

# Invasive Plant Science and Management

## Comparison of Subsurface and Foliar Herbicide Applications for Control of Parrotfeather (*Myriophyllum aquaticum*)

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# Comparison of Subsurface and Foliar Herbicide Applications for Control of Parrotfeather (*Myriophyllum aquaticum*)

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Parrotfeather is an invasive, aquatic plant in the United States that is native to South America. It has impaired the use of water bodies throughout the United States and is difficult to control, despite using a variety of management techniques. Our objectives were to examine the efficacy of subsurface applications of seven herbicides labeled for aquatic use and to compare those applications to herbicides that can also be applied to emergent foliage. A replicated mesocosm study was conducted in 378-L (100-gal) tanks beginning in August 2007 and repeated during the same period in 2008. The maximum and half-maximum labeled rates of copper chelate, diquat, endothall, fluridone, triclopyr, and carfentrazone-ethyl were applied to the water column in designated mesocosms. The maximum labeled rate for foliar applications of diquat, triclopyr, and 2,4-D were used to compare treatment methods. Six weeks after treatment (WAT), copper, endothall, fluridone, and carfentrazone-ethyl did not achieve 90% control; in fact, control was less than 50% for each herbicide, and therefore, the herbicides were not considered efficacious for controlling parrotfeather. Diquat at all rates and application methods resulted in 70 to 90% biomass reduction. Triclopyr, with both the highest aqueous concentration and foliar application, resulted in an 84 and 86%, respectively, reduction in biomass at 6 WAT. The foliar application of 2,4-D was the only herbicide and application method that resulted in  $\geq 90\%$  biomass reduction of parrotfeather. In these studies, regrowth occurred in all tanks regardless of herbicide or treatment method, indicating multiple applications would be necessary to provide longer-term plant control. Future research should identify possible herbicide combinations or timing of applications to maximize treatment efficacy.

**Nomenclature:** Copper chelate; diquat; endothall; fluridone; triclopyr; 2,4-D; carfentrazone-ethyl; parrotfeather, *Myriophyllum aquaticum* (Vell.) Verdc. MYAQ2.

**Key words:** Invasive, aquatic plant management, aquatic herbicide, biomass, plant control.

Parrotfeather (*Myriophyllum aquaticum* (Vell.) Verdc.) is a nonnative, invasive, aquatic plant that was introduced to the United States from South America in the 1890s (Sutton 1985). In South Africa, parrotfeather infests all of the major river systems, posing a direct threat to the country's water supply (Jacot-Guillarmod 1977). Parrotfeather also provides mosquito larvae a refuge from predation and can indirectly aid in the spread of insect-borne diseases (Orr and Resh 1989). The problems posed by parrotfeather are often perpetuated because this species is widely cultivated and sold in the United States via the water garden industry (Aiken 1981). Once established, it is capable of thriving in

a variety of environmental conditions and is difficult to control using a variety of management techniques (Moreira et al. 1999).

Previous research has often focused on foliar herbicide applications to control parrotfeather. Contact herbicides, such as diquat and endothall, have been evaluated, but these herbicides offer short-term control, and repeat applications are often necessary (Moreira et al. 1999; Westerdahl and Getsinger 1988). The systemic herbicides glyphosate, 2,4-D, triclopyr, and fluridone have been evaluated as foliar applications in mesocosm trials. When triclopyr (Garlon 3A) was applied at rates greater than  $2.0 \text{ kg ae ha}^{-1}$  ( $1.8 \text{ lb ac}^{-1}$ ), it resulted in complete control of parrotfeather for up to 30 wk after treatment (WAT) (Hofstra et al. 2006). Wersal and Madsen (2007) reported 50% and 100% control of parrotfeather with imazamox and imazapyr, respectively, when applied as foliar applications.

