980s due to increasing demand for its lumber and a growing market for landscape mulch (Vince and Duryea 2004). In Florida, out of about 1.2 million m^3 of cypress wood harvested annually (Brown 1996), 53% is cut for dimensional lumber and 47% is chipped for landscape mulch (Duryea and Hermansen 2006). According to Duryea (2000), about 60% of landscape mulch sold in Florida is cypress. However, there is controversy over the use of cypress trees for mulch (Anonymous 1996). A coalition of environmental groups contends that harvesting the trees for mulch is contributing to the destruction of Louisiana's fragile wetlands (Neveln 2007). In response to their concerns, several retailers in Louisiana imposed severe restrictions on selling cypress mulch (Anonymous 2008) and the U.S. Army Corps of Engineers halted cypress logging activity (Neveln 2007).

There is continuous debate about the sustainability of logged cypress swamps (Anonymous 2008; Brandt and Ewel 1989; M. Dunn, unpublished data; Sternitzke 1972). In Florida, the net annual 1.2 million m^3 cypress harvest exceeded the net annual growth of 1.1 million m^3 (Brown 1996), endangering the sustainability of the natural cypress resource in that state. Because natural regeneration is unpredictable, there is growing interest in reforestation of harvested cypress wetlands by planting seedlings (Brandt and Ewel 1989; Vince and Duryea 2004). Several researchers reported successful restoration of cypress swamps, even following severe disturbance (Kolka et al. 1998; Nelson et al. 2000).

An alternative to logging natural cypress stands is cypress cultivation, which is particularly applicable to mulch production since small diameter stems may be harvested every 5 to 10 yr with reproduction provided by stump sprouts. In a study by Krinard and Johnson (1976), the growth of a cypress plantation on a periodically flooded site was better than that of dominant trees in natural stands. However, the plantation was cultivated three to four times annually to ensure good growth. Rockwood et al. (2001) demonstrated the potential for commercial cypress plantations on non-wetland sites for the production of saw timber and mulch. According to Williston et al. (1980) bald cypress is well adapted to growth in even-aged plantations on a variety of soils but requires vegetation control using herbicides to foster rapid growth and ensure survival. Vince and Duryea (2004) share the opinion that bald cypress can be grown on many upland sites but may require vegetation control during establishment. Also Wilhite and Toliver (1990) state that a year or more of vegetation control may be necessary for bald cypress planted outside of swamps.

Besides its ecological and commodity value, bald cypress is also a versatile ornamental tree, recommended as a tough native plant for landscape use from Florida to Indiana (Flint 1994; Meerow and Norcini 2009), and it is gaining attention with increased popularity of native plant landscaping. Bald cypress is an excellent choice for landscaping coastal areas of southeastern United States because it is free of serious pests and has the greatest flood tolerance of all tree species, yet established tress can also tolerate drought (Broschat et al 2007; Phillips 2007). The Society of Municipal Arborists selected bald cypress as the 2007 Urban Tree of the Year, suitable for USDA Hardiness Zones 4 to 9 (Phillips 2007).

There is an obvious need to develop selective weed control treatments for bald cypress to facilitate reforestation, cultivation of mulch crops, and landscape plantings. Even though most authors agree that control of competing vegetation is critical to young cypress seedling survival and growth, there are no published studies identifying selective weed control treatments for bald cypress.

The objective of the two studies conducted in consecutive years was to evaluate five herbicides known to have conifer selectivity for selective weed control in bald cypress plantings. Herbicide efficacy and bald cypress tolerance were examined at two different application timings and for two or three rates of herbicides having both PRE and POST activity.

Materials and Methods

Study Area. Two studies were located at an upland, old-field site at the University of Florida, North Florida Research and Education Center, south of the city of Quincy (30°32′48″N, 84°35′52″W) at approximately 70 m elevation. This location has a temperate climate with highest temperatures in July (mean 27 C), lowest temperatures in January (mean 10 C), and 1,430 mm average annual precipitation (NOAA 2002). The soil is an Orangeburg-Norfolk complex (fine-loamy, kaolinitic, thermic Typic Kandiudults) (USDA-NRCS 2011b). Soil analyses confirmed medium to high concentrations of most macro- and micronutrients and a pH of 5.9. No fertilizer was applied in either study. Site preparation started in the fall preceding each bald cypress planting and consisted of a broadcast application of 4.4 kg ae ha^{-1} isopropylamine salt of glyphosate (Accord® XRT, 480 g ae L^{-1}, Dow AgroSciences LLC, Indianapolis, IN), followed by plowing and disking after 6 wk and another disking and harrowing 2 wk before planting.

