Appendix B

The information contained in Appendix B was reviewed by Dr. Henry Nowicki in Feb, 2015. Dr. Nowicki states in his memo to C2R Global dated Feb. 19, 2105, that the results of Dr. Bert McCarty's "Activated Charcoal For Pesticide Deactivation" report can be used to support the claims of Rx Destroyer.

ACTIVATED CHARCOAL FOR PESTICIDE DEACTIVATION

Bert McCarty

Activated charcoal (also called activated carbon) is often used to adsorb or deactivate organic chemicals such as pesticides. Activated charcoal has been used for many years to remove organic contaminants from waste waters and in water purification systems. Since most pesticides are organic chemicals, activated charcoal can effectively be used to deactivate or "tie up" these products in soil. Once the pesticide has been adsorbed onto activated charcoal, it is biologically inactive and cannot cause injury to the turfgrass. Therefore, this product can be beneficial to turfgrass managers in the case of an accidental pesticide spill or where a herbicide needs to be inactivated for seeding or sprigging of turfgrasses. Due to its dark color, thus ability to absorb heat, activated charcoal is also used to artificially warm the soil to minimize the effects of light frosts or to allow earlier seeding of an area.

Charcoal is porous, soft, black substance made by heating in an restricted amount of air, substances containing carbon such as material from hardwood trees and coconut shells. Powdered activated charcoal is made up of very small carbon particles that have a high affinity for organic chemicals such as pesticides. Activated charcoal has a large surface area and can absorb 100 to 200 times its own weight.

The amount of activated charcoal to apply to a pesticide-contaminated area varies with the chemical characteristics of the particular pesticide. Rates generally range from about 100 to 400 pounds of activated charcoal per acre (2.3 to 9.2 pounds per thousand square feet) for each pound of active ingredient of a pesticide applied per acre. A general rule is to apply about 200 pounds of activated charcoal per acre (4.6 pounds per thousand square feet) for each pound of pesticide active ingredient per acre.

Rates of activated charcoal used for spills and deactivating turf pesticides.

Application	Recommendation	Comments
Spills	For reducing the effects from spills of organic pesticides, some petroleum products, and hydraulic fluids.	Use 100 to 400 lbs of activated charcoal to every pound of active material spilled per acre (2.3 to 9.2 lbs/1000 ft^2). If the active material has not been diluted with water at the time of spill, apply the charcoal directly as a dry power. If the active material has been diluted with water, apply the activated charcoal in a slurry with a sprinkle can or common sprayer equipment. The charcoal must be incorporated into the contaminated soil, preferably to a depth of 6 inches. With severe spills, some of the contaminated soils may need removal prior to activated charcoal application.
'Deactivating' turf herbicides and soil warming	Turf areas that have been treated with preemergence herbicides can be reseeded earlier than normal by treating with activated charcoal.	Whenever it is desirable to terminate a preemergence herbicide, apply charcoal slurry at a rate of 2 to 4 lbs/1000 sq.ft. Water the slurry into the soil. Make sure the grass is washed free of heavy charcoal deposits. Where possible, it is desirable to rake the charcoal into the soil thoroughly. The area can be seeded 24 hrs after treatment.

Example: Suppose Balan 2.5G was inadvertently applied at 2 pounds of active ingredient per acre to an area to be seeded with a turfgrass. To completely inactive this herbicide, an application of activated charcoal at 400 pounds per acre (or 9.2 pounds per 1000 square feet) would be needed. See the following table for additional conversions of rates per acre to pounds per 1000 square feet.

Conversion from Pounds of Activated Charcoal Per Acre to Pounds of Activated Charcoal Per 1000 Square Feet.

Rate of Activated Charcoal (pounds per acre)	Activated Charcoal Needed (pounds per 1000 square feet)

100	2.3
200	4.6
400	9.2
800	18.4
1,600	36.7
3,200	73.5

Activated charcoal can be applied by various methods. It can be applied in the dry form with a drop spreader. However, activated charcoal particles are easily moved by wind, so it may be difficult to distribute the charcoal evenly when applied in the dry form. The easiest method is to suspend the charcoal in water and apply it by hand with a watering can (for small areas) or a power sprayer. Because activated charcoal does not mix easily with water, a 0.5 % solution of a nonionic surfactant (equivalent to 1 quart per 50 gallons) will enhance its suspension in water. Note that charcoal particles are very abrasive and can damage spray equipment (particularly rotary type pumps). Therefore, if a sprayer is used to apply activated charcoal, care should be taken to thoroughly clean the equipment when finished.