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## Interpretive Summary

Parrotfeather is an invasive aquatic plant in the United States that has become a popular plant in the water garden industry. Parrotfeather is often overlooked as a nuisance until sizable populations are present which have proven themselves to be difficult to control using a variety of management techniques. Therefore, we conducted a replicated mesocosm trial to examine the efficacy of subsurface applications of seven herbicides labeled for aquatic use and to compare those applications to herbicides that can also be applied to emergent foliage. There was no difference in applying herbicides as a foliar spray or to the water column based on the results of this study, with the exception of 2,4-D. The most effective herbicides for parrotfeather control were diquat, 2,4-D, and triclopyr. Although significant parrotfeather control was achieved using the aforementioned herbicides, there was no herbicide or application method that resulted in complete control of parrotfeather, so repeated applications would be necessary. Foliar applications of diquat, 2,4-D, and triclopyr are recommended because they are easier to make and typically less expensive than subsurface herbicide applications. Diquat and triclopyr are generally three times the cost per liter of herbicide as 2,4-D, and the maximum labeled rates per hectare for these herbicides are four times greater than that of 2,4-D, resulting in a 12-fold increase in application costs to control parrotfeather using foliar applications. Therefore, future work should identify herbicides, herbicide combinations, and application timings that could maximize treatment efficacy as well reduce the cost of chemical application.

The resiliency of parrotfeather may, in part, be attributed to its submersed growth form. Submersed tissues of parrotfeather become light-saturated at a much lower level than emergent tissues. The light saturation point of the submersed leaves is between 250 to 300  $\mu\text{mol m}^{-2} \text{s}^{-1}$  and indicates that photosynthesis of submersed plants is adapted to reduced light environments (Salvucci and Bowes 1982). The growth of submersed shoots were also found to have an inverse relationship with both light transmittance and water temperature, whereas, when both environmental variables increased, biomass of submersed shoots decreased (Wersal, unpublished data). This would suggest that a higher percentage of submersed biomass would occur in fall and winter. In California, submersed biomass was an important component in parrotfeather growth only in winter, but submersed biomass never exceeded 3% of the total annual biomass of the plant (Sytsma and Anderson 1993). Therefore, subsurface herbicide applications may offer increased control of parrotfeather by targeting those times in the plant's life cycle when biomass is reduced, such as the formation of submersed tissues.

Currently, of the herbicides labeled for aquatic use, only 2,4-D, diquat, and carfentrazone-ethyl have been evaluated as subsurface applications against parrotfeather (Glomski et al. 2006; Gray et al. 2007; Wersal et al. 2010). Therefore, a thorough evaluation of subsurface herbicide applications would offer insight into whether this application method is

efficacious on parrotfeather and which herbicides would result in control. Our objectives were to examine the efficacy of subsurface applications of seven herbicides labeled for aquatic use and to compare those applications to herbicides that can also be applied to emergent foliage.

## Materials and Methods

**Planting.** A mesocosm study was conducted at the R. R. Foil Plant Science Research Center, Mississippi State University, Starkville, MS, from August to October 2007, and was repeated in 2008. We chose to conduct this study during late summer and early fall to promote submersed shoot growth and to follow the natural phenology of parrotfeather in Mississippi. The study was conducted in 72, 378-L (100 gal) mesocosms. Planting consisted of placing two apical shoots of parrotfeather, approximately 20 cm (8 in) in length, from greenhouse stock into each of 432, 3.78-L pots containing a top soil, loam, and sand mixture (3 : 2 : 1). Sediment was amended in each pot with Osmocote 19–6–12 (N–P–K) fertilizer<sup>1</sup> at a rate of 2 g L<sup>-1</sup> (0.27 oz gal<sup>-1</sup>). Six pots of planted parrotfeather were placed into each of the 72 mesocosms that were filled with 246 L (65 gal) of water. Well water was supplied to each mesocosm from an irrigation reservoir adjacent to the mesocosm facility. Air was supplied to all mesocosms using 2.5 cm (1 in) stone diffusers and a polyvinyl chloride (PVC) lift pipe. Parrotfeather was allowed to grow until the shoots began to reach the water surface (approximately 2 wk) to achieve a mixture of submersed and emergent shoots for herbicide applications. Before herbicide application, one pot from each tank was harvested by cutting the plants at the sediment surface. Plants were dried for at least 48 h at 70 C (158 F) and weighed for pretreatment biomass.

