Use of Glyphosate and Imazapyr for Cogongrass (*Imperata cylindrica*) Management in Southern Pine Forests

Patrick J. Minogue, James H. Miller, and Dwight K. Lauer

ABSTRACT

Cogongrass (*Imperata cylindrica* [L.] P. Beauv. var. major [Nees] C.E. Hubb) is one of the most invasive perennial grasses worldwide and has progressively infested managed and natural habitats in the mid-South over the past 100 years. To extend past research toward the goal of eradication on forested sites, we tested the most effective herbicides (glyphosate and imazapyr) over a 3-year study period in a series of low to very high rates at two application timings, all followed by one retreatment a year later. A commonly used combination of glyphosate and imazapyr was also tested at three spray volumes. Factorial studies were established at two sites in the Coastal Plain of Alabama involving new or old infestations. Herbicide efficacy, measured 24 months after treatment and retreatment, increased linearly with increasing rates of glyphosate and imazapyr, but eradication was not achieved. On average, September applications provided greater control than October applications at both sites (61 versus 50%, respectively). The best levels of control 2 years after retreatment occurred with repeated September applications using 2.2 kg acid equivalent/ha imazapyr, providing 88 and 90% control in the new and old infestations, respectively. Control with the glyphosate and imazapyr combination did not differ with spray volumes, but the combination gave greater control than similar rates of the single herbicides on the new infestation.

Keywords: *alang-alang*, application volume, herbicide frequency, herbicide timing, invasive grass

Cogongrass is one of the ten worst global invasive plants and is reportedly established on more than 500 million hectares in tropical and subtropical climates (Holm et al. 1977). Following at least five introductions into Alabama, Florida, and Mississippi during the early and mid-1900s, this invasive grass continues to spread north and westward (MacDonald 2004). It appears mostly in Florida, Alabama, Mississippi, and Georgia, with scattered infestations in South Carolina, Louisiana, and East Texas (Center for Invasive Species and Ecosystem Health 2010). One outlier infestation in Lexington, Tennessee, was eradicated (Becky Koepke-Hill, University of Tennessee, personal communication, 2010), but this shows the threat for long-distance spread.

Cogongrass is a significant threat to southern forests and adjoining lands (Jose et al. 2002). Infestations reduce landscape biodiversity, hinder forest regeneration, prevent forest recreation and hunting, depreciate land and hunting lease values, and present an extreme fire hazard (Bryson and Carter 1993, Dozier et al. 1998). In the only report documenting forest productivity loss, cogongrass competition reduced survival of 3-year-old planted loblolly pine (*Pinus taeda* L.) seedlings twice as much as pine seedlings with native plant competition and significantly reduced height and volume of the survivors (Daneshgar et al. 2008). Cogongrass is among the most difficult invasive plants to control in the southeastern United States, and strategies, approaches, and policies for containing spread and eradicating infestations are needed.

Concerted cogongrass management programs are under way in all southern states that have infestations, although the Louisiana program has been temporarily suspended because of lack of funds. Programs in Mississippi, Alabama, and Georgia were greatly strengthened in 2009 with $10.6 million of Federal recovery grant funding for 3 years. Other states rely on US Forest Service Forest Health and Protection grants and state funds. Control programs have been ongoing on most federal, state, forest industry, and non-agency preserve lands in the region for several years. Some state and federal agencies have also have provided cost-share and incentive payments for cogongrass treatment. To address the broader threat, a regional strategy has been devised, with the initial objective being to contain the spread to adjoining states by targeting outlying infestations, to be followed by efforts to reclaim infested lands (Miller 2007a, Center for Invasive Species and Ecosystem Health 2010). Unfortunately, proven methods for cogongrass eradication in forests are lacking. It is widely recognized that rhizomes must be

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This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; kilometers (km): 1 km = 0.6 mi; hectares (ha): 1 ha = 2.47 ac; kilograms (kg): 1 kg = 2.2 lb, 1 kg/ha = 0.892 lb/ac; liter (L): 1 L = 61.02 $in.^3$, = 0.908 quart (dry), = 1.057 quart (liquid), 1 L/ha = 0.107 gal/ac.

targeted; thus, systemic herbicides offer one of the most effective tools in an integrated treatment approach.