When deactivating a pesticide in a seedbed, the activated charcoal should be incorporated with a rotary tiller or other appropriate equipment so that the charcoal is placed in the upper few inches of soil. The objective is to get the activated charcoal in the same proximity as the pesticide. Uniform application of activated charcoal followed by thorough mixing is the key to inactivating a pesticide-contaminated area. If the pesticide is on the turf, in the thatch layer, or uppermost surface of the soil (for instance, if the pesticide has not been watered in), the pesticide can be inactivated by simply applying the charcoal to the area and thoroughly watering once charcoal application is complete. Again, the objective is to place the charcoal in the same proximity as the pesticide. If activated carbon is applied and either incorporated or watered correctly, inactivation of the pesticide will be successfully accomplished. For application convenience, it is recommended that activated charcoal be applied as a water slurry. To minimize dusting, always add activated charcoal to water slowly, keeping the bag as close to the water surface as possible. The following steps are suggested when mixing and applying charcoal.

Spray Application

1. Make sure spray equipment, tubing, and nozzles are completely clean. Screens should be removed if practical.
2. The final spray mixture should contain 1 to 2 lbs of charcoal per gallon of water.
3. Add sufficient water to begin moderate agitation. Simultaneously add the balance of required water and charcoal. Continue agitation until a uniform mixture is obtained.
4. Maintain moderate agitation while spraying.

It is important to understand situations where activated charcoal will not work. If a herbicide has been applied for several weeks and rainfall has occurred and/or irrigation water has been applied, the herbicide is most likely past the thatch layer and, depending on water solubility and soil adsorption of the herbicide, is probably in the upper inch or so in the soil. In this case, activated charcoal would have to be physically incorporated with a rotary tiller or other implement to get the charcoal in contact with the herbicide. The reason is activated charcoal will not leach through soil. If activated charcoal is applied to the soil surface and watered, the charcoal will remain on top of the soil and will not inactivate the herbicide below the soil surface. Activated charcoal is considered ineffective for inorganic pesticides such as arsenates, lead compounds, sodium chlorate, sulfur, borax, etc., and water-soluble organic pesticides such as, but not limited to, MSMA, and DSMA.

Activated carbon is available from most suppliers of turfgrass products. It is a good idea to keep several bags on hand so it can be applied immediately instead of having to wait for delivery. Several different brands and formulations are on the market. There appears to be little if any differences in effectiveness of the different brands. However, some may be easier to apply than others, depending on the particular situation where it is to be used.

Suppliers of activated charcoal include:

'Gro-Safe' from: American Norit Co., Inc. 1050 Crown Pointe Parkway Atlanta, GA 30338 1-800-641-9245	‘Clean Carbon’ from: Aquatrols 5 North Olney Ave. Cherry Hill, NJ 08003 1-800-257-7797

'52 Pickup' from: Parkway Research Corp. 13802 Chrisman Road Houston, TX 77039 1-800-442-9821	'D-Tox' from: Cleary's Chemical Corporation 178 Ridge Road Dayton, NJ 08810-1501 800-524-1662 www.clearychemical.com

Quinclorac: Soil Behavior and Foliar vs. Root Absorption by Torpedograss (*Panicum repens*)

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Quinclorac: Soil Behavior and Foliar vs. Root Absorption by Torpedograss (*Panicum repens*)[1]

WALKER WILLIAMS, GLENN WEHTJE, and ROBERT H. WALKER[2]

Abstract: Selective placement studies were conducted under greenhouse conditions to determine the relative importance of root vs. foliar absorption of postemergence-applied quinclorac by torpedograss. Foliar + soil and soil-only applications were more effective than foliar-only in reducing torpedograss foliage at 4 wk after treatment (WAT). However, foliar-only and foliar + soil were more effective than soil-only in suppressing regrowth at 10 WAT. Quinclorac foliar absorption by torpedograss and subsequent translocation, as determined with radiotracer techniques, was minimal. After 72 h, only 26% of the applied quinclorac had been absorbed, and 13.7% of the amount applied remained within the treated leaf. Only 0.3% of applied was recovered in the roots, and none was detected in the developing rhizomes. Quinclorac was readily root absorbed and translocated. After 6 h, a 26.7 μg/plant dose of quinclorac had been absorbed, and 54% of this quantity remained in the roots; the remaining 46% having been translocated throughout the plant. The youngest leaf and the immature rhizomes accumulated 5 and 9% of the amount absorbed, respectively. Quinclorac was not readily soil sorbed as determined by soil solution experiments. Quinclorac was displaced nearly concomitant with the wetting front in soil chromatography. Soil solution concentration and soil mobility were greater at pH 6.7 than at 5.7. Results establish that consistent control of torpedograss with quinclorac is dependent on soil entry and root absorption. Unfortunately, the propensity of quinclorac to be water displaced could negatively affect this control.
Nomenclature: Quinclorac; torpedograss, *Panicum repens* L. #[3] PANRE.
Additional index words: Herbicide translocation, soil sorption, soil mobility, soil pH.
Abbreviations: WAT, weeks after treatment; LSS, liquid scintillation spectrometry.