Treatments and Experimental Design. Separate studies were conducted in 2007 and 2008, following a similar protocol to test: (1) various herbicides; (2) two distinct application timings relative to both bald cypress winter dormancy and weed emergence; and (3) herbicide application rate. Sudies consisted of a factorial treatment arrangement, and a randomized complete block design with four replications was used. Herbicides were applied in late winter prior to weed emergence (PRE) over bald cypress seedlings prior to foliage emergence (hereafter referred to as dormant), or to foliated seedlings after weed emergence (POST) in spring. In the 2007 study, four herbicides were tested and in the 2008 study a fifth herbicide, flumioxazin, was added (Table 1).Each herbicide was tested at two application rates, within the range labeled for other conifers, hereafter referred to as the low or high herbicide rate. In 2008, a third sulfometuron methyl (hereafter referred to as sulfometuron) rate was included (i.e., extra high) because of promising results with the high rate of this herbicide in 2007 and a need to ascertain the rate threshold for bald cypress tolerance.

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Table 1. Treatments evaluated PRE- and POST-applied for efficacy in newly planted bald cypress plantations near Quincy, FL, in 2007 and 2008.

Treatment[a,b]					
Herbicide	Relative rate	Actual rate	Trade name	Content	Manufacturer
		g ha^{-1}		ae/ai	
Aminopyralid[c]	Low (L)	70 ae	Milestone® VM	240 g L^{-1}	Dow AgroSciences LLC, Indianapolis, IN
Aminopyralid	High (H)	120 ae	Milestone® VM	240 g L^{-1}	http://www.dow.com/
Hexazinone	Low (L)	420 ai	Velpar® L	240 g L^{-1}	DuPont, Wilmington, DE
Hexazinone	High (H)	560 ai	Velpar® L	240 g L^{-1}	http://www2.dupont.com/DuPont_Home/en_US/
Imazapyr[d]	Low (L)	140 ae	Arsenal® AC	480 g L^{-1}	BASF, Research Triangle Park, NC
Imazapyr	High (H)	210 ae	Arsenal® AC	480 g L^{-1}	http://agproducts.basf.us/
Sulfometuron methyl	Low (L)	110 ai	Oust® XP	75%	DuPont, Wilmington, DE
Sulfometuron methyl	High (H)	160 ai	Oust® XP	75%	http://www2.dupont.com/DuPont_Home/en_US/
Sulfometuron methyl	Extra high (XH)[e]	210 ai	Oust® XP	75%	
Flumioxazin	Low (L)[e]	290 ai	SureGuard®	51%	Valent USA Corp., Walnut Creek, CA
Flumioxazin	High (H)[e]	430 ai	SureGuard®	51%	http://www.valent.com/
Nontreated check	—	—	—	—	

[a] Rates of all herbicides tested are within the range labeled for use in other conifers.

[b] Nonionic surfactant at 0.25% (v/v) was added to every herbicide-containing treatment.

[c] Triisopropanolammonium salt.

[d] Isopropylamine salt.

[e] Tested in 2008 only.

Treatments were assigned to plots that were 1.6 m wide and 22.6 m long and were separated by 1.5-m-wide nontreated buffers on the long dimension. Twelve bald cypress seedlings were planted 1.6 m apart through the center of the plot's long dimension, starting 1.2 m from the plot ends. Container-grown, 1-yr-old seedlings were hand-planted on January 25 in the 2007 study and on January 28 in the 2008 study.

PRE herbicide treatments were applied on February 9, 2007, and on February 19, 2008, approximately 2 and 3 wk after planting seedlings, respectively. POST treatments were applied on April 26, 2007, and April 21, 2008, approximately 13 and 12 wk after planting, respectively. Herbicides were applied using a CO_2-pressurized research sprayer equipped with a four-nozzle boom fitted with 8002 VS flat-fan nozzles on 46-cm centers, providing a 1.6-m effective swath. A ground speed of 4.8 km hr^{-1} was maintained using a metronome. The regulator was set to 207 kPa to produce 2.2 L min^{-1} through all four nozzles on the boom, thus providing 150 L ha^{-1} total spray volume. Spraying was done during calm conditions in the morning. Herbicide spray solutions contained 0.25% v/v nonionic surfactant (Timbersurf 90, Loveland Products, Greeley, CO).

Assessments. Groundcover visual estimates of the area free of live vegetation (percent bare ground), and percent live cover for graminoids (grasses and sedges) and broadleaves were made in four 1-m by 1-m sampling plots in each treatment plot. Groundcover estimates were done at 60 d after treatment (DAT) for PRE and POST applications (in April and June, respectively) and at 120 DAT for PRE applications (in June) by two evaluators. The dominant species within each vegetation group were recorded in the nontreated checks at these times.

Seedling injury symptoms were assessed at 60 DAT for PRE (in April) and POST (in June) applications. Each seedling was assigned an injury severity index (0 to 4) for each of the following symptoms: foliation inhibition, epinasty, fasciculation, foliar necrosis, defoliation, and leader die-back. The injury indices 0, 1, 2, 3, and 4 corresponded to none, slight, moderate, severe, and complete symptoms evident.

