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Physico-chemical Factors Influencing the Control of Torpedograss with Glyphosate[1]

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ABSTRACT

Three products were evaluated for rain protection of glyphosate: X-77[3] (alkylaryl polyoxyethylene glycols, free fatty acids and isopropanol), polysar[4] (modified styrene butadiene latex), and Cide-Kick[5] (citrus oil adjuvant). These adjuvants did not affect the rain-free period for glyphosate with a minimum rain-free period of three days required following treatment for optimum glyphosate efficacy. The effects of ammonium sulfate on glyphosate activity were influenced by water quality, glyphosate rate, and the concentration of ammonium sulfate in the tank mix. When glyphosate was applied at 2.24 or 4.28 kg active ingredient (a.i.)/ha in hard water, 0.1 M ammonium sulfate reversed the antagonism caused by hard water; however, at these rates in soft water ammonium sulfate had no effect on torpedograss control. When glyphosate was applied at 1.12 kg a.i./ha, ammonium sulfate had no effect or caused a decrease in herbicidal activity in hard water, or caused a slight increase in torpedograss control when applied in soft water. When glyphosate was applied at 2.24 kg a.i./ha, increasing the volume of hard water used as the carrier (diluent) caused a linear decrease in torpedograss control. Glyphosate applied at 1.12 kg a.i./ha using hard water as the carrier diluent resulted in a linear decrease in torpedograss control. However, when glyphosate was applied at 1.12 kg a.i./ha using hard water as the carrier, there was a decline in control of torpedograss as volume increased to 935 L/ha; but increasing carrier volume to 1870 L/ha completely reversed calcium antagonism. Carrier volume did not affect glyphosate activity when soft water was used as a diluent.

Key words: ammonium sulfate, diluent volume, calcium, surfactants, *Panicum repens*, rain protectants.

INTRODUCTION

Torpedograss (*Panicum repens* L.) is a weedy plant species which causes problems in both aquatic and terrestrial ecosystems (Holm et al. 1977, Panchal 1981, Shilling and Haller 1989) throughout Florida and other parts of the southeastern United States (Tarver 1979, Wilcut et al. 1988). Problems with flood control, navigation, recreation, turf production, and irrigation are caused by this species (Shilling and Haller 1989), and due to the diversity of ecosystems in which torpedograss causes problems, consistently effective control has been difficult (Baird et al. 1983a, Shilling and Haller 1989). The isopropylamine salt of glyphosate N-(phosphonomethyl)glycine, is the most widely used herbicide for the control of torpedograss in aquatic environments. Glyphosate is a non-selective post-emergence herbicide that is generally effective for the control of perennial weeds because it is translocated and will accumulate in vegetative tissues such as rhizomes (Banks and Bundschuh 1989, Majek 1980, Pereira and Crabtree 1986, Wyse 1988). Although glyphosate has been used extensively for the control of torpedograss in Florida, results have been inconsistent (Baird et al. 1983b, Shilling and Haller 1989). In addition, long-term (greater than one year) control of torpedograss in the aquatic habitat has virtually never been reported (Shilling and Haller 1989, Smith et al. 1993). Several factors, both natural (rain and diluent hard water (Buhler and Burnside 1983, Majek 1980, Manipura and Somaratne 1974, Sandberg et al. 1978, Shilling and Haller 1989)) and artificial (rain protectants, adjuvants, and diluent volume (Smith et al. 1993)), have been shown to influence the activity of glyphosate. Therefore, studies were conducted to determine if improved glyphosate efficacy on torpedograss could be obtained by evaluating factors known to affect the activity of this herbicide on other weedy plant species. These factors were: rain-free period, rain-protectants, hard water, diluent volume, and ammonium sulfate.

METHODS AND MATERIALS

Influence of rain-free period and rain protectants. The influence of rainfall following glyphosate applications to torpedograss and an evaluation of additives used to possibly ameliorate this influence was evaluated in field studies in May 1983. A study was conducted at the Indiantown Florida Power and Light (FPL) cooling reservoir in Martin County, Florida. The study site was located in an extensive sward of torpedograss rooted in approximately 1 m of water. Glyphosate (Rodeo formulation) was applied by helicopter with microfoil boom at 3.4 kg a.i./ha with one of the following additive/additive combinations: 1) 0.5% v/v X-77, 2) 0.5% v/v X-77 + 1.0% polysar latex, 3) 0.5% v/v x-77 + 1.0% v/v Cide-Kick. The helicopter was calibrated to deliver 374 L/ha total mix with each glyphosate-additive treatment applied to

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[3]X-77, was provided by and is a registered trade name of Chevron Chemical Company, Richmond, CA.