**Treatment Methods.** Herbicide applications consisted of the maximum and half-maximum labeled rates of copper,<sup>2</sup> diquat,<sup>3</sup> endothall,<sup>4</sup> triclopyr,<sup>5</sup> 2,4-D,<sup>6</sup> and carfentrazone-ethyl<sup>7</sup> with a 48-h exposure time. A concentrated aqueous solution of each herbicide was applied to each mesocosm containing 246 L of water to achieve the desired herbicide concentration. To achieve the 48-h exposure, designated mesocosms were drained and refilled once with freshwater to remove remaining residues. There was no additional water added to the mesocosms after the 48-h drain and refill. Fluridone<sup>8</sup> was applied under static exposure conditions because, as an aquatic herbicide, an exposure time of 60 to 90 d is often needed to control submersed aquatic plants (Netherland et al. 1993). Because parrotfeather was listed as being partially controlled on the fluridone label with no recommended herbicide rate of application, we choose to use concentrations that are considered lethal to Eurasian watermilfoil (*Myriophyllum spicatum* L.) (Crowell et al. 2006; Netherland et al. 1993).

Table 1. Visual percentage of control ratings of parrotfeather following subsurface and foliar aquatic herbicide applications.

Herbicide treatment	Application method <sup>a</sup>	Weeks after treatment <sup>b,c</sup>					
		1	2	3	4	5	6
Carfentrazone-ethyl 0.10 mg ai L <sup>-1</sup>	S	10 f	10 f	5 f	5 f	5 fg	0 f
Carfentrazone-ethyl 0.20 mg ai L <sup>-1</sup>	S	40 d	35 e	20 e	20 e	20 ef	10 e
Copper chelate 0.50 mg ai L <sup>-1</sup>	S	0 g	0 g	0 f	0 f	0 g	0 f
Copper chelate 1.0 mg ai L <sup>-1</sup>	S	0 g	0 g	0 f	0 f	0 g	0 f
Diquat 0.19 mg ai L <sup>-1</sup>	S	60 c	60 c	55 c	55 c	50 bc	50 d
Diquat 0.37 mg ai L <sup>-1</sup>	S	80 b	80 b	80 b	75 b	70 a	70 b
Diquat 4.5 kg ai ha <sup>-1</sup>	F	90 a	85 ab	80 b	70 b	70 ab	60 c
Endothall 2.5 mg ae L <sup>-1</sup>	S	0 g	0 g	0 f	0 f	0 g	0 f
Endothall 5.0 mg ae L <sup>-1</sup>	S	0 g	0 g	0 f	0 f	0 g	0 f
Fluridone 0.01 mg ai L <sup>-1</sup>	S	0 g	0 g	0 f	0 f	0 g	0 f
Fluridone 0.02 mg ai L <sup>-1</sup>	S	0 g	0 g	0 f	0 f	0 g	0 f
Triclopyr 1.25 mg ae L <sup>-1</sup>	S	45 d	45 d	35 d	30 d	25 de	15 e
Triclopyr 2.5 mg ae L <sup>-1</sup>	S	85 a	85 ab	80 ab	75 b	70 a	70 b
Triclopyr 6.7 kg ae ha <sup>-1</sup>	F	90 a	90 a	80 ab	80 b	70 a	70 b
2,4-D 2.0 mg ae L <sup>-1</sup>	S	5 g	10 f	10 f	5 f	5 fg	0 f
2,4-D 4.0 mg ae L <sup>-1</sup>	S	30 e	30 e	20 e	20 d e	20 ef	15 e
2,4-D 2.1 kg ae ha <sup>-1</sup>	F	90 a	90 a	90 a	90 a	85 a	85 a
Untreated reference		0 g	0 g	0 f	0 f	0 g	0 f
LSD		6	7	10	10	20	9

<sup>a</sup> Abbreviations: S, subsurface; F, foliar.

<sup>b</sup> Means in a column followed by the same letter are not statistically different according to a Fisher's Protected LSD test at a  $P < 0.05$  level of significance.