Bald cypress seedlings were measured 10 d after planting and at the final evaluation in July, approximately 6 mo after planting. At both initial and final evaluations, stem diameter at 5 cm aboveground (GLD_5) and live stem height (Ht) of all live seedlings were measured. Stem volume index was calculated as $GLD_5^2 \times Ht$. During the final evaluation each seedling was also classified into one of three condition categories: healthy, alive but not healthy, or dead. The percentage of seedlings in the first category (in relation to the number of planted seedlings) was analyzed as percent healthy seedlings, whereas the percentage of seedlings in the first two categories combined was analyzed as percent survival.

Data Analyses. Statistical analyses were performed with SAS 9.2 software (SAS 2007). ANOVA (for groundcover, seedling health and survival variables) or analysis of covariance (for seedling volume index, with the initial volume index as a covariate) was conducted, using mixed models (proc mixed), with blocks as a random effect (Littell et al. 2006). Percentage data were transformed using the arcsin square-root transformation and volume index data were transformed using the natural logarithm of $X + 1$, where X is the volume index value, to normalize variance. The back-transformed least square means (LS-means) have been reported. The critical level of significance for ANOVA and LS-means comparisons was $\alpha = 0.05$. Fisher's protected LSD was used to compare LS-means.

Two series of analyses were performed for each dependent variable. The first was a factorial analysis of a balanced design, excluding the nontreated check and extra high sulfometuron rate in the 2008 study, to evaluate the significance of the fixed main effects (herbicide, application timing, and herbicide rate) and their interactions. Groundcover assessments at 120 DAT were done only for the PRE applications, so application

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Table 2. Prevalence of bare ground or groundcover with graminoids and broadleaf species over time, following treatments applied either PRE over dormant bald cypress seedlings, or POST over foliated seedlings in plantation culture near Quincy, FL.

Treatment[a]			Bare ground			Graminoids			Broadleaves		
			60 DAT		120 DAT	60 DAT		120 DAT	60 DAT		120 DAT
Herbicide	Relative rate[b]	Actual rate	PRE[c]	POST[c]	PRE	PRE	POST	PRE	PRE	POST	PRE
		g ha^{-1}	% groundcover								
2007 study											
Aminopyralid	L	70 ae	89 b[d]	10 de	12 bc	10 a	75 ab	82 ab	1 b	12 ab	4 bc
Aminopyralid	H	120 ae	92 b	8 e	15 bc	7 a	85 a	80 b	1 b	6 bc	4 b–d
Hexazinone	L	420 ai	90 b	9 de	16 bc	9 a	87 a	83 ab	0 b	3 cd	0 d
Hexazinone	H	560 ai	92 b	13 c–e	7 c	8 a	86 a	92 a	0 b	0 d	1 cd
Imazapyr	L	140 ae	94 b	30 a	12 bc	5 a	55 c	81 b	1 b	10 a–c	4 bc
Imazapyr	H	210 ae	94 b	44 a	13 bc	6 a	38 d	82 ab	0 b	17 a	4 b–d
Sulfometuron[e]	L	110 ai	100 a	18 cd	22 b	0 b	69 bc	60 c	0 b	10 a–c	16 a
Sulfometuron	H	160 ai	100 a	23 bc	48 a	0 b	61 bc	45 c	0 b	14 ab	6 b
Nontreated check	—	—	90 b	7 e	20 b	5 a	75 ab	57 c	5 a	15 a	22 a
2008 study											
Aminopyralid	L	70 ae	79 cd	41 bc	31 bc	15 ab	51 bc	57 cd	6 b	7 c–f	10 bc
Aminopyralid	H	120 ae	80 b–d	31 c	29 cd	16 ab	64 ab	64 bc	4 b	5 df	7 b–d
Hexazinone	L	420 ai	79 cd	28 c	23 c–e	20 ab	64 ab	72 ab	1 b	5 df	5 cd
Hexazinone	H	560 ai	84 b–d	30 c	23 c–e	14 ab	67 a	69 ab	2 b	2 f	6 cd
Imazapyr	L	140 ae	75 de	57 a	17 e	23 a	22 e	77 a	2 b	19 ab	6 b–d
Imazapyr	H	210 ae	79 cd	57 a	21 de	19 ab	30 de	72 ab	2 b	12 b–d	7 b–d
Sulfometuron	L	110 ai	98 a	54 ab	42 ab	1 c	34 de	52 d	1 b	11 b–d	6 cd
Sulfometuron	H	160 ai	99 a	56 a	47 a	1 c	28 de	37 e	0 b	15 bc	15 b
Sulfometuron	XH	210 ai	98 a	64 a	45 a	1 c	25 e	47 de	1 b	9 cd	8 b–d
Flumioxazin	L	290 ai	87 bc	34 c	27 c–e	11 b	55 a–c	70 ab	1 b	9 cd	2 d
Flumioxazin	H	430 ai	89 b	29 c	28 cd	10 b	65 ab	69 ab	0 b	5 df	2 d
Nontreated check	—	–	64 e	29 c	29 cd	11 b	41 cd	41 e	25 a	29 a	29 a

[a] Nonionic surfactant at 0.25% (v/v) was added to every herbicide-containing treatment.