Cogongrass leaves grow directly from buds along rhizomes, without aboveground stems, and may reach 1.5 m in height (Holm et al. 1977, Bryson and Carter 1993). Because shoot meristems are below ground, cogongrass is tolerant of mowing and grazing. Cogongrass is fire tolerant, even though fires are intense during both the growing season and the winter, when the dry thatch remains standing (Dozier et al. 1998). Cogongrass rhizomes have buds at each node that are spaced 1–2 cm apart along the entire length of the rhizome. Rhizomes branch frequently, forming dense mats that can exclude most other vegetation (Ayeni 1985). Rhizome entanglements can fill the upper soil to more than 30 cm deep, they typically make up more than 60% of the total plant biomass, and they are allelopathic to some grass seeds (Sajise 1976, Koger and Bryson 2003). Rapid aboveground regrowth from the rhizomes is stimulated by mowing, disking, burning, or ineffective herbicide treatment (Sajise 1976, Willard et al. 1996, Lippincott 2000). Therefore, rhizomes must be completely killed, leaving no living segments, to achieve eradication. Difficulty in achieving eradication is thought to increase with infestation age as the rhizome mat density and depth increase, although this has not been fully tested.

The influence of the soil seed bank on eradication is not a primary concern during local eradication efforts. Prolific numbers of wind-dispersed seeds are produced by cogongrass, but viability is highly variable and declines rapidly after 1 year (Shilling et al. 1997, Dozier et al. 1998). Therefore, seed longevity in the soil seed bank is not a primary concern with regrowth after treatment, whereas spread to nearby mineral soil is a concern.

Repeated applications of herbicides, commonly applied in summer to early fall, are required for cogongrass control. Prescribed burning in late winter or early spring preceding treatment is common (Miller 2007b). However, the benefits of burning to eliminate winter thatch have been questioned. Although this approach may allow for more effective herbicide applications early in the spring, burning has been reported to stimulate rhizome initiation and branching, increasing plant density, flowering, and outward spread rates while killing constraining shrubs (Bryson and Carter 1993, Lippincott 2000, Yager et al. 2010). Burning can also produce bare areas favorable for cogongrass seed germination (Yager 2007).

Research in Florida and Asia has identified glyphosate, imazapyr, and the combination of these herbicides as the most effective herbicides for controlling cogongrass, although to date, eradication has not been reported even with retreatments (Brook 1989, Willard et al. 1996, 1997). Both glyphosate and imazapyr are readily absorbed by the foliage and translocated to rhizomes (Townson and Butler 1990). Soil-active imazapyr is also absorbed through roots (Little and Shaner 1991), which may foster greater control, although the importance of imazapyr uptake though rhizomes has not been determined. When used alone, imazapyr has proven more effective than glyphosate (Willard et al. 1996, 1997, Ramsey et al. 2003). Willard et al. (1997) found combinations of glyphosate and imazapyr in various proportions equally effective compared with the highest rates tested for either glyphosate or imazapyr applied alone (3.4 kg acid equivalent (ae)/ha glyphosate or 1.1 kg ae/ha imazapyr). Shoot biomass was reduced only 70% and rhizome biomass only 39% in their study. Additional research in Florida has shown that the highest rates tested for glyphosate (up to 9 kg ae/ha) or imazapyr (up to 1.1 kg ae/ha) applied in early winter were the most effective (Shilling et al. 1997, Willard et al. 1997, Ramsey et al. 2003). However, complete control was not achieved, indicating the need for research using higher rates of these herbicides combined with repeated applications.

Application timing and carrier volume can also influence herbicide efficacy. November or December applications of glyphosate or imazapyr proved most effective for cogongrass control in Florida (Shilling et al. 1997). However, cogongrass is typically dormant by this time of the year when growing further north, indicating the need for testing earlier application dates for use in areas with a shorter growing season. Few formal studies address the impact of application volume, although imazapyr was more effective at 234 L/ha than 47 L/ha, whereas glyphosate was not responsive to changes in application volume (Willard et al. 1997). Furthermore, information regarding the optimum application volume for use of glyphosate and imazapyr in combination is lacking.