[4]Polysar Latex is a clear latex base that was provided by 4-D Products, Inc. Chattanooga, TN.

[5]Cide-Kick was provided by and is a registered trade name by Brewer International, Vero Beach, FL.

an 0.8-ha area. Within each of these areas, 35, 9.3 m^2 subplots were demarcated using PVC stakes. Simulated rainfall events (SRE) were applied on selected subplots at 3, 6, 12, 24, 48 and 72 hours after glyphosate application. Each of these SRE's were replicated five times. SRE's were made using a handgun sprayer which delivered the equivalent of 1.3 cm of water evenly over the subplots in a known time period. A seventh set of 5 subplots received no SRE, but at 19 days after treatment 1.1 cm of rain fell.

Torpedograss control was evaluated 6 weeks after treatment by four evaluators. Control was evaluated on a 0 to 100 scale, where 0 equaled no control and 100 equaled complete control. Analysis of variance procedure was utilized to determine the effect of additives, rain-free period, and evaluator (Helwig and Council 1982). Only rain-free period had a significant effect on torpedograss control, therefore all other factors were pooled. Various linear and curve-linear models of control versus rain-free period were tested for fit with the relationship between rain-free period and control predictions based on regression analysis (Helwig and Council 1982).

A greenhouse study was conducted to corroborate rain-free period on torpedograss control with glyphosate as noted in the field study. Torpedograss rhizome sections were planted in 500 ml pots containing Metro-Mix and plants were allowed to develop for 6 weeks prior to treatment (30 to 40 cm tall). Glyphosate was applied at 0.56 or 1.68 kg a.i./ha with 0.25% v/v MON-0818[6] surfactant (polyoxyethylene tallow amine). Solutions were applied using CO_2-pressurized micro-applicator equipped with a TeeJet TX-6 hollow cone nozzle. Simulated rainfall (1.3 cm) was applied by watering can, uniformly directed over selected plants 3, 6, 9, 24, 48, 72, 96 and 144 hours after herbicide treatment.

Plants were maintained prior and subsequent to treatment in a greenhouse with the following conditions: mean day-light intensity 100 $\mu E\ m^{-2}\ sec^{-2}$, 32 ± 5 C, and 16 hours light/8 hours dark (natural day length extended using a combination of florescent and incandescent lights). Four weeks after treatment, shoot tissue was removed from all plants. After four additional weeks, regrown shoot tissue was harvested and dried at 60 C. Regrown shoot dry weight was then determined and used to calculate percent inhibition using the following equation:

$$\%I = [1-(\text{treatment}/\text{control})] \times 100$$

Data were subjected to ANOVA to determine the influence of glyphosate rate and rain-free period (Helwig and Council 1982). Glyphosate rate and rain-free period did not interact, therefore the average of the two rates is presented. Inhibition means were subjected to regression analysis to develop a model that was utilized to predict minimum required rain-free period to provide maximum torpedograss control.

Influence of diluent calcium content and ammonium sulfate. The influence of calcium in diluent water used for glyphosate applications and the interaction of added ammonium sulfate in diluent water was evaluated in greenhouse and field studies. The field study was conducted in March 1988 in a torpedograss-infested canal at the previously described FPL site. Raw irrigation well water containing 320 mg/L calcium carbonate and softened well water (12 mg/L calcium) were used with ammonium sulfate added at concentrations of 0, 0.05, and 0.1 M. Frigate[7] (polyoxyethylene tallow amine) surfactant was added to all treatments at 0.25% v/v with glyphosate applied at rates of 1.12, 2.24, and 4.48 kg a.i./ha. All treatment combinations of calcium, ammonium sulfate, and glyphosate were applied using a truck-mounted manifold sprayer calibrated to deliver 281 L/ha. Each treatment was applied to a 2.5 × 100 m area of torpedograss and replicated three times.