[b] Abbreviations: L = low, H = high, XH = extra high rate; refer to Table 1.

[c] PRE applications were on February 9 and 19 for 2007 and 2008, respectively; POST applications were on April 26 and 21, respectively. One-year-old dormant seedlings had been planted in late January of each year.

[d] For each study, LS-means within a column followed by the same letter are not significantly different using Fisher's protected LSD at $\alpha = 0.05$.

[e] Sulfometuron = sulfometuron methyl.

timing was not a factor in analyses of these data. The second analysis series compared all tested treatments, including the nontreated check and extra high sulfometuron rate in the 2008 study. Orthogonal contrasts were used to test for the significance of planned comparisons among these treatments, such as differences among PRE or among POST treatments, comparisons to the nontreated check, or the significance of herbicide rate and timing effects for individual herbicides.

Results and Discussion

Weed Control. The ANOVA revealed highly significant effects of herbicide, application timing, and the herbicide by timing interaction at 60 DAT, as well as a highly significant effect of herbicide at 120 DAT, on all groundcover variables (percent bare ground, graminoid, and broadleaf cover) in both 2007 and 2008 studies. The effects of rate or any interaction with rate were not significant for any of these variables in either study, except for the highly significant ($P = 0.004$) effect of the rate by herbicide interaction on percent bare ground at 120 DAT in 2007.

Bare Ground. In both studies sulfometuron resulted in the greatest percent bare ground among PRE herbicides at 60 DAT, regardless of the herbicide rate (Table 2). In 2007, percent bare ground was significantly more for sulfometuron than for a relatively weed-free (90%) nontreated check, caused by a droughty period preceding evaluation. In 2008, greater percent bare ground was recorded at 60 DAT for all PRE treatments, except the low imazapyr rate, as compared to the nontreated check. Sulfometuron exhibited the longest lasting herbicidal effect. It was the only herbicide resulting in greater percent bare ground than the nontreated check at 120 DAT. In 2007, percent bare ground for the high sulfometuron rate at 120 DAT was more than twice the percent bare ground for the low rate, which was responsible for the significance of the herbicide by rate interaction. Among POST herbicides, the greatest percent bare ground at 60 DAT was observed for imazapyr in 2007 and for imazapyr and sulfometuron in 2008. This is consistent with imazapyr being more effective in most situations when applied POST (Beardmore et al. 1991).

Similar to our results, Kuhns and Harpster (2002b) reported effective, long-lasting weed control with PRE sulfometuron in young Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] and Fraser fir [*Abies fraseri* (Pursh) Poir.] Christmas trees. They rated weed control as "excellent" 13 wk after treatment (WAT) with PRE sulfometuron at 80 g ha^{-1}, a rate lower than the lowest one in our studies. The results of

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Table 3. Bald cypress seedling injury index for selected symptoms following treatments applied either PRE over dormant bald cypress seedlings, or POST over foliated seedlings in plantation culture near Quincy, FL.

	Foliation inhibition		Epinasty		Fasciculation		Foliar necrosis		Defoliation	
Herbicide[a]	PRE[b]	POST[b]	PRE	POST	PRE	POST	PRE	POST	PRE	POST
	Injury index[c]									
2007 study										
Aminopyralid	0.5 a*[d]	0.0 a	2.2 a*	0.6 a*	0.0 a	0.0 b	0.0 a	0.8 b*	0.0 a	1.4 a*
Hexazinone	0.0 b	0.0 a	0.0 b	0.0 b	0.0 a	0.0 b	0.0 a	1.4 a*	0.1 a	1.2 a
Imazapyr	0.0 b	0.1 a	0.0 b	0.0 b	0.0 a	0.3 a*	0.0 a	0.5 c*	0.0 a	1.1 a
Sulfometuron[e]	0.0 b	0.0 a	0.0 b	0.0 b	0.0 a	0.0 b	0.0 a	0.1 d	0.0 a	0.2 b
Nontreated check	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.7
2008 study										
Aminopyralid	1.9 a*	0.0 a	1.7 a*	0.2 a*	0.0 a	0.0 b	0.0 a	0.7 a	0.0 d	3.3 a*
Hexazinone	0.1 c	0.0 a	0.0 b	0.0 b	0.0 a	0.0 b	0.0 a	0.8 a	0.0 d	2.0 b
Imazapyr	0.1 c	0.1 a	0.0 b	0.0 b	0.0 a	0.5 a*	0.0 a	0.2 b*	0.0 d	0.7 c*
Sulfometuron	0.4 b*	0.0 a	0.0 b	0.0 b	0.0 a	0.0 b	0.0 a	0.1 b*	0.0 d	0.1 d*
Flumioxazin	0.1 c	0.0 a	0.0 b	0.0 b	0.0 a	0.0 b	0.0 a	0.3 b*	0.0 d	0.7 c*
Nontreated check	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	2.2

[a] Nonionic surfactant at 0.25% (v/v) was added to every herbicide-containing treatment.

