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Influence of Herbicide Combinations and Application Technology on Cogongrass (*Imperata cylindrica*) Control[1]

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Abstract: Field experiments were conducted to evaluate various herbicides and application technologies for the control of cogongrass. Imazapyr at 0.8 kg ae/ha provided the highest cogongrass control, followed by glyphosate (3.4 kg ae/ha) and sulfometuron (1.1 kg ai/ha) when applied as a single application. When sequential applications were evaluated, glyphosate plus imazapyr provided the best control. Sulfometuron could be applied sequentially after imazapyr or glyphosate with no loss of control, but control was less if sulfometuron was the initial herbicide. Tank mix combinations of glyphosate and imazapyr (100% rate at 3.4 and 1.1 kg ae/ha, and subsequent rates of 0 + 100, 25 + 75, 50 + 50, 75 + 25, and 100 + 0% of each herbicide, respectively) provided similar cogongrass control regardless of rate. Control using imazapyr improved from 20 to 40% with 234 L/ha diluent volume when compared to 46 L/ha. Glyphosate at either of these volumes provided from 0 to 21% inhibition of cogongrass. A 50% concentration of imazapyr applied twice with a ropewick provided greater control than a 33% concentration with one pass or either concentration of glyphosate with one or two passes. Efficacy with glyphosate applied using a ropewick was not affected by concentration or number of passes.

Nomenclature: Imazapyr, (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid; sulfometuron, 2-[[[[(4,6-dimethyl-2 pyrimidinyl)amino]carbonyl]-amino]sulfonyl]benzoic acid; cogongrass, *Imperata cylindrica* (L.) Beauv. #[3] IMPCY.

Additional index words: Low-volume applications, methods of control, ropewick, sequential herbicide combinations, tank-mix.

Abbreviation: CRBD, completely randomized block design.

INTRODUCTION

Cogongrass is a serious perennial pest throughout the subtropical and tropical regions of the world (Holm et al. 1977). It ranks as the seventh most troublesome weed worldwide, spreading by both seed and rhizomes. Cogongrass has been reported to adversely affect banana (*Musca paradiscaca* L. var.), citrus (*Citrus* spp.), coconut (*Cocus nucifera* L.), oil palm (*Elaeis guineensis* Jacq.), pasture, pineapple [*Ananas comosus* (L.) Merr.], pine (*Pinus* spp.), rubber (*Hevea brasiliensis*), and tea (*Camellia sinensis*). In addition, cogongrass has become a problem in many noncrop areas, such as forests, roadsides, reclaimed mined areas, recreational areas, and natural ecosystems. It has little utiity except for thatch, forage production, and soil stabilization. Cogongrass research has been geared toward short-term control, and long-term control of this species has proven extremely difficult. Slash-and-burn and shifting agriculture has resulted in transient control, usually allowing only a year or two of crop production before reinfestation. By eliminating natural vegetation that competes effectively with cogongrass and concomitantly distributing seeds and rhizomes, these control strategies have increased the area of cogongrass infestation (Prommool 1984).

At least 30 herbicides and hundreds of combinations have been evaluated and reported for cogongrass control (Bacon 1986; Dickens and Buchanan 1975; SEAWIC 1988). Of these herbicides, dalapon (2,2-dichloropropanoic acid), glyphosate [*N*-(phosphonomethyl)gycine], and imazapyr have shown the greatest activity on cogongrass with the fewest adverse effects (i.e., bioaccumulation of heavy metals, extending periods of soil sterilization, nontarget species injury, or applicator injury). In most situations, long-term control or complete control has not been achieved from a single application of any of these compounds. Repeat applications have been nec-

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[3] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA.

essary to kill or deplete rhizomes. Long-term control can be achieved only if rhizomes are controlled.