Our overall goal was to further refine recommendations for control of cogongrass infestations in states north of Florida. Specific objectives of our research were to (1) test a range of rates of glyphosate or imazapyr applied alone, including higher rates than previously tested, (2) refine late summer and early fall timing for the Gulf Coastal Plain by testing both September and October applications, (3) determine the optimum application volume for the commonly used combination of glyphosate and imazapyr, and (4) test the efficacy of retreating plots with the same treatment 1 year after initial application.

Materials and Methods

Study Areas

Two experiments were installed in 1996 at locations near Bay Minette in Baldwin County, Alabama. These sites are located in the Middle Coastal Plain physiographic province, which contains most of the cogongrass infestations in the region. Bay Minette is approximately 100 km northeast of the first introduction of cogongrass into the southeastern United States in about 1911 (Dickens 1974). The area has a temperate climate, with an average high temperature of 25°C, average low temperature of 13°C, and average annual precipitation of 168 cm. Study locations were upland sites having slopes less than 3%.

The initial cogongrass cover (96–100%) was similar between the two study sites, whereas age, dry biomass, and average foliage height differed between the sites. At one study location (30°43.732′N, 87°51.475′W), cogongrass completely covered the understory of a sparse 35-year-old slash pine (*Pinus elliottii* Engelm.) plantation. According to the landowner, the infestation was more than 20 years old (referred to as the old infestation). The site had historically been burned every other year and was broadcast burned in February 1996, approximately 6 months prior to our first herbicide applications, and again in February 1997, before retreatments. All understory pine seedlings and most shrubs within the study area were killed by these burns. Cogongrass height ranged from 0.3 to 1.3 m in September before the first treatment. Cogongrass foliar dry biomass, as determined by clipping nine randomly located 0.5-m^2 plots and oven drying at 70°C for 72 hours, averaged 3,170 kg/ha (standard error, 139 kg/ha). Soils at this site are classified as Faceville fine sandy loam, very deep, well drained, moderately permeable, Thermic Typic Kandiudults (USDA Natural Resources Conservation Service 2010).

The second experiment was established within relatively new cogongrass infestations (referred to as the new infestation) that developed after harvest and site preparation in two young loblolly pine

(*Pinus taeda* L.) plantations approximately 31 km apart. Multiple circular infestations of various sizes occurred across these plantations. To accommodate each experimental block within a single infestation, one block was established in one plantation (30°32.537′N, 87°39.331′W), whereas the other two blocks were established in two infestations located within the second plantation (30°49.180′N, 87°41.944′W). Both plantations had been site prepared by chopping, followed by broadcast burning before planting, and they were 1 and 2 years old, respectively. Cogongrass height was considerably less than in the old infestation and ranged from 0.15 to 0.3 m. The cogongrass aboveground biomass, determined as described above with three 0.5-m^2 plots per infestation, was 2,861 kg/ha (standard error, 307 kg/ha). Common associated shrub species, sparsely scattered across all blocks, were gallberry (*Ilex glabra* [L.] A. Gray.), yaupon (*Ilex vomitoria* Aiton), and waxmyrtle (*Morella cerifera* [L.] Small). Herbaceous ground cover was largely displaced by cogongrass. Soils within these two plantations are classified as Lakeland loamy fine sand, very deep, excessively drained, Thermic, coated Typic Quartzipsamments (USDA Natural Resources Conservation Service 2010).

Treatments and Experimental Design

Separate replicated studies were conducted at the new and old infestations. In both studies, the same treatments were assigned in a randomized complete block, split plot design with three replications. Within the new plantations, separate circular infestations were the blocks. Plots measured 6.1 × 12.2 m and were split lengthwise for testing retreatment. Plots were laid out contiguously within each block to hinder edge reinvasion during the study. An untreated check and 22 herbicide treatments were included in each block. Treatments were structured to provide three separate factorial arrangements of glyphosate [1] rate with application timing, imazapyr [2] rate with application timing, and tank mix spray volume with application timing.