[b] PRE applications were on February 9 and 19 for 2007 and 2008, respectively; POST applications were on April 26 and 21, respectively. Injury was evaluated 60 DAT for both PRE and POST applications. One-year-old dormant seedlings had been planted in late January of each year.

[c] Injury indices 0, 1, 2, 3, and 4 correspond to none, slight, moderate, severe, and complete, respectively. Data pooled over the low and high rates of each herbicide; refer to Table 1.

[d] For each year-study, LS-means within a column followed by the same letter are not significantly different using Fisher's protected LSD at $\alpha = 0.05$.

[e] Sulfometuron = sulfometuron methyl.

* LS-means are significantly different from the nontreated check using Fisher's protected LSD at $\alpha = 0.05$.

Kuhns and Harpster (2002a) with flumioxazin were also consistent with ours. They reported "good to excellent" weed control in young Douglas-fir and Fraser fir trees up to 7 WAT, but not at 13 WAT with PRE flumioxazin rates (280 and 430 g ha^{-1}), which were also effective in our 2008 study up to 60 DAT, but not at 120 DAT.

Graminoid Cover. The best graminoid control among PRE herbicides was provided by sulfometuron at all rates (Table 2). This led to the best overall weed control, since graminoids constituted a predominant weed group in both studies. Sulfometuron was the only herbicide that resulted in less graminoid cover than the nontreated check at 60 DAT. At 120 DAT other herbicide treatments had greater graminoid cover than the check. For POST applications, the best graminoid control was achieved with imazapyr, the only herbicide that resulted in less graminoid cover than the nontreated check at 60 DAT in 2007. In the 2008 study significantly less graminoid cover than the check was also recorded following the extra high sulfometuron rate.

Broadleaf Cover. Broadleaf cover was reduced by all PRE herbicides as compared to the nontreated check at 60 and 120 DAT in both studies (Table 2). Effective control of competing broadleaves appeared to be responsible for the increase in graminoid cover, as compared to the nontreated check at 120 DAT, for those herbicides that did not provide long-lasting graminoid control. Among POST-applied herbicides, hexazinone was most effective in controlling broadleaves. However, in 2008 all POST-applied herbicides resulted in less broadleaf cover than the nontreated check at 60 DAT.

Weed Species Composition. The weed species composition was similar in both the 2007 and 2008 studies. Numerous graminoid and broadleaf species were present, but only a few comprised the majority of weed cover. At the April assessment, the most common graminoids in nontreated checks were yellow nutsedge (*Cyperus esculentus* L.), bermudagrass [*Cynodon dactylon* (L.) Pers.], bahiagrass (*Paspalum notatum* Flueggé), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and southern crabgrass [*Digitaria ciliaris* (Retz.) Koel.]. By the June assessment graminoids became dominant, with increasing bahiagrass cover and the addition of yellow foxtail [*Setaria glauca* (L.) P. Beauv.] and a signal grass species (*Brachiaria* sp.). The most prevalent broadleaves in April were henbit (*Lamium amplexicaule* L.), yellow woodsorrel (*Oxalis stricta* L.), and swinecress [*Coronopus didymus* (L.) Sm.]. In June, stiff verbena (*Verbena rigida* Spreng.) became a dominant species as well; the cover by woodsorrel increased, while swinecress decreased and henbit disappeared.

Seedling Injury Symptoms. Since the herbicide rate effect was not significant for most symptoms in both studies, mean injury indices across low and high rates are reported, unless otherwise indicated. The significance of herbicide, application timing, and the herbicide by timing interaction varied by symptom.

The herbicide rate effect was significant for bald cypress fasciculation in 2007, with the high POST imazapyr rate resulting in significantly greater injury index than the low rate (0.4 and 0.2, respectively). In 2008, herbicide rate was significant for foliation inhibition, with the high PRE aminopyralid rate resulting in significantly greater injury index than the low rate (2.2 and 1.6, respectively).

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Table 4. Bald cypress seedling first-year survival,[a] health,[b] and stem volume index[c] following treatments applied either PRE over dormant seedlings, or POST over foliated seedlings in plantation culture near Quincy, FL.