Various innovations in application technology have also been tested to improve the activity of these herbicides on cogongrass. Low- and ultralow-volume (ULV) applications (usually in the range of 20 to 100 L/ha diluent volume) have been reported to enhance the activity of glyphosate on selected annual grasses (Buhler and Burnside 1983), common bermudagrass [*Cynodon dactylon* (L.) Pers.] (Jordan 1981), quackgrass [*Elytrigia repens* (L.) Nevski] (Sandberg et al. 1978), but control of johnsongrass [*Sorghum halepense* (L.) Pers.] was equal for various herbicides at spray volumes of 94 and 374 L/ha (McWhorter and Hanks 1993). The use of low-volume technology with glyphosate and imazapyr on cogongrass has been reported (Townson and Price 1987). However, results have been variable and not definitive as to the enhancement of activity or long-term control.

Townson and Butler (1990) evaluated "cloth-wiping" and "rope-wicking" of imazapyr and glyphosate on cogongrass, and reported that ropewick wipers were more effective for both herbicides, but that imazapyr concentration must remain below 10 g ae/L to be effective. The authors also reported that increasing imazapyr concentration reduced imazapyr translocation, while the reverse was true for glyphosate.

The concept of control has been frequently defined as the initial effects of the herbicide treatment. Research that provides the most useful information (i.e., long-term efficacy) about cogongrass and other perennial weed control allows sufficient time following treatment before evaluation (Dickens 1973). Short-term evaluation of herbicide efficacy on perennial species can often be misleading (Shilling and Haller 1989). The most accurate measure of perennial weed control is the inhibition of regrowth from perennating organs. This measure can be accomplished by harvests of foliage regrowth and the amount of productive perennating tissue remaining after an extended period of time (i.e., one growing season following application).

Because herbicides have not provided effective cogongrass control, an experiment was initiated to develop a program that would provide long-term control using herbicides applied alone or in combination, sequential herbicide programs, and application methodology (i.e., low volume and ropewick applications).

MATERIALS AND METHODS

Sequential Herbicide Applications. Sequential herbicide applications for cogongrass control were evaluated over a 3-yr period (1986 to 1988) at Chiefland, FL. The area was located in a flatwoods, noncropped field, and the soil type was a Sparr fine sand (Loamy, Siliceous, Hyperthermic, Grossarenic, Paleudults) heavily infested with cogongrass.

The herbicides and rates applied were: (a) dalapon, 16.8 kg/ha; (b) glyphosate, 3.4 kg/ha; (c) imazapyr, 0.8 kg/ha; (d) sulfometuron, 1.1 kg/ha; and (e) untreated control. Initial herbicide applications were made to cogongrass foliage 60 to 90 cm tall and the second treatment of the sequential program was made to regrowth 60 to 120 cm tall. Treatments were applied using a CO_2-pressurized backpack boom-sprayer delivering 280 L/ha at 210 kPa. Treatments were arranged as a 3 by 5 factorial using a completely randomized block design (CRBD) (initial treatments of glyphosate, imazapyr, and sulfometuron and second treatments of dalapon, glyphosate, imazapyr, and sulfometuron, or untreated) with three replications on 1.8- by 4.6-m plots. Sequential applications for the first experiment were made on July 9, 1985 and September 19, 1986, respectively. Treatments were made July 9, 1985 and September 19, 1986 in the first experiment and September 19, 1986 and October 8, 1987 in the second experiment. In January 1986 and 1987, cogongrass was mowed to 2 cm in both experiments. This allowed the sequential applications to be made to regrown foliage without any interception by dead foliage. A substantial regrowth period was necessary to provide an accurate assessment of the long-term effects of herbicide treatments for cogongrass control. To accomplish this, a 1.8-m-wide swath was mowed through each plot. From this area, foliage regrowth within a 0.25-m^2 (reported on a 1.0-m^2 basis) quadrat was harvested. In addition, rhizome biomass was determined by harvesting six random samples (182 cm^2 diam soil cores to a depth of 12 cm; 4,710 cm^3 total volume; reported on a 1.0 m^3 basis) within each plot. Foliage and rhizome tissue was dried at 60 C for 72 h and dry weights were determined.

Plots for the initial and sequential herbicide applications, low- and conventional-volume applications of glyphosate and imazapyr, and the ropewick applications of glyphosate and imazapyr experiments were mowed in January 1987 for the first experiment and in January 1988 for the second experiment. These plots were then harvested in September 1987 and June 1988 for the first and second experiments, respectively.