Data collected were visual ratings on a 0 to 100 scale and biomass of torpedograss leaf regrowth taken 7 weeks after treatment. Torpedograss shoots were randomly harvested above the water line from three, 0.25 m^2 areas using PVC frames tossed randomly within each treatment. Dry weights of torpedograss shoots were averaged and converted to percent inhibition relative to the non-treated control. Data were then subjected to ANOVA to determine the influence of the test factors and the presence of any interactions.

A greenhouse study was conducted to characterize further the influence of ammonium sulfate on torpedograss control. The culture, application methodology, data collection, and statistical analysis of this greenhouse study were the same as described previously, with the following exceptions. Treatment combinations were factorially arranged: glyphosate (0, 0.56, and 1.12 kg a.i./ha) and ammonium sulfate (0, 0.01, 0.05, and 0.1M).

Influence of diluent calcium content and diluent volume. The influence of diluent volume and calcium content of diluent water on glyphosate control of torpedograss was also evaluated at the FPL cooling reservoir site. Glyphosate was applied at 1.12 and 2.24 kg a.i./ha in 262, 496, 944, or 1879 L/ha of well water containing 320 mg/L calcium carbonate. Frigate surfactant was added to treatments at 0.25% (v/v). Treatments were applied using a 2.4-m airboat-mounted boom sprayer. Diluent volumes were achieved by varying nozzle size within a pressure range of 200 to 300 kPa and a boat speed within a range of 5 to 12 KPH. Treatments were applied to 3.0 × 50 m long areas of torpedograss and replicated 4 times. Torpedograss regrowth was harvested from three random areas within each plot 6 weeks after treatment. Non-treated torpedograss was also harvested to determine inhibition of regrowth. Data were subjected to ANOVA and means were separated using LSD at the 0.1 level (Helwig and Council 1982). Glyphosate rate and diluent volume interacted, therefore, diluent means were compared within a rate of glyphosate.

The effects of diluent volume on torpedograss control with glyphosate were further evaluated in a greenhouse study. Plant culture, application methodology, data collection, and statistical analysis was the same as described previously, with the following exceptions: treatment combinations were factorially arranged, 0 and 300 mg/L calcium, glyphosate rates of 0, 1.12, and 2.24 kg a.i./ha, and diluent volumes of 63, 234, 468, 935, and 1870 L/ha. All solutions contained 0.25% v/v MON-0818 surfactant. All applications were made using the same nozzle and pressure. To avoid potential con-

[6]Mon-0818 is a numbered surfactant provided by and manufactured for Monsanto Agricultural Products, St. Louis, MO.

[7]Frigate is a registered trade name for Fermenta Plant Protection Company, Mentor, OH.

founding effects of spray pressure or droplet sizes, diluent volumes were achieved by varying the total amount of solution applied to plants. Diluent volume, calcium content, and glyphosate rate interacted, therefore regression analysis was utilized to determine the influence of diluent volume within each calcium content-glyphosate rate combination.

RESULTS AND DISCUSSION

Influence of rain-free period and rain protectants. None of the compounds tested under field conditions affected the rain fastness of glyphosate on torpedograss so data from all treatments were pooled to analyze the affect of rain-free period following glyphosate application on torpedograss control. Both the field and greenhouse studies indicated that the control of torpedograss increased as the rain-free period following application increased up to 3 days (Figures 1 and 2). Though the maximum level of control attained in the field study (approximately 80%) is not considered adequate, these data can be used to indicate the importance of timing applications to avoid rain events soon after application. However, timing applications to avoid rain is difficult in the Southeastern U.S. due to the frequency of afternoon thunderstorms in the summer months. Improved perennial weed control is generally obtained when glyphosate is applied in the fall when photosynthate translocation is primarily basipetal (Majek 1980, Sandberg et al. 1980, Wyse 1988), and in Florida, rainfall events are more predictable. If these factors are taken into consideration, possible improvements in glyphosate activity on torpedograss could be obtained.