Treatment[d]			Survival		Healthy seedlings		Volume index	
Herbicide	Relative rate[e]	Actual rate	PRE[f]	POST[f]	PRE	POST	PRE	POST
		g ha^{-1}	%		%		cm^3	
2007 study								
Aminopyralid	L	70 ae	37 c[g]	68 c	15 e	15 c	12 e	14 a
Aminopyralid	H	120 ae	39 c	76 c	17 e	21 bc	13 de	13 a
Hexazinone	L	420 ai	98 ab	75 c	73 b–d	34 bc	17 cd	13 a
Hexazinone	H	560 ai	95 ab	79 c	63 cd	38 bc	17 cd	14 a
Imazapyr	L	140 ae	96 ab	81 c	66 cd	37 bc	19 bc	14 a
Imazapyr	H	210 ae	95 ab	74 c	76 bc	47 b	19 c	16 a
Sulfometuron[h]	L	110 ai	100 a	99 a	91 ab	82 a	25 b	17 a
Sulfometuron	H	160 ai	100 a	99 a	98 a	80 a	35 a	19 a
Nontreated check	—		84 b	84 bc	45 d	45 b	14 de	14 a
2008 study								
Aminopyralid	L	70 ae	48 d	29 g	32 ef	14 e	11 fg	10 h
Aminopyralid	H	120 ae	46 d	43 fg	23 f	29 de	10 g	12 gh
Hexazinone	L	420 ai	75 bc	68 d–f	65 b–d	61 bc	17 c–e	20 ef
Hexazinone	H	560 ai	65 cd	52 e–g	59 cd	48 cd	17 cd	28 cd
Imazapyr	L	140 ae	78 a–c	91 bc	58 cd	75 b	14 d–g	16 fg
Imazapyr	H	210 ae	63 cd	98 a–c	54 c–e	74 b	15 d–f	16 fg
Sulfometuron	L	110 ai	86 a–c	99 ab	83 ab	99 a	19 b–d	37 bc
Sulfometuron	H	160 ai	78 a–c	99 ab	76 a–c	99 a	20 b–d	47 b
Sulfometuron	XH	210 ai	86 a–c	100 a	86 a	100 a	21 bc	63 a
Flumioxazin	L	290 ai	95 a	83 cd	87 a	79 b	24 b	20 ef
Flumioxazin	H	430 ai	92 ab	99 ab	91 a	96 a	35 a	25 de
Nontreated check	—		65 cd	65 d–f	47 de	47 cd	12 e–g	12 gh

[a] Survival = percentage of seedlings that are visually alive.

[b] Health = percentage of seedlings that are visually alive and free of injury symptoms.

[c] Stem volume index = $GLD_5^2 \times Ht$; GLD_5 = outside bark stem diameter 5 cm above the ground, Ht = live stem height.

[d] Nonionic surfactant at 0.25% (v/v) was added to every herbicide-containing treatment.

[e] Abbreviations: L = low, H = high, XH = extra high rate; refer to Table 1.

[f] PRE applications were on February 9 and 19 for 2007 and 2008, respectively; POST applications were on April 26 and 21, respectively. One-year-old dormant seedlings had been planted in late January of each year.

[g] For each study, LS-means within a column followed by the same letter are not significantly different using Fisher's protected LSD at α=0.05.

[h] Sulfometuron = sulfometuron methyl.

In both studies PRE aminopyralid applied to dormant bald cypress seedlings resulted in inhibition of foliation at 60 DAT (Table 3). In 2008, PRE sulfometuron also caused slight foliation inhibition. In both studies, significant epinasty resulted from aminopyralid application to dormant seedlings and, to a lesser degree, to foliated seedlings. Fasciculation was only observed after treating foliated seedlings with imazapyr.

Herbicide applications to dormant bald cypress seedlings did not result in foliar necrosis in either study (Table 3). In June 2007, 60 d following POST application to foliated seedlings, the greatest foliar necrosis index was recorded for hexazinone, followed by aminopyralid and imazapyr. Since hexazinone acts by inhibiting photosynthesis (Senseman 2007), foliar chlorosis followed by necrosis is commonly associated with this herbicide. The only POST treatment that did not result in significant foliar necrosis that year was sulfometuron. In June 2008, drought-induced foliar necrosis occurred in the nontreated check. Seedlings treated with POST hexazinone or aminopyralid showed the same degree of necrosis as the check, but seedlings treated with other POST herbicides had significantly less foliar necrosis than the nontreated check. The effective weed control provided by POST imazapyr and sulfometuron may in part explain this result.

In both studies, the only treatment that resulted in greater bald cypress defoliation than the nontreated check was POST aminopyralid. In June 2008, there was less defoliation 60 d after treating foliated seedlings with imazapyr, sulfometuron, or flumioxazin than in the nontreated check, as was recorded for foliar necrosis. Necrosis and defoliation observed in nontreated check in June, especially in 2008, may have been caused by insufficient soil moisture availability, due to weed pressure and low precipitation. Total precipitation during a month preceding June symptom evaluation was 80 mm in 2007 and 29 mm in 2008, in both years below normal.