Plots for the first and second glyphosate and imazapyr tank-mix combination experiments were mowed in January 1986 and 1987 and harvested in September 1986 and June 1987, respectively.

Tank-Mixed Glyphosate and Imazapyr. Glyphosate and imazapyr were tank-mixed and applied as a single application to cogongrass foliage on July 9, 1985 (first experiment) and on September 16, 1986 (second experiment). Applications were made using the CO_2-pressurized boom system previously described. The 100% rate of each herbicide was designated as 3.4 and 1.1 kg/ha for glyphosate and imazapyr, respectively. From this rate, glyphosate and imazapyr mixtures of 0 + 100, 25 + 75, 50 + 50, 75 + 25, and 100 + 0% were formulated. The experimental design was a randomized complete block with three replications on 1.8- by 4.6-m plots. Cogongrass was mowed in January 1986 and 1987 for the first and second studies, respectively, and the foliage regrowth was harvested in September 1986 and June 1987 for the first and second studies, respectively.

Spray Volume Applications of Glyphosate and Imazapyr. The influence of carrier volume on the efficacy of glyphosate and imazapyr was evaluated in two experiments over a 3-yr period. In the first experiment, applications were made using a tractor-mounted boom sprayer traveling at 6.4 km/h. To deliver 46 L/ha, the boom was equipped with 11001LP[4] flat fan nozzles calibrated at 124 kPa. To deliver 234 L/ha, the boom was equipped with 11005 flat fan nozzles calibrated at 276 kPa. In the second experiment a CO_2-pressurized backpack boom sprayer was used. With this system, 46 L/ha was applied by using TX-6[5] hollow cone nozzle calibrated at 207 kPa and traveling at 8 km/h while 234 L/ha was applied by using 11003[4] flat fan nozzles calibrated at 221 kPa traveling at 4.8 km/h. Glyphosate and imazapyr were applied in 46 and 234 L/ha at two rates.

Treatments were applied on July 8, 1985 (first experiment) and September 16, 1986 (second experiment). The experimental design was a CRBD with treatments arranged in a 2 by 2 by 2 factorial with three replications. Plots were 3.0 by 6.1 m in the first experiment and 1.8 by 4.6 m in the second experiment. In January 1987 and 1988 cogongrass was mowed. Regrown foliage and soil-rhizome cores were obtained, as previously described, in September 1987 and June 1988 for the first and second experiment, respectively.

Ropewick Applications. Ropewick applications of glyphosate and imazapyr were evaluated for cogongrass control. Glphosate and imazapyr (33 and 50% v/v, respectively) were applied once or twice (in opposite directions). The study was conducted twice in consecutive years. The ropewick apparatus used was 2.1 m long with a reservoir capacity of 17.3 L. Two rows of half-overlapping Pistachios[5] rope (nine sections per row 20 cm long) were attached using rubber bushings within a screw-cap compression fitting, the body of which was glued to the PVC reservoir, creating 1.8 m of wicking surface. Two sets of ropewicks were constructed, one for each herbicide. Applications were made by two people carrying the ropewick through the plot at 4.8 km/h with the wicking surface held horizontally to the ground approximately 20 cm below the leaf apex.

The experimental design was a CRBD using a two (glyphosate and imazapyr) by two (33 and 50% concentrations) by two (one or two passes) factorial arrangement with three replications in the first experiment and four replications in the second experiment. The plot size in both experiments was 1.8 by 4.6 m. Applications were made on July 9, 1985 for the first experiment. In the second experiment, glyphosate was applied October 2, 1986 and imazapyr was applied October 3, 1986. In both experiments, cogongrass was 60–90 cm tall at the time of application. In January 1987 and 1988 plots were mowed. Regrowth foliage was harvested as previously described in September 1987 and June 1988 for the first and second year, respectively.

Analysis of variance was used to test for main factor effects and interactions, and means were separated using the appropriate Fisher's least significant difference (SAS Institute 1989). There were no year-by-treatment interactions ($P > 0.05$) in any study; consequently, the data were pooled across years.