INTRODUCTION

Torpedograss is a perennial, rhizomatous, C_4 plant indigenous to the Gulf Coast region of the southern United States from Florida to Texas (McCarty et al. 1993). Torpedograss frequently infests warm-season turfgrasses. It can reduce the growth of common bermudagrass [*Cynodon dactylon* (L.) Pers.] by nearly 40% within 2 yr after introduction (Wilcut et al. 1988). Torpedograss does not propagate by seed in the United States (Wilcut et al. 1988).

Torpedograss spreads primarily through sharp-pointed rhizomes, which can extend up to 6 m from the parent plant (Holm et al. 1977). Very small rhizome fragments have the potential to regenerate (Tenpenny et al. 2001). Because of the lack of apical dominance, every node along the entire rhizome may sprout nearly simultaneously (Wilcut et al. 1988). Although tillage is generally ineffective for control in agronomic crops, in contrast, certain tillage-type operations commonly conducted in turf, such as core aerification, may serve as an ideal means of further dispersing torpedograss. Torpedograss tolerates many selective herbicides used in warm-season turf. However, quinclorac has been recently registered for selective torpedograss control within several species of warm-season turf including common and hybrid bermudagrass.[4] Before this registration, nonselective control with multiple applications of glyphosate, followed by resodding, was the only option available (Brecke and Unruh 2001). Specific label recommendations for torpedograss control are either two sequential applications of 1.50 kg/ha each or three sequential applications of 1.00 kg/ha each. The total amount of quinclorac applied must not exceed 3.0 kg/ha per season, and sequential applications are to be 3 wk apart. Torpedograss control with

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds,* Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.
[4] Formulated as "Drive 75DF". Available from BASF Corp., 100 Cherry Hill Road, Parsippany, NJ 07054.

quinclorac is dependent on rate and the number of applications. McCarty et al. (1993) reported that quinclorac rates in excess of 2.2 kg ai/ha were required for >80% torpedograss control in bermudagrass turf and that sequential applications were more effective than single applications. Although rates above 2.2 kg/ha were more effective, turf quality was reduced. Brecke et al. (2001) reported that three applications of quinclorac at 0.60 kg/ha each, spaced 3 wk apart, controlled torpedograss 88%, and bermudagrass turf quality was not reduced.

Quinclorac is a substituted quinolinecarboxylic acid, a class of highly selective auxin herbicides. Reviews on the mode of action and basis of selectivity are available elsewhere (Grossman 1998; Grossman and Kwiatkowski 2000; Grossman and Scheltrup 1998; Koo et al. 1994; Zawierucha and Penner 2000). Mode of action and associated symptomatology varies between grass and broadleaf species. In sensitive grasses, there is an accumulation of cyanide, which causes phytotoxicity characterized by inhibition of roots and shoot growth with tissue chlorosis and subsequent necrosis. Conversely, typical auxin-type herbicide symptoms occur in sensitive broadleaf species. Foliar absorption of quinclorac by target species has been quantified by several authors, however, results have been variable (Chism et al. 1991; Grossman and Scheltrup 1998; Zawierucha and Penner 2000). Chism et al. (1991) reported that within 0.5 h of foliar application, 85 and 66% of the amount applied was absorbed by southern crabgrass [*Digitaria ciliaris* (Retz.) Koel] and Kentucky bluegrass (*Poa pratensis* L.), respectively. These authors speculated that differential selectivity between species may be the result of differences in uptake, distribution, and root exudation. In contrast, Zawierucha and Penner (2000) reported that quinclorac absorption after an 80-h exposure time by the foliage of large crabgrass (*Digitaria sanguinalis* L.) and goosegrass (*Eleucince indica* L.) was only 27 and 22% of amount applied, respectively. Large crabgrass was identified as quinclorac sensitive and goosegrass was as quinclorac tolerant. However, the minimal difference in amount absorbed was not considered to be the contributing factor in the differential species response.

According to the product label, ''[quinclorac] is absorbed by foliage and roots and translocated throughout the plant.'' Root absorption has been documented (Grossman and Scheltrup 1998) in laboratory studies. And observations by the authors (unpublished data) have suggested that root absorption of quinclorac may be component of its overall activity. Determining the relative importance of root vs. foliar absorption of quinclorac by torpedograss was our first experimental objective. For quinclorac to be effective in controlling torpedograss, some portion of the applied quinclorac must be absorbed by or be translocated into the rhizomes. Our second objective was to quantify root and foliar quinclorac absorption and evaluate subsequent translocation to rhizomes. Quantification of absorption and translocation was accomplished with radiotracer techniques.