We are unaware of any literature regarding herbicide phytotoxicity in bald cypress, but there is some information on the effect of the tested herbicides on young seedlings of other conifers. According to Kuhns and Harpster (2002a), the quality of young seedlings of Fraser fir and Douglas-fir was not affected by an over-the-top spring application of flumioxazin at 850 g ha^{-1}, a rate almost double the high rate tested in this study. The same authors (Kuhns and Harpster 2002b) reported some decrease in quality ratings, without severe damage, of Fraser fir and Douglas-fir following PRE, but not POST-applied sulfometuron at 39 or 78 g ha^{-1}, rates less than the low rate in our study. After

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testing various herbicides on young seedlings of several conifers in forest nurseries in the western United States, Steward (1977) concluded that coast redwood [*Sequoia sempervirens* (D. Don) Endl.], belonging to the same cypress family as bald cypress, was one of the two species most sensitive to herbicides. On the other hand, Aulgur (1994) reported "excellent" tolerance of young coast redwood seedlings to sulfometuron rates up to twice the highest rate in this study, resulting in lower mortality and injury compared to the nontreated check.

Seedling Growth Response. *Seedling Survival.* The herbicide effect on bald cypress seedling survival and the herbicide by application timing interaction were significant in both studies. Additionally, timing and the timing by rate interaction were marginally significant ($P = 0.046$ and $P = 0.053$, respectively) in 2008.

Practically all sulfometuron-treated bald cypress seedlings survived in 2007, regardless of application timing or rate (Table 4). With hexazinone and imazapyr greater survival occurred when seedlings were treated at the dormant rather than at foliated stage. The opposite was true in the case of aminopyralid for which, averaged across rates, survival was 38% for dormant and 72% for foliated seedlings. Among PRE herbicides applied to dormant seedlings, aminopyralid resulted in the least survival, about half that of the nontreated check. No other herbicide reduced survival, but only sulfometuron treatments increased survival compared to the nontreated check. When applied POST to foliated seedlings, sulfometuron resulted in greater survival than any other herbicide or the nontreated check.

In the 2008 study, POST application of sulfometuron or imazapyr to foliated bald cypress seedlings resulted in greater survival (average across rates 99 and 95%, respectively) compared to PRE application to dormant seedlings (82 and 71%, respectively). For other herbicides, application timing did not affect survival. As in 2007, aminopyralid caused the greatest mortality of all herbicides tested (Table 4). Among PRE-applied herbicides, flumioxazin resulted in the best survival, significantly greater than the nontreated check, but not different from sulfometuron or low rates of imazapyr or hexazinone. Following POST application of sulfometuron, imazapyr, or the high flumioxazin rate, survival exceeded the nontreated check.

Final Seedling Condition. The percentage of healthy bald cypress seedlings at study completion was significantly affected by herbicide and application timing, but not by herbicide rate. In 2008, the interaction between herbicide and application timing was highly significant. In general, the tendencies for percent healthy seedlings were similar to the tendencies for percent survival, even though the fraction of seedlings evaluated as healthy among surviving ones differed by herbicide. In both studies only about half of surviving seedlings were evaluated as healthy following aminopyralid treatment, whereas most of surviving sulfometuron-treated seedlings remained healthy (Table 4). These final seedling condition results corresponded with the severity of injury symptoms observed during the growing period.

At the final assessment in the 2007 study, dormant treated bald cypress seedlings were healthier (65%) than foliated treated (44%), when averaged across all herbicides and low and high rates. However, no effect of application timing was found for aminopyralid ($P = 0.808$), which resulted in only 15 to 21% healthy seedlings with either timing or rate (Table 4). Averaging across application timings and rates, sulfometuron resulted in the greatest (89%) and aminopyralid in the lowest (17%) percentage of healthy seedlings. Compared to the nontreated check, the percentage of healthy seedlings was greater for sulfometuron and lower for aminopyralid treatments (Table 4).

Similarly, in the 2008 study, when averaged across low and high herbicide rates, the percentage of healthy bald cypress seedlings after POST application to foliated seedlings was greatest for sulfometuron (99%) followed by flumioxazin (89%) and lowest for aminopyralid (21%). Also, among PRE herbicides applied to dormant seedlings, flumioxazin and sulfometuron resulted in the most (89 and 79%, respectively) and aminopyralid in the fewest (28%) healthy seedlings. Following PRE or POST sulfometuron or flumioxazin or POST imazapyr the seedlings were healthier than those in the nontreated check (Table 4). Unlike the 2007 study, sulfometuron and imazapyr treatments had more healthy seedlings after POST compared to PRE application, whereas application timing had no effect for other herbicides.

Seedling Volume Index. The herbicide and application timing effects on bald cypress seedling volume index, as well as the herbicide by timing interaction, were significant in both studies. In 2008, the herbicide rate effect was also significant ($P = 0.005$). That year, when averaged across all herbicides and both application timings, high rates produced significantly greater volume index (20.2 cm^3) than low rates (17.6 cm^3), possibly because of the greater weed pressure during spring than in 2007. According to orthogonal contrasts for individual herbicides, the rate effect was significant for sulfometuron in 2007 and 2008 and for flumioxazin in 2008, with seedling size generally increasing with increasing rates (Table 4).