RESULTS AND DISCUSSION

Sequential Herbicide Applications. Cogongrass shoot regrowth and rhizome biomass were affected differently by herbicide treatments (Table 1). Using data from single applications the herbicidal activity ranked as follows (high to low): imazapyr (76 and 34% inhibition of shoot and rhizome growth, respectively), glyphosate (61 and 34% of shoot and rhizome growth, respectively), sulfometuron (38 and −22% inhibition of shoot and rhizome growth, respectively). Regardless of the order of application, all combinations of glyphosate and imazapyr provided the best control.

Sequential applications of imazapyr plus glyphosate controlled cogongrass as well as or better than when each herbicide was followed by dalapon or sulfometuron. Sequential applications of imazapyr or glyphosate following sulfometuron provided excellent control (greater than 90%) of shoot regrowth. Sulfometuron by

[4] Spraying Systems Co., North Avenue, Wheaton, IL 60188.
[5] Gulf Rope and Cordage Inc., P.O. Box 5516, Mobile, AL 36605.

Table 1. The effect of sequential herbicide treatments on cogongrass regrown shoot and rhizome dry weight from 1985 to 1988.

Sequential application (kg/ha)	Initial application: Imazapyr (0.8 kg/ha) SDW[a]	Imazapyr RDW[a]	Glyphosate (3.4 kg/ha) SDW	Glyphosate RDW	Sulfometuron (1.1 kg/ha) SDW	Sulfometuron RDW
	% inhibition[b]					
Dalapon (16.8)	74	47	95	58	52	−5
Glyphosate (3.4)	88	67	87	48	94	−13
Imazapyr (0.8)	99	64	98	69	94	16
Sulfometuron (1.1)	62	60	37	43	−6	−38
Untreated	76	34	61	34	38	−22

[a] Regrowth shoot dry weight (SDW) and root-rhizome dry weight (RDW) harvested 10 mo after sequential treatment.

[b] $LSD_{(0.1)}$ = 14 and 20 for SDW and RDW row comparisons, respectively; $LSD_{(0.1)}$ = 18 and 25 for SDW and RDW column comparisons, respectively. Inhibition values were computed using untreated areas that contained 128 g/m² (harvested from 0.25 m²) and 860 g/m³ (harvested from 4,170 cm³) of foliage and rhizome tissue, respectively.

itself, or preceding dalapon, provided little or no control of cogongrass shoots or rhizomes.

Tank-Mixed Combinations. Tank-mixed combinations of glyphosate and imazapyr provided the same level (P > 0.1) of control regardless of the rate combination (data not shown); however, all combinations significantly (P < 0.05) reduced cogongrass shoot biomass 70% and rhizome biomass 39%. Therefore, either of these two herbicides can substitute for the other in a single tank-mix application, and are at least as effective applied alone. This flexibility could provide possible economic and environmental advantages. By increasing the proportion of glyphosate in the tank-mix, a cost savings could be realized. In addition, decreasing the proportion of imazapyr would reduce the time interval before revegetation could be reduced. Conversely, if longer term bare soil were desired, imazapyr would be the herbicide of choice due to soil residual activity. Imazapyr could be an effective herbicide choice if tolerant plant species were desirable vegetation.

Spray Volume Applications of Glyphosate and Imazapyr. Herbicides (glyphosate and imazapyr), herbicide rates (half or full rate), and carrier volumes (46 or 234 L/ha) affected cogongrass control interactively (P < 0.05) as measured by shoot regrowth (Table 2). Imazapyr provided significantly greater cogongrass control (20 to 70%) than did glyphosate at both rates when applied at 234 L/ha. Imazapyr rate did not influence control. Both rates of glyphosate resulted in poor control (0 to 21%). Imazapyr provided a greater level of control when applied at the higher volume. This may indicate that in dense stands of cogongrass greater coverage is more important than diluent concentration (Townson and Butler 1990).

Table 2. The effect of carrier volume and imazapyr and glyphosate rate on cogongrass shoot dry weight.

Carrier volume (L/ha)	Imazapyr 0.4 kg/ha	Imazapyr 0.8 kg/ha	Glyphosate 1.7 kg/ha	Glyphosate 3.4 kg/ha
	% inhibition[a]			
46	33[b]	48[b]	16	21
234	73[b,c]	71[b,c]	−10[c]	12[c]

[a] Inhibition values were computed using untreated areas that contained 99 g/m² of foliage (harvested from 0.25 m² area).