For any herbicide to be subject to root absorption, a portion of the soil-applied herbicide must remain available within the water phase of the soil, i.e., not adsorbed to soil colloids (Schmidt and Pestemer 1980). Yet an excessive propensity to remain within the soil solution renders a herbicide subject to displacement by way of leaching. Determining the propensity of soil-applied quinclorac to remain in the soil solution, and its soil mobility, neither of which have been established, was our third objective. The aqueous solubility of quinclorac is 62 μg/L, and the molecule has a single carboxyl group; pKa = 4.34 (Ahrens 1994). Consequently, both the solubility and associated herbicidal activity of quinclorac is likely to be pH dependent. Soil pH was included as an additional experimental variable in soil solution and soil mobility experiments.

MATERIALS AND METHODS

General Information. Studies involving plant growth were conducted in a glass-glazed greenhouse, equipped with evaporative cooling. Day/night temperatures were set to 28/22 C, and photoperiod from natural light ranged from 14 to 11 h for July and September, respectively. Midday light typically did not exceed 285 μmol/m^2/s. Relative humidity averaged 40 to 50%.

All experiments were conducted in completely randomized designs. However, the replicate number varied across experiments. All experiments were repeated in time. All data were subjected to ANOVA using the general linear model procedure (SAS 1992). For all experiments, preliminary statistical analysis detected no interaction between treatments and experimental repetitions. Consequently, data were pooled across repetitions. Further description of statistical analysis, pertinent means separations, and data presentations are dealt with on an individual experiment basis.

Root vs. Foliar Absorption of Quinclorac by Torpedograss. Soil used in this study was from the Ap horizon of a Kalmia series. The Kalmia series is a coarse-loamy, siliceous, subactive, Typic Paleudults with 83% sand, 14% silt, and 3% clay. Soil pH was 5.7. Soil was air-

dried and sieved to a particle size of <5 mm. Individual rooted torpedograss shoots, with developing rhizomes evident, were planted in 1-L styrofoam cups using this soil. The cup bottoms had been perforated to allow drainage. Torpedograss plants were maintained within a greenhouse for approximately 3 wk, at which time the plants were well established and the rhizome-based spread was evident. The cups were saturated by hand watering at 2 d intervals. Plants received no nutrients other than what was available within the soil.

A factorial treatment arrangement of four quinclorac rates (0.56, 0.78, 1.01, and 1.23 kg/ha) and three application methods was used. Application methods were foliar + soil, foliar-only, and soil-only. The plants were removed from the greenhouse to an adjacent paved area for treatment application and returned immediately thereafter. Foliar-only and foliar + soil applications were applied with a CO_2-pressurized, backpack sprayer calibrated to deliver 280 L/ha. A methylated seed oil type adjuvant,[5] as specified by the product label, was included at the recommended rate of 0.25% v/v of the spray solution. Foliar-only application was achieved by applying a 1-cm layer of activated charcoal over the soil surface before treatment. Charcoal was removed within 24 h after application. For the soil-only application, the amount of spray solution that would be intercepted by the surface area of the cup was diluted into 10 ml of water and distributed over the soil surface while avoiding foliar contact. No compensation was taken for the quantity that would have been retained by the foliage. A nontreated control also was included. Treatments were applied within 6 h of a routine irrigation, and irrigation was not resumed until 72 h after treatment application. Each treatment was applied to four single-cup replicates.

Torpedograss foliage was clipped within 1 cm of the soil surface at 4 wk after treatment (WAT). Clipped tissue was dried at 45 C (24 h) and weighed. Torpedograss was subsequently allowed to regrow for three additional weeks (i.e., 7 WAT), at which time all foliage was again harvested and weighed. Regrowth and subsequent foliage harvest was repeated again at 10 WAT. Torpedograss foliage at 4 WAT, and the regrowth at both 7 and 10 WAT were expressed as percent reduction relative to the nontreated control. Statistical analysis addressed the factorial treatment arrangement, and treatment main effects were separated with an LSD ($P = 0.05$) comparison.

The experiment as described above was repeated but with soil pH included as an experimental variable. Two pH values were included, i.e., 5.7 and 6.7. Soil of pH 5.7 was obtained directly from the field as previously described. A supply of this soil was amended with dolomitic agricultural limestone at a rate of 1.61 g/kg soil. Amended soil was wetted to field capacity and allowed to equilibrate for 2 mo. Soil was then dried and sieved as previously described before use; pH determination confirmed that the desired change had been achieved. Experimental particulars, data collection, and statistical procedures were identical to the previous experiment with the only exception being that seven single-cup replicates were used.