<sup>c</sup> Analyses were conducted within weeks not across weeks, therefore comparisons can only be made within a given column.

The maximum labeled rate for foliar applications of diquat, triclopyr, and 2,4-D were used to compare treatment methods. Foliar herbicide applications were made evenly over the water surface using a spray volume of 934 L ha<sup>-1</sup> (100 gal ac<sup>-1</sup>) with a CO<sub>2</sub>-pressurized, single-nozzle (8002 flat fan<sup>9</sup>) spray system.<sup>10</sup> A nonionic surfactant<sup>11</sup> was added to the spray solution of the foliar applications at a rate of 0.5% vol : vol. Water in the foliar-applied mesocosm tanks was drained and was replaced with fresh, untreated water after application to remove herbicide residues that may have entered the water column during application. Draining the water in these mesocosms ensured that any effects from foliar applications were due to herbicide uptake from the emergent portion of the plant and not from submersed plant tissues in the water column. All herbicide treatments were replicated in four mesocosms.

**Data Analysis.** Parrotfeather was visually rated weekly from 0 to 100% control (0, no control; 100, complete control) for 6 wk. Six weeks after treatment (WAT), noticeably live plant material was harvested at the sediment surface, dried for at least 48 h at 70 C, and weighed to determine plant mass. Pretreatment biomass was 1.51 g (0.05 oz) dry weight (DW) pot<sup>-1</sup>, and by 6 WAT,

reference plant biomass increased 92% to 18.01 g DW pot<sup>-1</sup> indicating plants were actively growing throughout the study. A general linear model was used to determine differences between control ratings within weeks, and a Fisher's Protected LSD was used to separate any differences. A similar analysis was conducted on biomass at 6 WAT. All analyses were conducted at a  $P < 0.05$  level of significance. There was no difference ( $P = 0.10$ ) between years; therefore, data were pooled.

## Results and Discussion

Copper chelate, endothall, and fluridone applications were not efficacious on parrotfeather from 1 to 6 WAT (Table 1). Carfentrazone-ethyl and the subsurface 2,4-D applications resulted in less than 40% control from 1 to 6 WAT (Table 1). The contact herbicide carfentrazone-ethyl may have been more efficacious if water pH was more acidic. The water used in this study was taken from an irrigation reservoir where the pH fluctuates between 7.8 to 9. A pH approaching 9 would result in a half-life of approximately 3 to 4 h, reducing the contact of the plants to a lethal dose of the herbicide (Ngim and Crosby 2001). However, the initial activity of this herbicide may offer

increased control when combined with a systemic herbicide, such as 2,4-D or triclopyr. During a similar mesocosm trial, 100% control of parrotfeather was achieved at 3 WAT when carfentrazone-ethyl was combined with several concentrations of 2,4-D as a subsurface application (Gray et al. 2007). Combinations of a contact and a systemic herbicide may be of benefit to exploit the rapid effects of the contact herbicide and to maintain the long-term control typically offered by the systemic herbicide. However, this will depend upon herbicide selection because significant antagonism has been found with combinations of diquat and penoxsulam applied to the foliage of waterhyacinth [*Eichhornia crassipes* (Mart.) Solms](Wersal and Madsen 2010).

The foliar application of diquat ( $4.5 \text{ kg ai ha}^{-1}$ ) resulted in 90% control at 1 WAT, with control declining to 60% by 6 WAT. Diquat at  $0.37 \text{ mg ai L}^{-1}$  provided 70% control at 6 WAT, which was not expected for a fast-acting contact herbicide. The foliar application of 2,4-D and triclopyr (as both the maximum subsurface and foliar application) resulted in significant control of parrotfeather; however, there was no rate or application method that achieved at least 90% control. The foliar application of 2,4-D ( $2.1 \text{ kg ae ha}^{-1}$ ) resulted in 85% control of parrotfeather at 6 WAT, which was the best control out of all herbicides and application methods.

