J. Aquat. Plant Manage. 45: 43-46

Eurasian Watermilfoil and Parrotfeather Control Using Carfentrazone-ethyl

CODY J. GRAY[1], J. D. MADSEN[2,3], R. M. WERSAL[2] AND K. D. GETSINGER[4]

ABSTRACT

Two invasive weed species, Eurasian watermilfoil (*Myriophyllum spicatum* L.) and parrotfeather [*Myriophyllum aquaticum* (Vell.) Verdc.], were grown in outdoor mesocosms to determine the efficacy of carfentrazone-ethyl (a,2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]-4-fluorobenzenepropanoic acid, ethyl ester), alone and in combination with 2,4-D, a herbicide routinely used for watermilfoil control. Eurasian watermilfoil control was ≥98% when carfentrazone rates were applied alone at ≥150 µg ai L^{-1}. Carfentrazone alone initially controlled parrotfeather; however, tissue viability 3 weeks after treatment suggested plant recovery was likely. Both Eurasian watermilfoil and parrotfeather control was 100% when 2,4-D was applied at 1000 µg ae. L^{-1}; however, when 2,4-D rate was reduced to 100 µg ae L^{-1} control declined to <50%. Herbicide applications containing carfentrazone with low rates of 2,4-D resulted in 100% death of both plant species. These results indicate that Eurasian watermilfoil control can be obtained using carfentrazone alone; but the addition of low levels of 2,4-D may be needed to achieve desired parrotfeather control.

[1]University of Florida-IFAS, 3205 College Avenue, Fort Lauderdale, FL 33314.

[2]GeoResources Institute, Mississippi State University, Box 9652 Mississippi State, MS 39762.

[3]Corresponding author; e-mail: jmadsen@gri.msstate.edu.

[4]U.S. Army Engineer Research and Development Center, Environmental Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180. Received for publication July 25, 2005 and in revised form July 31, 2006.

Key words: Myriophyllum spicatum, Myriophyllum aquaticum, herbicide, biomass reduction, protox inhibitor.

INTRODUCTION

Eurasian watermilfoil and parrotfeather are two exotic invasive dicot species found in freshwater lakes, ponds, and irrigation and drainage canals in the northern and western United States. Both species reproduce vegetatively, usually via stem fragmentation. Fragments are easily spread by boats, trailers, water movement, and by dumping aquarium plants in water sources (Madsen and Smith 1997, Madsen 1997a). Until 2005, only eight herbicides have been registered with Section 3 labels in the United States for use in aquatic sites. Due to increased problems with newly introduced invasive plants and the development of herbicide resistance, additional chemistries and active ingredients are being developed and evaluated for invasive species management in aquatic and wetland systems (Netherland et al. 2005).

Carfentrazone-ethyl (hereafter referred to as carfentrazone) is one such herbicide that is being evaluated in aquatic plant management. In November 2004 the US Environmental Protection Agency granted full Federal registration of carfentrazone for use in aquatic sites (FMC 2005).

Carfentrazone controls plants by disrupting chlorophyll biosynthesis via inhibition of protoporphyrinogen oxidase, leading to subsequent buildup of phytotoxic intermediates (Vencill 2002). Rapid foliar desiccation results in limited symplastic phloem movement of carfentrazone. In terrestrial use, carfentrazone is absorbed rapidly by the foliage and

plants become necrotic and die within a few days after treatment. Environmentally, carfentrazone is non-volatile (Vencill 2002) and rapidly metabolized in plants (Dayan et al. 1997). Elmarakby et al. (2001) reported rapid conversion of the parent ester to carfentrazone-chloropropionic acid in less than 2 days under aerobic aquatic conditions, while Koschnick et al. (2004) showed that both the parent molecule and the chloropropionic acid metabolite degraded rapidly from the aquatic environment (half-lives = 83 h) with no accumulation in the sediment.