Quinclorac Soil Adsorption and Mobility. These experiments were conducted under laboratory conditions where the room temperature was approximately 20 C. Quinclorac soil adsorption was evaluated using a soil solution technique that has been described elsewhere (Adams et al. 1982; Goetz et al. 1986, 1989). Briefly, appropriate amounts of formulated[4] quinclorac and uniformly ring-labeled ^{14}C-quinclorac[6] were added to the soil (1.0-kg samples) to achieve the desired soil concentrations (identified below). The formulated and ^{14}C-labeled quinclorac were first combined with 140 ml of tap water. This amount of water was required to bring the soil sample to field capacity. Field capacity had been previously determined to be 14% by the method described by Adams et al. (1982). This solution was then applied to the dry, 1-kg soil sample in a glass beaker, mixed thoroughly, covered with plastic film and aluminum foil to prevent evaporation and allowed to equilibrate for 24 h. After equilibration, soil samples were divided into four subsamples (285 g each) and placed into individual soil solution extraction cups. Extraction cups consisted of a plexiglass cylinder (inner diameter of 8 cm by depth of 20 cm) with a perforated bottom. This allowed the soil solution to be extracted from the soil and collected in a catch cup that was attached below the soil-containing portion. Filter paper was placed between the soil sample and the perforated bottom to prevent soil clogging the perforations. Samples were centrifuged at 2,500 rpm (1,960 *g*) for 2 h, and 1-ml subsamples of the extracted soil solution were assayed for ^{14}C using liquid scintillation spectrometry (LSS). Radioactivity in the recovered soil solution typically ranged from 30 to 60 kBq/ml. Minimal counting efficiency, based on the automatic external standard quench curve, was at least 94%. The difference between radioactivity

[5] Destiny® as marketed by Agriliance, LLC., P.O. Box 64089, St. Paul, MN 55164-0089.

[6] Supplied by BASF Corp., 100 Cherry Hill Road, Parsippany, NJ 07054. Specific activity = 1.5 MBq/mg.

in solution before adding to the soil and the radioactivity in solution recovered from the soil was assumed to represent quinclorac that had been retained (i.e., adsorbed) by the soil.

The experimental variables were quinclorac concentration and soil pH. Three concentrations were included: 0.85, 8.5, and 85 μg/g; dry weight basis. The middle concentration was based on the 1.01 kg/ha application rate. This rate is equivalent to 10.10 μg/cm^2. The soil bulk density was 1.18 g/cm^3. Assuming this rate of quinclorac was to be incorporated to a depth of 1 cm, the resultant concentration would be 8.5 μg/g. The other two concentrations bracket this concentration by a factor of 10. Two pH values were included, 5.7 and 6.7. The soil with these two pH values was obtained as previously described. The experiment consisted of a factorial treatment arrangement of three concentrations and two pH values. The experiment included four replicates for each concentration–pH treatment. Statistical analysis addressed the factorial treatment arrangement, and treatment main effects were separated with an LSD (P = 0.05) comparison.

Soil mobility was evaluated by soil thin-layer chromatography using procedures based on those first described by Helling (1971). Briefly, a 3-mm-thick layer of soil (40-mesh screening) was deposited on a 20- by 20-cm glass plate as a water slurry that was then dried (45 C). A quinclorac solution (0.5 mg/L), which had been spiked with ^{14}C-quinclorac at approximately 600 kBq/ml was spotted 1 cm from the bottom of the plate. The plate was placed on a holding stand, which was lowered into a glass chromatography tank. The tank was filled with water until the water level came in contact with the soil. Water was absorbed by the soil and moved up the plate for a distance of approximately 17 cm. The distance between the herbicide-spiked origin and the wetting front was divided into 10 equal increments. Each increment was removed, combined with 10 ml of scintillation fluid, and radioactivity was quantified by LSS. Radioactivity recovered in each increment was expressed as a percentage of the total amount recovered for each plate. An experimental unit consisted of an individual plate. Mobility was evaluated at pH 5.7 and 6.7 with four replicates for each pH value. Comparisons between the two pH values within common increments were made using an LSD (P = 0.05) value.

Foliar Absorption and Translocation of Quinclorac by Torpedograss. Experiments were conducted in the greenhouse as previously described. A 30- by 40-cm stainless steel pan was filled with half-strength Hoagland's solution (Hoagland and Arnon 1950). A 1-cm-thick sheet of styrofoam was trimmed so that it floated freely on the surface with only minimal side clearance. One-cm holes had been cut through the styrofoam. Torpedograss plants (single-rooted shoots) were placed within these holes such that the roots entered the nutrient solution. A small aquarium pump was used to continually aerate the solution. Plants were maintained for 4 d in hydroponic culture, at which time rhizome development was evident.

A 1-cm section in the center of the youngest, fully expanded leaf blade was covered with aluminum foil. Plants were treated with quinclorac at 1.01 kg/ha as previously described. After treatment, the foil was removed and a 2 μl aliquot of the quinclorac spray solution, spiked with ^{14}C-quinclorac was applied to the previously covered leaf area using a microapplicator.[7] The final concentration of quinclorac and radioactivity in the spiked solution was 5,370 μg/L and 192 kBq/2 μl, respectively.