Individual glyphosate and imazapyr rates tested are expressed relative to the typical use rate (×) for cogongrass management. Glyphosate alone was applied at 1.68 (0.5×), 3.36 (1×), 6.72 (2×), and 13.44 kg ae/ha (4×) in 93.5 L/ha water carrier. Applications of glyphosate with relatively low spray volumes such as this have been shown to improve efficacy on cogongrass (Arif et al. 1986) and other grasses (Ramsdale et al. 2003). Imazapyr alone was applied at 0.275 (0.5×), 0.55 (1×), 1.1 (2×), and 2.2 kg ae/ha (4×) in 234 L/ha water carrier. This carrier volume was used because tests of two spray volumes by Willard et al. (1997) found that imazapyr provided significantly greater cogongrass control at 234 L/ha compared with 46 L/ha. For treatments testing the combination of these herbicides (glyphosate + imazapyr [Gly+Ima]), a mix of 3.36 kg ae/ha glyphosate (1×) plus 0.55 kg ae/ha imazapyr (1×) was applied in 93.5, 234, or 374 L/ha water carrier. All treatments contained 0.5% glycol amine surfactant. [3]

At the old infestation site, initial herbicide applications were made on Sept. 11 and Oct. 16, 1996, and plots were retreated a year later, on Sept. 11 and Oct. 15, 1997, for the two application timings, respectively. At the new infestations, initial herbicide applications were made on Sept. 12 and Oct. 17, 1996, and plots were retreated 1 year later on Sept. 12 and Oct. 16, 1997. All applications were made using a research backpack sprayer with a two-nozzle boom, fitted with 9502E tips spaced 77 cm apart and held at 80 cm above the mean grass height. The CO_2 sprayer was pressurized at 139 kPa. Whole plots received four passes, with two passes for each split plot, on measured centers. Application volume was adjusted by walking speed that was timed with a metronome.

Assessments

The efficacy of herbicide treatments for control of cogongrass was assessed using ocular estimates of percentage of cover before treatment; at exactly 1 year after treatment (YAT), in September and October 1997; at 2 YAT or 1 year after retreatment (YART), on Oct. 8, 1998; and at 3 YAT or 2 YART, on Nov. 18, 1999. All estimates were made using interior portions of the plots, omitting the 0.6-m buffer adjacent to each edge.

Data Analyses

A combined analysis including both new and old infestation sites and a separate analysis for each site were performed. Both used a mixed model approach, with blocks considered random. The combined analysis treated site as a fixed effect because sites were intentionally selected for infestation age (new versus old). All control plots had 100% cover of cogongrass over the life of the study and were not included in the statistical analysis. The analysis of individual sites tested main effects and interactions for each of the factorial treatment arrangements of glyphosate rate with application timing, imazapyr rate with application timing, and tank mix spray volume with application timing. Rate effects were examined using the following sequential approach described by Gomez and Gomez (1984). First, the effect of application volume for the combination treatment and the effect of glyphosate rate or imazapyr rate were examined by testing for interactions between these factors and application timing or retreatment. Next, sums of squares due to rate effects and interactions of rate effects with other factors were partitioned using orthogonal polynomials to determine the largest significant degree polynomial effect (linear, quadratic, or cubic). This information was then used with treatment means to fit an equation of the appropriate order for graphs. This equation estimates the relationship between control and rate that is supported by the analysis.

An arcsine square root transformation of percentage of control was required to normalize the variance for both analysis of variance (ANOVA) and regressions. Untransformed percentage of control means and standard error limits are reported. The arcsine square root transformation is nonlinear. Linear regressions fit on this transformed scale will not be linear when algebraically arranged to predict untransformed percentages. Regression lines included in figures were fit on the transformed scale. The algebraic equations used to calculate predictions of percentage of cover for regressions fit on the transformed scale are included in figures when appropriate. Percentage of control was computed as initial cover minus cover 2 years after the last treatment, divided by initial cover and multiplied by 100. Note that the analysis compared percentage of control observed 2 years after a single treatment to percentage of control 2 years after retreatment, so that percentage of control results are always for 2 years after the last treatment. Treatment means were compared using Fisher's protected least significant difference at $\alpha = 0.05$. Significance of source effects (p) in ANOVA were evaluated at $\alpha = 0.05$ or as otherwise noted.