[b] Indicates a significant (P < 0.05) volume effect baesd on ANOVA.

[c] Indicates a significant (P < 0.05) herbicide effect based on ANOVA.

Ropewick Applications of Glyphosate and Imazapyr. There was a significant (P < 0.05) three-way interaction betwen herbicides, percent solution, and number of passes (Table 3). Control with glyphosate (both shoot and rhizome dry weight) was unaffected by solution concentration and number of passes with the ropewick applicator. Control from imazapyr applied in a 33% solution was not affected by the number of passes and was not significantly greater than control observed from glyphosate at either solution concentration. Imazapyr provided better control at a 50% solution than at a 33% solution. Control based on shoot regrowth was not affected by the number of passes, whereas two passes provided significantly greater control of cogongrass rhizomes than a single pass. Boerboom and Wyse (1988) speculated that the reason for poor control of Canada thistle [*Cirsium arvense* (L.) Scop.] achieved using ropewick-applied glyphosate was that the concentration applied was greater than the optimum level needed for

Table 3. The effect of ropewick applications of imazapyr and glyphosate rate on cogongrass shoot and rhizome dry weight.

Solution	Passes	Imazapyr SDW[a]	Imazapyr RDW[a]	Glyphosate SDW	Glyphosate RDW
%	no.	% inhibition[b]			
33	1	67	−17[c]	55	17
33	2	68	11[c]	65	31
50	1	76[d]	24[c,e]	38[d]	28
50	2	78[d]	45[c,e]	60[d]	27

[a] Regrown shoot dry weight (SDW) and rhizome dry weight (RDW), respectively.

[b] Inhibition values were computed using untreated areas that contained 174 g/m² (harvested from 0.25 m²) and 1,390 g/m³ (harvested from 4,170 m³) of foliage and rhizome biomass, respectively.

[c] Indicates a significant (P < 0.05) % solution effect within herbicides and passes based on ANOVA.

[d] Indicates a significant (P < 0.05) herbicide effect within % solutions and passes based on ANOVA.

[e] Indicates a significant (P < 0.05) number of passes effect within herbicides and % solutions based on ANOVA.

maximum translocation to the roots. Geiger and Bestman (1990) determined that glyphosate lowered photosynthesis and limited import into developing sink leaves of sugar beet (*Beta vulgaris* L.). In essence, by overdosing the leaf tissue, glyphosate provides more contact activity, to the detriment of systemic activity. Therefore, the use of concentrations of more than 33% glyphosate would be economically unsound. In fact, the use of concentrations lower than 33% may provide as much, if not more, control of cogongrass. Imazapyr at the 50% concentration provided better control of cogongrass shoot regrowth than did glyphosate. The highest level of control was achieved at 50% v/v applied twice. These data would seem to indicate that imazapyr absorption and/or translocation is not as sensitive to high concentrations as glyphosate. However, Townson and Butler (1990) reported that ropewicked imazapyr concentrations above 10 g ae/L reduced radiolabeled imazapyr movement in cogongrass. The use of two passes at the 50% concentration provided the highest level of control of any of the treatments. Although 100% control was not achieved with either herbicide, multiple ropewick applications of glyphosate or imazapyr may be a viable alternative for cogongrass control in situations where broadcast applications are not desirable.

None of the treatments provided 100% control of cogongrass. The best control was achieved with sequential applications of glyphosate or imazapyr. Varying the concentrations of imazapyr and glyphosate in a tank-mix application while maintaining the same level of control offers flexibility to vegetation managers. Less imazapyr in the mixture reduces soil residual activity, and earlier revegetation of an area would be possible. More imazapyr in the mixture offers a longer period of complete vegetation control. Glyphosate and imazapyr are also interchangeable in sequential applications, offering the same type of management flexibility. Application techniques such as reduced carrier volume, ropewick, and tank-mixes did not enhance the activity of these herbicides on cogongrass. If, for economic or site considerations, ropewick or high-diluent-volume application technology are used, then imazapyr could provide better control.

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