Treated plants remained in hydroponic culture until harvested at either 48 or 72 h. At harvest, the treated leaf blade was detached, the target area that received the ^{14}C-herbicide was excised, and washed with a water–methanol solution [50:50 (v/v)]. Single 1-ml aliquots of this wash solution had been previously added into 20-ml scintillation vials. An excised target area was placed into a vial and agitated with a swirling motion for 30 s. Target area tissue was then removed, and 10 ml of scintillation fluid was added to the vial in preparation for counting. The remaining portions of the treated leaf blade, i.e., the portions above and below the target area also were collected. The remainder of the plant was further partitioned as described in the tables. All plant tissue sections were dried at 45 C (24 h), combusted in a biological tissue oxidizer, and radioactivity was quantified through LSS. Radioactivity detected in leaf wash and tissues sections was expressed as the percent relative to the amount applied. Total recovery was >99% of the amount applied. The experiments included either 10 single-plant replicates (first repetition) or four replicates (second repetition). An LSD (P = 0.05) value was used for comparing between-individual amounts.

Root Absorption and Translocation of Quinclorac by Torpedograss. Torpedograss plants were hydroponically grown as previously described. To initiate quinclorac root exposure, plants were transferred to a small beaker containing the same nutrient solution only spiked with both formulated[4] and ^{14}C-labeled quinclorac such that the

[7] Burkard manufacturing Co. Ltd., Woodcock Hill Industrial Estate, Rickmansworth Hertfordshire WD3 IPJ, U.K.

Table 1. Response of torpedograss to rate and selective placement applications of quinclorac; main effects only.

Main effect	Fresh weight foliage (4 WAT)[a]	Fresh weight regrowth	
		7 WAT	10 WAT
	% reduction		
Quinclorac (kg ai/ha)			
0.56	33 a[b]	33 b	14 ab
0.78	26 a	35 b	8 b
1.01	36 a	53 ab	22 a
1.23	36 a	65 a	26 a
Application method			
Foliar + soil	36 a	74 a	26 a
Foliar-only	21 b	25 b	24 a
Soil-only	39 a	40 b	2 b

[a] Foliage was harvested 4 wk after treatment (WAT). Regrowth was harvested twice at 3-wk intervals, i.e. 7 and 10 WAT. Data were expressed as percent reduction relative to nontreated controls (not shown).

[b] Main effect means within a common column and followed by the same letter are equivalent according to the appropriate LSD (P = 0.05) comparison.

quinclorac concentration and radioactivity were 38 μg/L and 42 kBq/ml, respectively. This 38-μg/L concentration was based on the 1.01 kg/ha application rate, which with the previously mentioned assumptions results in a soil dry weight concentration of 8.5 μg/g. As previously mentioned, the field capacity of this soil is 14%. Therefore, the maximum potential quinclorac concentration (i.e., none lost to adsorption) with the soil water was 61 μg/L. In preliminary trials of the soil solution technique as described herein, the proportion of quinclorac that remained in the soil solution (i.e., not retained by soil colloids) was 63%. Thus, the theoretical maximum concentration of quinclorac within the soil solution resulting from the 1.01 kg/ha rate was 38 μg/L.

The plants were transferred to the spiked solution at 6:00 A.M. and harvested at 6, 12, and 24 h later. At harvest, the plants were removed from the spiked solution and the roots were washed twice with tap water. The roots were cut off, and the remaining foliage was sectioned into various portions (see tables). Tissue samples were dried at 45 C for 48 h and weighed before combustion in a biological tissue oxidizer. Radioactivity, which was quantified by LSS as previously described, was converted to the amount of quinclorac. The quinclorac concentration was then calculated for each of the plant portions harvested. The experiment had five single-plant replicates for each of the three exposure times. An LSD value (P = 0.05) was used for comparing between-individual amounts.

RESULTS AND DISCUSSION

Root vs. Foliar Absorption of Quinclorac by Torpedograss. Statistical analysis revealed that all response variables were influenced by quinclorac rate and application method. However, a rate by application method interaction was not detected for any of the response variables. Consequently, only the main effects data are presented (Table 1). Reduction in fresh weight was independent of rate. However, reductions in regrowth were influenced in a positive manner by quinclorac rate (Table 1). Torpedograss control also was influenced by the application method, but this response was not consistent across the response variables. Both the soil-only and foliar + soil applications had maximum 4 WAT foliage weight reduction. At 7 WAT, only the foliar + soil application had maximum regrowth reduction. However, at 10 WAT both the foliar + soil and foliar-only applications had maximum regrowth reduction. Speculation as to why the application methods varied in relative efficacy is presented below.

Table 2. Proportion of quinclorac within the water phase of a Kalmia, sandy loam soil at field capacity as influenced by soil pH and quinclorac concentration; main effects only.