Results and Discussion

Herbicide regimes performed differently at the two sites. A combined ANOVA across study sites found significant interactions

Table 1. Analysis of variance summary for the new infestation for herbicide rate or volume, application timing, and retreatment effects on cogongrass control 2 years after treatment (main effects) and control 2 years after retreatment (subplot effects). These effects were tested for glyphosate rate, imazapyr rate, and glyphosate + imazapyr (Gly + Ima) treatment application volume. Differences were considered significant if the probability of a greater *F* value (Prob. > *F*) was less than 0.05. Degrees of freedom (df) for partitioning of rate effects are in parentheses.

	Glyphosate rate		Imazapyr rate		Gly + Ima volume	
Source of variation	df	Prob. >*F*	df	Prob. >*F*	df	Prob. >*F*
Main effects						
Application timing	1	0.004	1	0.641	1	0.007
Rate or volume effect	3	0.001	3	0.001	2	0.791
Linear	(1)	0.001	(1)	0.001	(1)	0.524
Quadratic	(1)	0.752	(1)	0.521	(1)	0.807
Cubic	(1)	0.275	(1)	0.812		
Timing × rate or volume	3	0.943	3	0.784	2	0.803
Subplot Effects						
Retreat	1	0.001	1	0.001	1	0.001
Retreat × timing	1	0.086	1	0.700	1	0.353
Retreat × rate or volume	3	0.083	3	0.153	2	0.491
Retreat × linear	(1)	0.108	(1)	0.181	(1)	0.527
Retreat × quad	(1)	0.123	(1)	0.072	(1)	0.314
Retreat × cubic	(1)	0.171	(1)	0.593		
Retreat × rate or volume × time	3	0.622	3	0.806	2	0.643

Table 2. Analysis of variance summary for the old infestation for herbicide rate or volume, application timing, and retreatment effects on cogongrass control two years after treatment (main effects) and control two years after retreatment (subplot effects). These effects were tested for glyphosate rate, imazapyr rate, and glyphosate + imazapyr (Gly + Ima) treatment application volume. Differences were considered significant if the probability of a greater *F* value (Prob. >*F*) was less than 0.05. Degrees of freedom (df) for partitioning of rate effects are in parentheses.

	Glyphosate rate		Imazapyr rate		Gly + Ima volume	
Source of variation	df	Prob. >*F*	df	Prob. >*F*	df	Prob. >*F*
Main effects						
Application timing	1	0.147	1	0.024	1	0.062
Rate or volume effect	3	0.001	3	0.001	2	0.231
Linear	(1)	0.001	(1)	0.001	(1)	0.155
Quadratic	(1)	0.068	(1)	0.132	(1)	0.340
Cubic	(1)	0.733	(1)	0.148		
Timing × rate or volume	3	0.192	3	0.869	2	0.214
Subplot effects						
Retreat	1	0.001	1	0.001	1	0.001
Retreat × timing	1	0.641	1	0.915	1	0.414
Retreat × rate or volume	3	0.177	3	0.001	2	0.805
Retreat × linear	(1)	0.042	(1)	0.001	(1)	0.580
Retreat × quad	(1)	0.390	(1)	0.134	(1)	0.726
Retreat × cubic	(1)	0.975	(1)	0.706		
Retreat × rate or volume × time	3	0.285	3	0.904	3	0.128

between site and herbicide treatment ($P = 0.0185$), treatment frequency ($P = 0.0001$), and herbicide treatment by frequency ($P = 0.0033$). Therefore, separate analyses were performed for each site. These analyses indicated that application timing, herbicide rate, and retreatment were all important factors influencing cogongrass control (Tables 1 and 2). Cogongrass control in the new infestations improved with increasing herbicide rate for both glyphosate and imazapyr, and control was also improved with retreatment (Figure 1). For the new infestations, there were no significant interactions among these factors. For the old infestation, significant interactions were found between retreatment and linear rate effects for both glyphosate and imazapyr. Compared with the new infestations, the responses to herbicide rate were more variable at the old infestation, as indicated by the standard error bars (Figure 2). At both sites, simple rate effects for glyphosate or imazapyr were directly related and strongly linear. In contrast, in the old infestation, the positive rate response was not as strong with retreatment, and there were differences between herbicides. For glyphosate, control at the old infestation improved with increasing rate, but the benefit of retreatment diminished as rate increased. For imazapyr, control at the old infestation increased with rate for single applications, but there was little or no improvement with increasing rate for retreatment.