In the 2007 study, PRE applications resulted in larger bald cypress seedlings than POST applications for all herbicides, except for aminopyralid, for which volume index was not affected by application timing. Among PRE-applied herbicides, the largest seedlings resulted from sulfometuron applications, followed by imazapyr, and were in both cases larger than the nontreated check (Table 4). No differences were found among POST treatments.

In the 2008 study, PRE applications resulted in greater bald cypress volume index than POST applications only for flumioxazin, whereas the opposite was true for sulfometuron and hexazinone. There was no application timing effect on volume index for aminopyralid or imazapyr. Compared to the nontreated check, greater volume index was observed following PRE or POST applications of sulfometuron, flumioxazin, or hexazinone (Table 4). Among the PRE herbicides, the high rate of flumioxazin resulted in the largest seedlings, whereas among POST herbicides the largest seedlings were observed with the extra high rate of sulfometuron.

The differences between 2007 and 2008 study results may be attributed to differences in precipitation and the effect that had on seedling vigor and weed pressure. Total rainfall from

January to March 2008 was double the amount for this period in 2007 (404 vs. 196 mm, respectively). Better bald cypress seedling vigor during 2008 may have improved herbicide tolerance at the time of POST application in April. Also, because weed cover in the nontreated check in April was greater in 2008 (64% bare ground) than in 2007 (90% bare), effective POST weed control may have resulted in greater bald cypress seedling responses. During the June evaluation in 2008, greater percent bare ground was observed for most POST (60 DAT) compared to PRE treatments (120 DAT).

Overall, sulfometuron consistently produced the best growth response, improving seedling survival and health condition and increasing tree volume. This could be expected because it provided good weed control and did not cause injury to bald cypress seedlings, other than minor inhibition of foliation. In the case of sulfometuron, seedling growth response corresponded with the degree of weed control and was positively affected by the rate increase. In the 2007 study, the high sulfometuron rate (160 g ai ha^{-1}) applied PRE was most effective, resulting in the greatest bare ground at June evaluation (48%) and the greatest seedling volume index (35 cm^3). In 2008, the POST-applied extra high sulfometuron rate (210 g ai ha^{-1}) was most effective, resulting in the greatest bare ground in June (64%) and the greatest volume index (63 cm^3). Similar relations were demonstrated by Aulgur (1994) for 1-yr-old container grown seedlings of coast redwood. Four months after over-the-top PRE application of sulfometuron at 210 g ai ha^{-1}, forb control was 80%, while seedling mortality and injury were 23 and 28%, respectively, as compared to 60 and 45% for the nontreated check. Increasing sulfometuron rates corresponded with increasing levels of vegetation control and seedling growth response. In another study of several conifers in the Pacific Northwest, including coast redwood, mean stem volume, basal diameter, and height of seedlings increased significantly with increasing area of weed control achieved by sulformeturon at 160 g ha^{-1} sulfometuron or hexazinone at 1.6 kg ha^{-1} (Rose and Ketchum 2002).

We are not aware of any studies regarding the effect of selective herbicides on bald cypress growth, but the results of McLeod et al. (2000) indicate that controlling herbaceous vegetation with glyphosate increased height of bald cypress seedlings in swamp restoration in Louisiana. Our results confirm bald cypress sensitivity to competing vegetation and underscore the importance of finding a balance between effective vegetation control and herbicide tolerance. Imazapyr was most effective for weed control among POST treatments but did not enhance seedling growth because of the direct negative effect on the seedlings, manifested by fasciculation. In contrast, PRE flumioxazin did not increase percent bare ground compared to the nontreated check in June (Table 2), but resulted in the greatest bald cypress volume index among 2008 PRE treatments, explained in part by a lack of significant phytotoxicity.

Aminopyralid was the most phytotoxic to bald cypress, even though the rates used were within the labeled range for use in other conifers (CDMS 2011). When applied to dormant bald cypress seedlings, it delayed foliation, caused epinasty, and eventually increased incidence of foliar necrosis, defoliation, and leader dieback. POST-treated foliated seedlings showed less severe epinasty, but also exhibited foliar necrosis and defoliation. Aminopyralid is an auxin-mimicking herbicide, for which epinasty is a typical symptom (Senseman 2007). Severe phytotoxicity resulted in the poorest seedling survival and health and lowest volume index for aminopyralid-treated seedlings, regardless of application timing, compared with other herbicide treatments and the nontreated check. However, weed control observed with aminopyralid was moderately good, comparable to that provided by hexazinone.

Among herbicides tested in our studies, Oust® XP (sulfometuron methyl; DuPont, Wilmington, DE) is the only one labeled for bald cypress (CDMS 2011), yet no published research supports this. Our data support the use of sulfometuron at the labeled rates over-the-top of young field-cultivated bald cypress seedlings and indicate the need to further examine the rate response and optimal timing for sulfometuron application. We have also shown that other selective herbicides, like flumioxazin, are viable alternatives for herbaceous weed control in bald cypress and should be considered for labeling.

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