Main effect	Proportion in soil solution
	%
Quinclorac spiking concentration (μg/g dry weight)	
0.85	44.1 c[a]
8.50	62.7 b
85.00	77.2 a
Soil pH	
5.7	61.3 b
6.7	65.9 a

[a] Means within a common main effect that are followed by different letters are significantly different according to the appropriate LSD (P = 0.05) comparison.

As previously mentioned, this experiment was repeated with soil pH as a variable. Both soil-only and foliar + soil applications were equally effective in reducing foliage fresh weight at 4 WAT (data not shown). Foliage reduction as averaged over all other experimental variables was 57 and 64% at pH 5.7 and 6.7, respectively (difference not significant and data not shown). Regrowth was minimal across all treatments. Consequently, these data are not presented.

Quinclorac Soil Adsorption and Mobility. Proportion of quinclorac that remained in the soil solution (i.e., not adsorbed) was influenced only by the main effects of concentration and soil pH (Table 2). Quinclorac soil adsorption, as indicated by the reciprocal of the amount detected in soil solution and as averaged over all concentrations, was 38.7 and 34.1% at pH 5.7 and 6.7, respectively. Thus, quinclorac was more soil available and more subject to leaching at the higher pH value. At the middle concentration (8.5 μg/g), regardless of pH, over

Table 3. Quinclorac mobility in a Kalmia, loamy sand soil as determined by soil chromatography.

Increment	Soil pH	
	5.7	6.7
	%	
1 (origin)	2.2	2.2
2	1.8	1.8
3	1.9	2.0
4	2.1	2.2
5	2.7	2.5
6	3.6*[a]	3.0
7	5.8*	4.2
8	14.0*	7.5
9	46.8*	17.8
10 (wetting front)	19.0*	56.7

[a] Asterisk indicates significant difference between pH values within the same increment based upon appropriate LSD (P = 0.05) comparison.

60% of the applied quinclorac was recovered in soil solution. This response is relatively high for a soil-active herbicide. In previous unrelated research conducted by Goetz et al. (1989), the proportion of atrazine, metribuzin, and chlorimuron that remained in the soil solution in a Lucedale fine sandy loam (pH = 5.9) was 6, 16, and 50%, respectively. A comparable value for imazaquin (pH = 5.8) was 47% (Goetz et al. 1986).

Soil chromatography indicated that soil mobility and soil solution experiments were in general agreement in that quinclorac was readily displaced by water, and this displacement was somewhat pH dependent (Table 3). For both pH values, more than 89% of the applied quinclorac was displaced to at least the sixth increment. However, at pH 6.7, >56% of the applied amount was displaced to the 10th increment, indicating that movement with the wetting front that was largely uninhibited by the soil.

Foliar Absorption and Translocation of Quinclorac by Torpedograss. Statistical analysis revealed that absorption and distribution of applied quinclorac was equivalent between 48 and 72 h. Consequently, data were pooled over time (Table 4). Only 26% of the applied quinclorac was absorbed. Approximately 22% of the amount applied remained within the treated leaf. Within the treated leaf, the amount recovered in the blade tip was nearly twice that recovered in the base. Thus, quinclorac was more subject to acropetal than basipetal translocation. Only 0.3% of the amount applied was recovered in the roots, and none was detected in the developing rhizomes. The limited foliar absorption of quinclorac by torpedograss that we observed is in opposition to the results obtained by Chism et al. (1991). These authors reported that quinclorac foliar absorption by smooth crabgrass (*Digitaria ischaemum* L.) was ≥66% of amount applied after only 0.5-h exposure time.

Table 4. Absorption and translocation of foliar-applied quinclorac by torpedograss.[a]

	% of applied
Leaf wash	74.0
Treated leaf	
1-cm target	1.8
Blade tip	13.7
Blade base	7.1
All younger leaves including growth tip and the stalk back to second fully expanded leaf	1.1
Second fully expanded leaf	0.4
Stalk below second leaf	0.2
Third fully expanded leaf	0.1
Stalk below third leaf	0.1
All remaining foliar tissue above crown	0.3
Developing rhizomes	0
Roots	0.3
LSD (P = 0.05) = 2.9	

[a] Hydroponically grown torpedograss plants. Data pooled over 48 and 72 h exposure times since results were equivalent.

However, our results are in close agreement with those obtained by Zawierucha and Penner (2000) who reported that after an 80-h exposure time quinclorac foliar absorption by large crabgrass and goosegrass was only 27 and 22% of the amount applied, respectively. Zawierucha and Penner (2000) also noted that they obtained much less foliar absorption than Chism, and they identify several differences in experimental procedures that may provide an explanation. These differences included the solvent in which the ^{14}C-quinclorac was applied and droplet size. Our procedures were very similar to those used by Zawierucha and Penner (2000), and thus these differences are also pertinent to our study. Zawierucha and Penner (2000) also noted that translocation of foliar-applied quinclorac out of the treated leaf by large crabgrass and goosegrass only did not exceed 2% of the amount applied in either species after 80 h. Their limited translocation is in agreement with our torpedograss results.