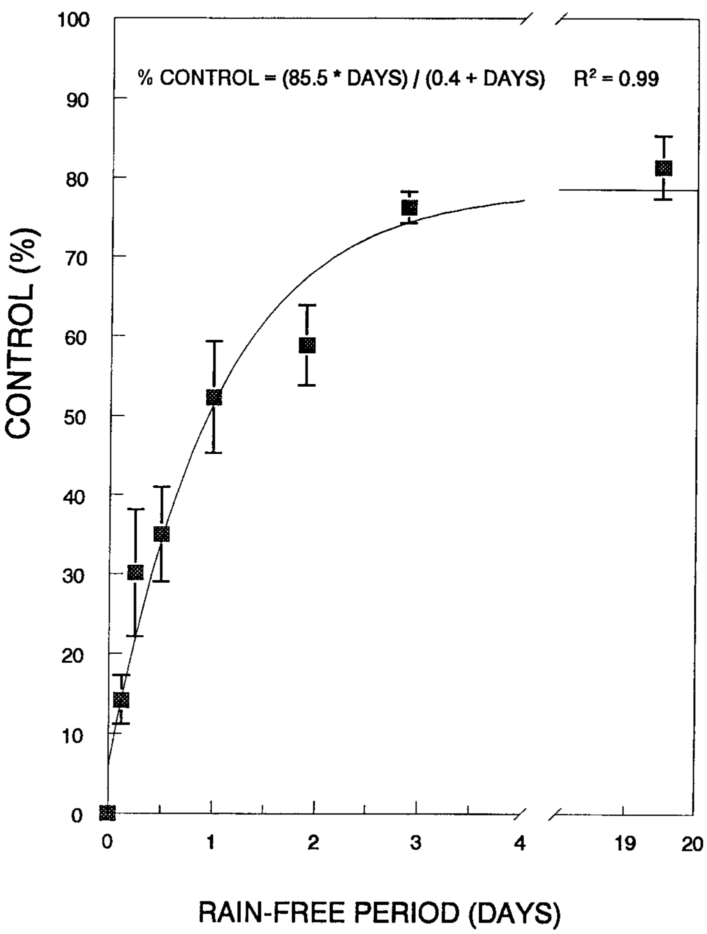

Figure 1. The influence of rain-free period on the control of torpedograss with glyphosate under field conditions. Evaluations were conducted at 6 weeks post-treatment. Shaded areas (squares) indicate rainfall events.

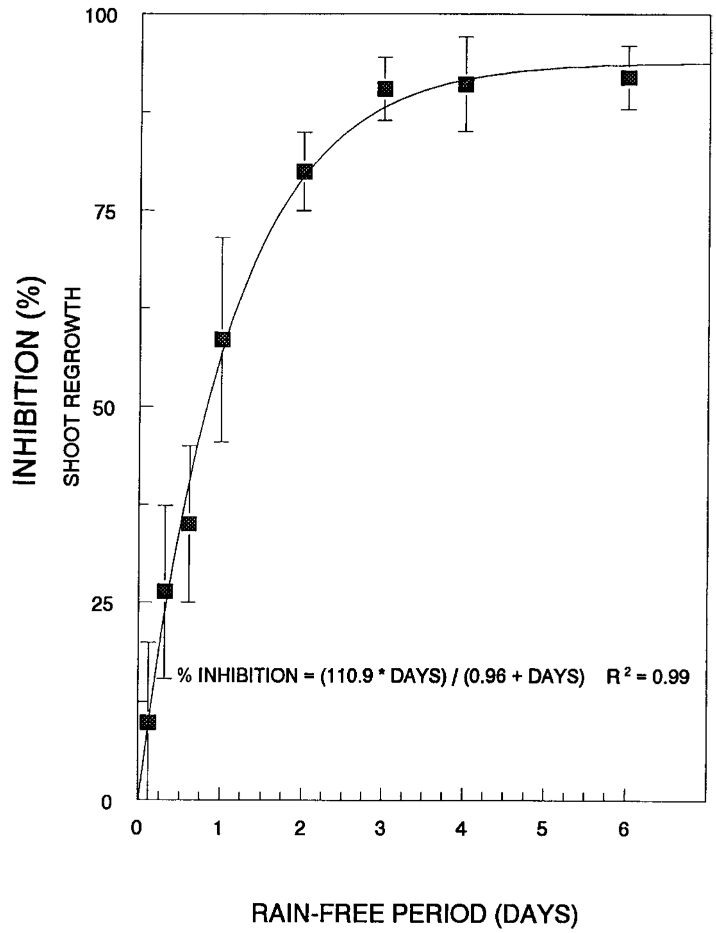

Figure 2. The influence of rain-free period on the activity of glyphosate on greenhouse grown torpedograss. Evaluations were made on torpedograss regrowth 8 weeks post-treatment. Shaded areas (squares) indicate rainfall events.