Parrotfeather biomass was not significantly reduced by copper chelate at any herbicide concentration. Endothall at  $5.0 \text{ mg ae L}^{-1}$  and fluridone at  $0.02 \text{ mg ai L}^{-1}$  ( $0.02 \text{ ppmv}$ ) did reduce parrotfeather biomass; however, reductions were only 30% and 26% of untreated reference plants, respectively, at 6 WAT (Figure 1). Some shoot reddening and bleaching of leaves was observed at the highest fluridone concentration by 4 WAT, but these symptoms were transient. The concentrations of fluridone evaluated were within the range typically used in controlling Eurasian watermilfoil because specific recommendations for parrotfeather were not available (Crowell et al. 2006; Pedlow et al. 2006). The exposure time in this study was only 45 d, and this likely limited maximum efficacy. Netherland et al. (1993) reported that an exposure time of approximately 60 d was needed for fluridone concentrations of  $12 \text{ } \mu\text{g ai L}^{-1}$  ( $12 \text{ ppbv}$ ) to control Eurasian watermilfoil. The symptoms observed on parrotfeather in the current study indicate that fluridone has activity, but higher concentrations or longer exposure times or both are needed for parrotfeather control.

The systemic herbicides, 2,4-D (as a foliar application) and triclopyr (as both the maximum subsurface and foliar application rate), resulted in more than 80% biomass reduction. The poor efficacy of the subsurface 2,4-D applications was not expected because plants treated with the lowest concentration were not different from untreated reference plants at 6 WAT (Figure 1). In a previous study,

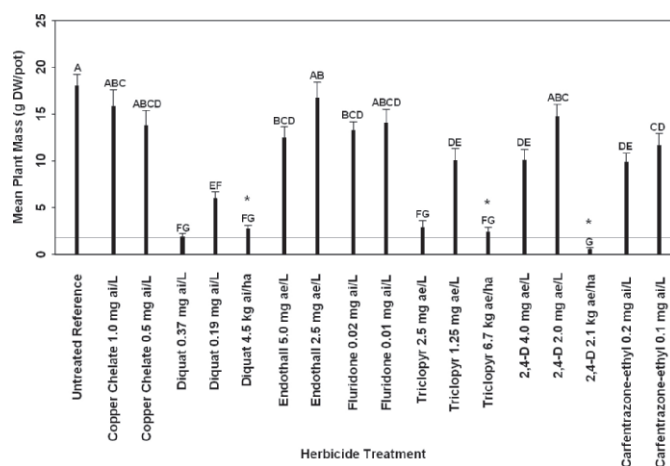


Figure 1. Mean ( $\pm 1$  SE) dry weight biomass of parrotfeather harvested 6 wk after treatment with selected aquatic, labeled herbicides. Bars sharing the same letter do not differ according to a Fisher's Protected LSD test at a  $P < 0.05$  level of significance. An asterisk denotes foliar-applied herbicides. The solid horizontal line represents a 90% reduction in biomass from untreated reference plants.

a  $1.0 \text{ mg ae L}^{-1}$  of 2,4-D concentration resulted in complete parrotfeather control at 3 WAT (Gray et al. 2007). The difference between previous research and the current study is the exposure of parrotfeather to the herbicide. The study conducted by Gray et al. (2007) used a static exposure, whereas our study had a 48-h exposure time. Therefore, in order for a subsurface 2,4-D application to be effective, exposure times need to be longer than 48 h.

Similar results were observed in this study for triclopyr as those reported by Hofstra et al. (2006), with the exception of the  $1.25 \text{ mg ae L}^{-1}$  concentration. In New Zealand, triclopyr provided significant parrotfeather control in both mesocosm and field trials with reported significant reductions in the percentage of cover by parrotfeather under controlled conditions, and  $> 90\%$  control for field applications up to 12 WAT (Hofstra et al. 2006). However, similar to results from our study, triclopyr did not result in complete control of parrotfeather because regrowth was evident by 5 WAT. Plant recovery was from root crowns because new, submersed shoots grew to the water surface and produced a new emergent apical tip by the conclusion of this study. The regrowth from the sediment indicates that triclopyr may not have been fully translocated to the root crown or roots, and sufficient energy reserves remained to initiate new growth. Higher rates of triclopyr may have limited herbicide translocation through rapid tissue destruction, preventing a lethal dose of triclopyr from translocating to tissues below the sediment surface, thereby allowing plant regrowth (Gardner and Grue 1996).