Root Absorption and Translocation of Quinclorac by Torpedograss. Quinclorac was readily absorbed by torpedograss roots and translocated to other regions of the plant. After 6 h, a 26.7 μg/plant dose of quinclorac, or 0.58 ml of the hydroponic solution, had been absorbed (Table 5). Only 54% of the root-absorbed quinclorac remained in the roots; the remaining 46% was translocated throughout the plant. Five and 9% of the absorbed amount was detected in the youngest leaf and the immature rhizomes, respectively. As a result, these tissues had quinclorac concentrations of 0.23 and 0.15 μg/mg, respectively. Total quinclorac absorption after 12 and 24 h was 37.6 and 53.3 μg/plant, respectively. Yet, the sub-

Table 5. Root absorption and translocation of quinclorac by torpedograss over time.

Selected portions of torpedograss plants[a]	Amount of quinclorac detected			Quinclorac concentration in tissue		
	6 h	12 h	24 h	6 h	12 h	24 h
	μg[b]			μg/mg		
Youngest leaf	1.3 (5)	3.1 (8)	3.2 (6)	0.23[b]	0.25	0.36
All mature leaves	3.0 (11)	5.3 (14)	6.5 (12)	0.07	0.13	0.20
Stalk	5.6 (21)	10.3 (27)	12.6 (24)	0.10	0.16	0.30
Immature rhizomes	2.4 (9)	3.9 (10)	6.1 (11)	0.15	0.20	0.34
Roots	14.3 (54)	15.0 (40)	25.0 (47)	0.46	0.52	0.87
Total[c]/average	26.7	37.6	53.3	0.18	0.22	0.36

[a] Average weight of torpedograss plants was 131 mg, and average weights of the selected plant parts as presented in first column were 10, 33, 47, 14, and 29 mg, respectively.

[b] Value in parentheses indicates percent relative to total amount detected. LSD values ($P = 0.05$) for the comparison of total amount between plant parts were 5.8, 5.7, and 5.0 μg for the three times, respectively. Comparable values for concentration were 0.08, 0.12, and 0.30 μg/mg, respectively.

[c] Torpedograss plants were grown in a hydroponic solution which had been spiked with quinclorac at 38 ppm. The total amounts detected indicate that 0.38, 0.39, and 0.66 ml of the solution had been absorbed after 6, 12, and 24 h, respectively. The average concentration is on a whole-plant basis.

sequent distribution within the plant was relatively constant, resulting in progressively greater concentrations within sampled torpedograss tissues. The absorption and translocation of root-applied quinclorac by torpedograss that we documented is in general agreement with other researchers. Grossman and Scheltrup (1998) treated hydroponically grown cleavers (*Galium aparine* L.), wheat (*Triticum aestivum* L.), sugarbeet (*Beta vulgaris* L.), and oilseed rape (*Brassica napus* L.) with either 1 or 10 μM (0.242 or 2.42 μg/L) of quinclorac. After 4 h, approximately 15, 24, 21, and 72% of the root-absorbed quinclorac had been translocated to the shoot by the previously listed species, respectively. However, species sensitivity could not be related to differential absorption or translocation (or both) of root-applied quinclorac.

The data presented indicate that quinclorac is much more readily absorbed and subsequently translocated through the roots than the foliage. For quinclorac to be effective in controlling torpedograss, some potion of the applied quinclorac must be absorbed by or be translocated into the rhizomes. Root-based absorption and subsequent translocation was the only means by which any amount of quinclorac was delivered to the developing rhizomes. In the selective placement study, foliage reduction at 4 WAT (first response variable measured after treatment) was greater with soil-based applications. However, at 10 WAT, regrowth reduction was greater with foliar-based applications, and the soil-only application was the least effective. This apparent loss in efficacy over time may be due to the soil-applied quinclorac being leached out of the rooting zone. Foliar + soil was consistently the most effective application method, both in terms of foliage reduction at 4 WAT and subsequent regrowth suppression. We speculate that while quinclorac retained on the foliage is neither readily absorbed nor translocated, it may serve as a reservoir by which quinclorac can be introduced into the soil for a protracted period of time during subsequent irrigations. This hypothesis is supported by the results obtained by both McCarty et al. (1993) and Brecke et al. (2001). Both authors have reported that repeat applications of quinclorac at lower rates were far more effective than a single, higher-rate application. Repeat applications may simply serve to maintain an adequate concentration of the readily root-absorbed, but also readily leached, quinclorac within the root zone of torpedograss. Future research will examine this hypothesis.

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