Influence of diluent calcium content and ammonium sulfate. Calcium has been reported to antagonize the activity of glyphosate (Buhler and Burnside 1983, Sandberg et al. 1978, Shilling et al. 1990) and in these studies, 320 mg/L of calcium carbonate in the diluent water decreased the control of torpedograss at all rates of glyphosate tested (Table 1). This is believed to result from the complexing of glyphosate with divalent ions such as calcium (Shilling and Haller 1989). Under these field conditions, 0.05 M ammonium sulfate either had no effect on the activity of glyphosate or caused a slight reduction in activity regardless of water quality or herbicide rate. Ammonium sulfate (0.1 M) with 2.24 and 4.8 kg/ha glyphosate reduced the antagonism caused by calcium, but did not affect the activity of glyphosate applied in soft water. However, at 1.12 kg/ha, 0.1 M ammonium sulfate enhanced the activity of glyphosate applied in soft water but did not reduce the antagonism caused by calcium. Ammo-

Table 1. Influence of calcium and ammonium sulfate on the control of torpedograss with glyphosate under field conditions. Values in table are percent inhibition of shoot regrowth.

Ammonium sulfate (M)	Calcium (mg/L)	Glyphosate (kg a.i./ha) 1.12	2.24	4.48
0	12	73	89	97
0	320	67	68	85
0.05	12	70	72	82
0.05	320	49	64	83
0.10	12	81	90	95
0.10	320	65	73	93

LSD 0.1 = 5 for glyphosate and ammonium sulfate comparisons.
LSD 0.1 = 4 for calcium comparisons.

nium sulfate has been reported to enhance the activity of acidic herbicides including glyphosate (Wills and McWhorter 1985), and in addition, ammonium sulfate has been shown to reduce the antagonism of glyphosate by calcium ions (Shilling et al. 1990). Under greenhouse conditions (data not shown), ammonium sulfate had no effect on the activity of glyphosate. This could have been caused by the fact that maximum activity (all treatments were lethal) was obtained without any additive thereby precluding any possible enhancement in activity.

Influence of diluent calcium content and volume. Data from this field study indicated that diluent volume influenced torpedograss control obtained with glyphosate (Table 2). These applications were made using water that contained 320 mg/L calcium as calcium carbonate. At 1.12 kg a.i./ha glyphosate, control of torpedograss regrowth was 92-93% when applied in 262, 496, and 1979 L/ha. However, at 944 L/ha there was significant reduction in control (78%). At 2.24 kg a.i./ha, glyphosate provided excellent control (94-97%) at diluent volumes ranging from 262 to 944 L/ha. However, at 1879 L/ha, control was significantly reduced (87%). These interactions of glyphosate rate and diluent volume (when applied in hard water) seemed to be in contradiction with results from other studies on perennial weed control with glyphosate that indicated glyphosate activity increases linearly with decreasing diluent volume (Baird et al. 1983b, Buhler and Burnside 1983).

The greenhouse study was conducted in an effort to clarify the interactions of calcium, glyphosate, and diluent volume. When glyphosate was applied in water containing no

Table 2. Influence of diluent volume on the control of torpedograss under field conditions using hard water. Diluent hardness was 320 mg/L calcium carbonate. Values in table are percent inhibition of shoot regrowth.

Diluent volume (L/ha)	Glyphosate (kg a.i./ha) 1.12	2.24
262	92	96
496	92	97
944	78	94
1879	93	87

LSD 0.1 = 6 for diluent volume and glyphosate comparisons.