Application volume did not influence the performance of Gly+Ima at either infestation age (Figures 1 and 2), whereas retreatment significantly improved control (Tables 1 and 2). One might expect that more spray on the foliage of this tall and dense invasive grass would translate into increased uptake to yield increased control, but applications using up to a 4-fold greater spray volume did not improve control.

September applications gave better cogongrass control than the October treatment for glyphosate and Gly+Ima at the new infestations and for imazapyr alone at the old infestation (Table 3). Averaged across herbicide treatments, September applications provided better cogongrass control than October treatments for both the new (59 versus 45%) and old (64 versus 55%) infestation sites. The lack

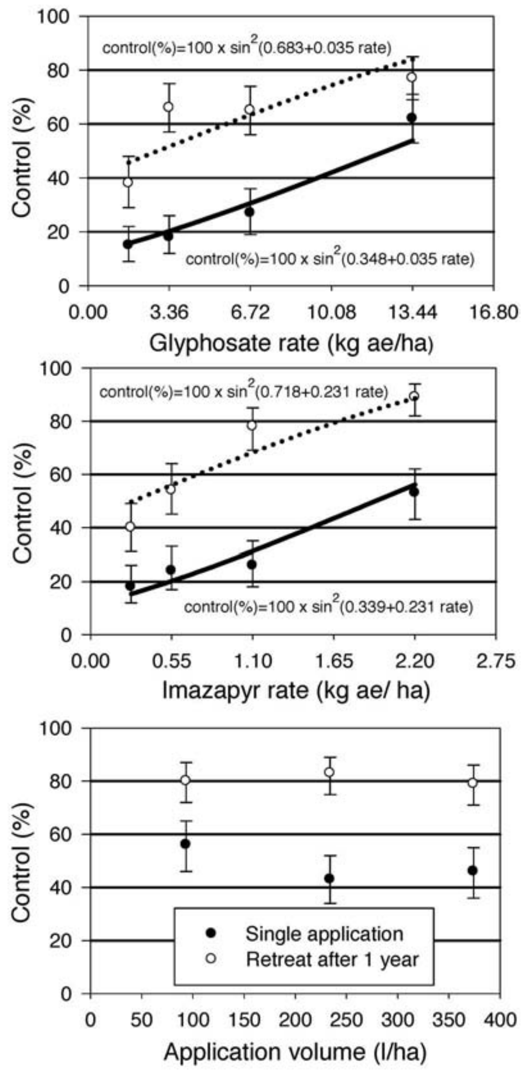

Figure 1. New infestation: percentage of control of cogongrass 2 years after treatment and 2 years after retreatment. Error bars are ±1 standard error. Regression equations using the sine function in radians describe average rate response.