The use of diquat at all rates and application methods resulted in significant reductions in parrotfeather biomass at 6 WAT. This was particularly surprising because diquat applied alone or as a one-time treatment, typically offers rapid plant control with subsequent regrowth (Moreira et al. 1999). Plant recovery from diquat exposure was from the sediment, similar to that described for triclopyr. Subsurface applications of diquat resulted in the fragmentation of parrotfeather plants. A necrotic region formed on the stolons of treated plants at the water–air interface, resulting in the emergent shoots separating from the stolons. These free-floating, emergent shoots rapidly grew adventitious roots and survived throughout the remainder of the study and were included in biomass determinations. It is unclear whether these fragments would have been viable, but given that tissues were still intact and fragments were growing adventitious roots, it is likely that, under field conditions, these fragments would repopulate the treated area or spread to new habitats. The mechanism causing the fragmentation is unknown and further investigation is needed, but it has been reported under similar, controlled circumstances (Wersal et al. 2010).

Overall, there was no difference in applying herbicides as a foliar spray or to the water column based on the results of this study, with the exception of 2,4-D. In this study, the most effective herbicides for parrotfeather control were diquat, 2,4-D, and triclopyr; however, the use of diquat as a subsurface treatment caused plant fragmentation that may result in new infestations in field situations. Copper chelate, carfentrazone-ethyl, endothall, and fluridone did not control parrotfeather. Although significant parrotfeather control was achieved, there was no herbicide or application method that resulted in complete parrotfeather control.

In general, foliar applications are easier to make and typically less expensive than subsurface herbicide applications; therefore, the use of diquat, 2,4-D, or triclopyr as a foliar spray are recommended based on the results of this study. When considering the industry standards, 2,4-D would be the most economical choice, when there are no restrictions on its use. Diquat and triclopyr are generally three times the cost per liter of herbicide as 2,4-D and the maximum labeled rates per hectare for these herbicides are four times that of 2,4-D, resulting in a 12-fold increase in application costs using foliar applications. Future work should evaluate herbicides, herbicide combinations, and application timings that could maximize treatment efficacy as well reduce the cost of herbicide application.

### Sources of Materials

<sup>1</sup> Osmocote fertilizer, Scotts-Sierra Horticultural Products Company, 14111 Scottslawn Road, Marysville, OH 43040.

<sup>2</sup> Copper chelate, Komeen, SePRO Corporation, 11550 North Meridian Street, Carmel, IN 46032-4565.

<sup>3</sup> Diquat, Reward, Syngenta Professional Products, P.O. Box 18300, Greensboro, NC 27419.

<sup>4</sup> Endothall, Aquathol K, United Phosphorus, Inc., 630 Freedom Business Center Drive, King of Prussia, PA 19406.

<sup>5</sup> Triclopyr, Renovate3, SePRO Corporation, 11550 North Meridian Street, Carmel, IN 46032-4565.

<sup>6</sup> 2,4-D, DMA 4-IVM, Dow Agrosciences, 9330 Zionsville Road, Indianapolis, IN 46268.

<sup>7</sup> Carfentrazone-ethyl, Stingray, FMC Corporation, 1735 Market Street, Philadelphia, PA 19103-7597.

<sup>8</sup> Fluridone, Sonar A.S., SePRO Corporation, 11550 North Meridian Street, Carmel, IN 46032-4565.

<sup>9</sup> 8002 flat-fan nozzle, TeeJet Technologies, P.O. Box 7900, Wheaton, IL 60187-7901.

<sup>10</sup> CO<sub>2</sub> pressurized single nozzle spray system, R&D Sprayers, 419 Highway 104, Opelousas, LA 70570-2108.

<sup>11</sup> Non-ionic surfactant, Dyne-Amic, Helena Chemical Company, 225 Schilling Boulevard, Collierville, TN 38017-7177.

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