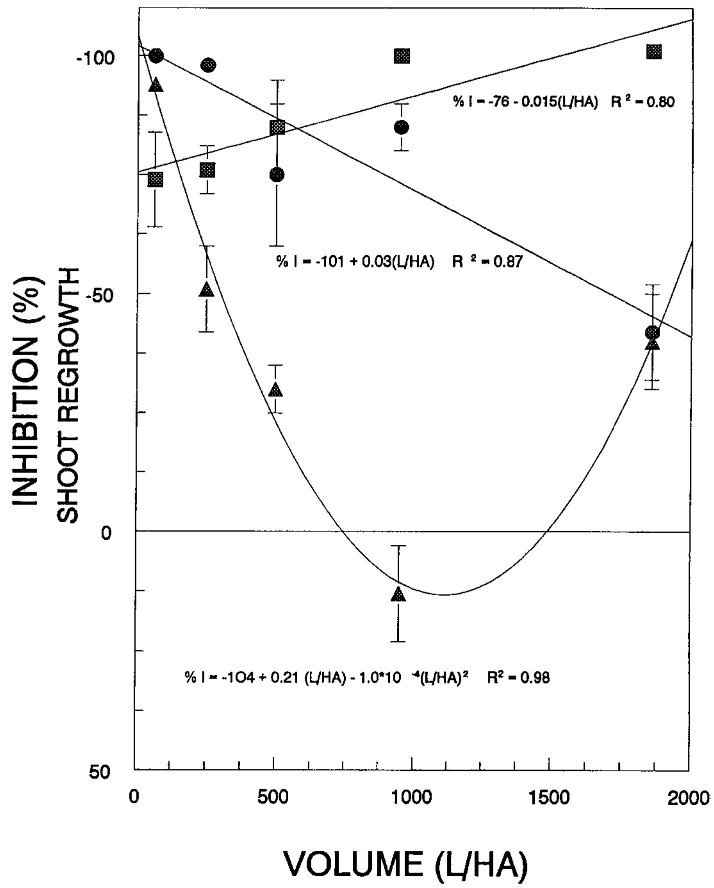

Figure 3. Interaction of glyphosate and diluent volume and calcium content on the suppression of torpedograss regrowth by glyphosate; (●) 0 mg/L calcium and 1.12 kg a.i./ha glyphosate, (■) 300 mg/L calcium and 2.24 kg a.i./ha glyphosate, and (▲) 300 mg/L calcium and 1.12 kg a.i./ha glyphosate.

calcium, 100% control of regrowth was obtained at 2.24 kg a.i./ha regardless of diluent volume ($P > 0.05$; data not shown). However, when glyphosate was applied at 1.12 kg a.i./ha without calcium, control increased linearly as diluent volume increased (Figure 3). When 2.24 kg a.i./ha of glyphosate was applied in water containing 300 mg/L calcium (hard water), control of regrowth decreased linearly with increasing diluent volume. Ostensibly, as diluent volume increased the concentration of glyphosate decreased while the concentration of calcium remained constant. This resulted in an increasing proportion of glyphosate being deactivated by calcium as the relative amount of glyphosate decreased. As diluent volume increased, the ratio of calcium to glyphosate increased, which resulted in a decrease in torpedograss control. This is because the higher the proportion of calcium to glyphosate, the more likely calcium is to interact and bind with glyphosate.

When 1.12 kg a.i./ha glyphosate was applied in hard water, control decreased with increasing diluent volume up to 935 L/ha (Figure 3). The decrease in activity with increasing diluent volume occurred for the same reason stated previously. However, at 1870 L/ha, control increased and was comparable to the control achieved with 234 L/ha. One possible explanation for this result is that greater coverage compensated for a decrease in available glyphosate. Torpedograss grows in dense stands. Consequently at low diluent volumes many plants were not treated and translocation will not overcome incomplete coverage within a treated population. This phenomenon may be of practical importance when attempting to control torpedograss that has been allowed to produce a dense mat. In order to maximize the amount of glyphosate translocated to rhizomes throughout the mat it may be necessary to increase the diluent rather than decrease it, especially if the diluent water is hard.

A rain-free period of at least three days is required to optimize torpedograss control with glyphosate. Three potential rain protectants failed to provide rain fastness under experimental conditions in which they were evaluated. Hard water reduced glyphosate efficacy and the addition of ammonium sulfate did not consistently protect glyphosate from calcium inhibition. The interaction of glyphosate and diluent volume is complicated by plant coverage and the influence of divalent ions in the diluent water.

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