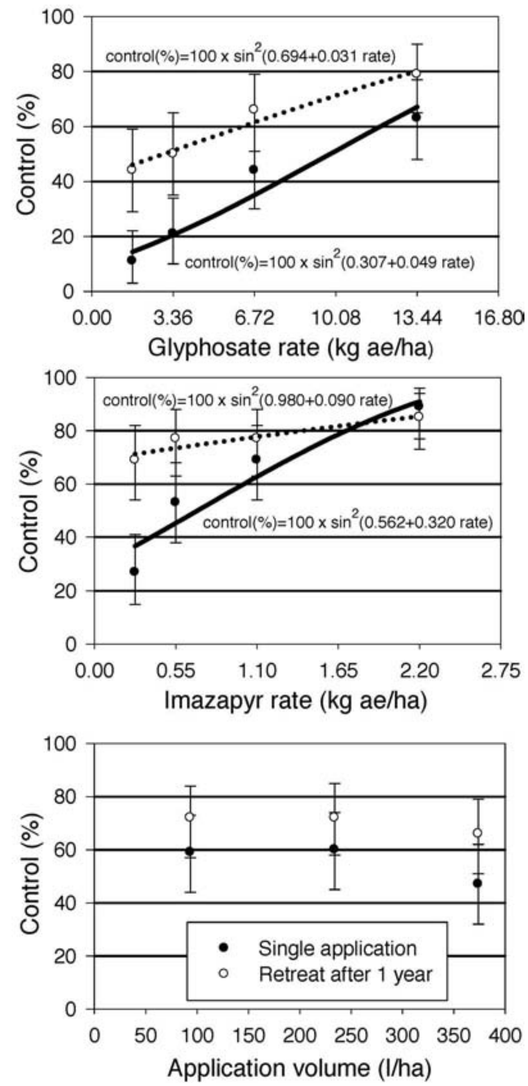

Figure 2. Old infestation: percentage of control of cogongrass 2 years after treatment and 2 years after retreatment. Error bars are ±1 standard error. Regression equations using the sine function in radians describe average rate response.

of significant interactions between timing and other factors for either infestation age (Tables 1 and 2) indicates that October applications never improved control compared with September applications. Better efficacy in September was consistent across treatments during two different years of application, and the difference was significant for half of the treatments.

Timing will be a crucial decision for cogongrass treatment programs that are under way or that will soon start in several states. Our findings indicate a general decline in treatment efficacy between late summer and early fall. This is a period when cogongrass plant metabolism is undergoing substantial changes, as this perennial grass progresses toward dormancy with frost. Our findings add to the results of glyphosate timing studies in the more subtropical climate in central Florida, where November or December applications are most effective (Shilling et al. 1997).

Retreatment improved cogongrass control for glyphosate, imazapyr, and Gly+Ima treatments at both the new and old infestations (Table 4). For the old infestation, there was a significant interaction between treatment frequency and imazapyr rate ($P = 0.0004$), because differences in control following retreatment diminished with increasing imazapyr rate (Figure 2). These results support earlier findings of improved control with sequential treatments by Willard et al. (1997), who also mowed between treatments. In our research without mowing, imazapyr at 2.2 kg ae/ha applied in September averaged 90% control on the sites with new infestations and 88% on the site with the old infestation 2 years after retreatment. This is a high degree of control relative to previous research with cogongrass. It was also observed on many plots that both herbicides released gallberry, which is a prolific shrub and provides additional cogongrass suppression by the third year. The objective of any cogongrass management program in forests will be to suppress or eradicate this grass and foster or establish native shrubs and trees as a long-term solution (Yager 2007).

For the combination of glyphosate and imazapyr at 1× rates (3.36 kg ae/ha and 0.55 kg ae/ha, respectively) application volume had no effect on cogongrass control at the new infestation ($P = 0.79$) or the old infestation ($P = 0.23$) sites. In selecting our spray volumes for single herbicides, we considered the report by Willard et al. (1997) that showed cogongrass control using glyphosate was not

Table 3. Percentage of control of cogongrass 2 years after retreatment compared by application timing at the new and old infestations.

Application timing	New infestation				Old infestation			
	Glyphosate	Imazapyr	Gly + Ima	Average	Glyphosate	Imazapyr	Gly + Ima	Average
	(% control)							
September	56[a]	50[a]	75[a]	59[a]	50[a]	74[a]	67[a]	64[a]
October	36[b]	47[a]	55[b]	45[b]	43[a]	64[b]	58[a]	55[b]

Gly + Ima, combination of glyphosate and imazapyr.
[a,b] Means in a column followed by the same letter are not significantly different at a probability of $\alpha = 0.05$.

Table 4. Percentage of control of cogongrass 2 years after treatment and 2 years after retreatment by application frequency for new and old infestations.

Application frequency	New infestation			Old infestation		
	Glyphosate	Imazapyr	Gly + Ima	Glyphosate	Imazapyr[a]	Gly + Ima
	(% control)					
Single	29[b]	30[b]	48[b]	33[b]	61[b]	55[b]
Retreatment	62[c]	67[c]	80[c]	60[c]	77[c]	70[c]

Gly + Ima, combination of glyphosate and imazapyr.
[a] This difference between single and retreatment percentage control diminished with increasing imazapyr rate (significant interaction) at the old infestation site (see Figure 2).
[b,c] Means in a column followed by the same letter are not significantly different at a probability of $\alpha = 0.05$.

Table 5. Percentage of control of cogongrass 2 years after retreatment compared for the 1X rate of glyphosate (3.36 kg ae/ha), imazapyr (0.55 kg ae/ha), or the mix of 1X glyphosate plus 1X imazapyr rates for the new and old infestations.

Herbicide	New Infestation		Old Infestation	
	1×	All rates	1×	All rates
	(% control)			
Glyphosate	41[a]	45[b]	35[a]	47[a]
Imazapyr	39[a]	48[b]	66[b]	69[b]
Gly + Ima	65[b]		63[b]	

Gly + Ima, combination of glyphosate and imazapyr.
[a,b] Means in a column followed by the same letter are not significantly different at a probability of $\alpha = 0.05$.

responsive to application volume in the range of 46 to 234 L/ha and that imazapyr provided better control at 234 L/ha than at 46 L/ha. We tested a range of application volumes within current herbicide label recommendations and did not find a positive response to increasing volume. This is valuable information for practitioners, as application costs increase when higher carrier volumes are used.

When compared with the 1× rate of glyphosate or imazapyr alone, the Gly+Ima treatment improved control over either herbicide at the new infestation sites and improved control over the 1× rate of glyphosate for the old infestation site (Table 5). Overall, percentage of control averaged across all rates of glyphosate or all rates of imazapyr did not differ at the new infestation sites. However, percentage of control for imazapyr was significantly greater than for glyphosate at the old infestation site. This demonstrates the variability of control of cogongrass infestations and how different herbicides and mixtures can provide equal control depending on the situation. The tolerance of native plants or desirable vegetation can be a consideration for selection of herbicide treatments to promote successful restoration of the site. Only through restoration of infested sites can lands be safeguarded from cogongrass reinvasion or invasion by other exotic plants.

Eradication was not achieved with any treatment, whereas the best control was obtained with repeated applications using the highest rates of glyphosate or imazapyr tested. The highest rates previously tested with retreatments in the following year were performed by Ramsey et al. (2003) in Florida, who tested half our highest glyphosate rate and about one-third our highest imazapyr rate. These repeated treatments in November had no additional effect on cogongrass cover 1 YART. Our repeated September applications using the highest test rate of 13.44 kg ae/ha glyphosate yielded 77 and 80% control 2 YART at the new and old infestation sites, respectively. Repeated September applications using 2.2 kg ae/ha imazapyr provided 88 and 90% control 2 YART at new and old infestation sites, respectively. Herbicide rates higher than those tested may have improved control, but they would be in excess of current labeled maximum use rates for established pines. The current glyphosate product label permits up to 11.88 kg ae/ha per year. Unlike glyphosate, imazapyr is soil active and absorbed by tree roots, such that its selective use in southern pine forests is dependent on herbicide application rate and presence of pine species that vary in tolerance to imazapyr. The maximum annual use rate for selective weed control using the current imazapyr product is 0.7 kg ae/ha in loblolly stands and 0.56 kg ae/ha in slash pine stands.

The large, belowground biomass of persistent rhizomes in established cogongrass infestations makes this species very difficult to control. As with all invasive species, diligence in identifying and controlling new infestations is essential to prevent the spread of this ecologically destructive invasive grass. Retreatment of cogongrass regrowth should be performed when the grass is about 30 cm tall to foster herbicide absorption and translocation to new rhizomes that are initiated at this stage (Ayeni 1985). Delaying application longer than the yearly schedule tested here could result in rapid reoccupation by survivors.

Endnotes

[1] Glyphosate in the form of Accord Concentrate (Dow AgroSciences LLC, Indianapolis, IN, USA), containing 485 g ae/L (3 lb ae/gal).
[2] Imazapyr in the form of Arsenal AC (BASF Corporation, Research Triangle Park, NC, USA), containing 479 g ae/L (4 lb ae/gal).
[3] Glycol amine surfactant in the form of Entry II (Monsanto Company, St. Louis, MS, USA).

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