Carfentrazone is labeled for use in a number of agricultural crops including corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and small grain crops (Boydston 2004, Nandula and Manthey 2002, Thompson and Nissen 2000). The product has also been evaluated as an alternative to methyl bromide fumigants in strawberry production (Manning and Fennimore 2001).

Carfentrazone has been reported to control floating species such as waterlettuce (*Pistia stratiotes* L.), waterhyacinth [*Eichhornia crassipes* (Mart.) Solms], and common salvinia (*Salvinia minima* Baker); however, submersed species control was not evaluated (Koschnick et al. 2004). Glomski et al. (2006) reported only 55 to 70% control of three submersed species, Eurasian watermilfoil, parrotsfeather and sago pondweed (*Stukenia pectinata* (L.) Böerner) when treated with carfentrazone and suggested combining low levels of 2,4-D ((2,4-dichlororphenoxy)acetic acid) with carfentrazone to improve control of watermilfoils. Carfentrazone is combined with low levels of auxin-like products such as 2,4-D and triclopyr ([(3,5,6-trichloro-2-pyridinyl) oxy]acetic acid) to enhance performance against terrestrial dicots (Boydston 2004), Therefore, the objective of this research was to evaluate the efficacy of carfentrazone for control of the submersed macrophytes, Eurasian watermilfoil and parrotfeather, alone and in combination with 2,4-D.

MATERIALS AND METHODS

Experiments were conducted in 1100-L outdoor mesocosm tanks that measured 1.6 m in length and 1.75 m in width, each tank was 0.6 m deep. The experiments were located at the R. R. Foil Plant Research Facility (North Farm), Mississippi State, MS. On 15 September 2004, two apical plant cuttings (15 cm in length) of a single species were propagated in 3.9 L plastic containers containing approximately 2 L of topsoil. Osmocote fertilizer[5] (19-6-12) was incorporated into the topsoil at a rate of 2 g/L of soil. A layer of pea gravel was placed on top of the soil to minimize topsoil from leaching into the water column. In Experiment #1, six containers of each species were placed in each mesocsom tank and plants were allowed to grow for four weeks. While in Experiment #2, one container of each species was placed in each mesocosm tank and plants were allowed to grow for six weeks. At the time of herbicide applications, plants were healthy and apical tips were at or just below the surface of the water.

Treatments in the first experiment consisted of carfentrazone[6] (100 µg ai L^{-1}) and 2,4-D[7] (1000 µg ae L^{-1}) applied alone and in combination (carfentrazone:2,4-D = 100:250, 100:500, 100:1000 and 100:2000) and an untreated control. Treatments in the second experiment were selected to augment rates from the first experiment and consisted of carfentrazone (150 and 200 µg ai L^{-1}) and 2,4-D (100 µg ae L^{-1}), and in combination (carfentrazone:2,4-D = 100:100 µg ai L^{-1}), and an untreated control. A concentrated aqueous solution was applied to each mesocosm tank such that, when diluted in 1100 L, it provided the desired herbicide concentration throughout the water column. Plants remained in the herbicide exposed tanks throughout the study. Visual ratings were taken weekly based upon a scale of 0 (no control) to 100% (death of plant). Shoot biomass was harvested 3 weeks after treatment (WAT) and dried to a constant weight in a forced air oven at 70°C.

The study was set-up as a randomized complete block design, where mesocosm tanks were aligned in three rows (blocks) of seven tanks each, with a treatment replicate randomly located within each row (n = 3). A block design was used to ensure any differences in plant biomass were due to our treatments and not other factors (Steel et al. 1997). A data logger[8] was placed at random in one mesocosm tank per block to measure water temperature throughout the study.

Analysis of variance (ANOVA) was used to determine block and treatment effects. No differences occurred between blocks for all analysis procedures. Treatment means were analyzed using Fisher's least significant difference test ($p < 0.05$). Water temperatures were pooled across blocks and days into respective weeks after treatment for each experiment.

RESULTS AND DISCUSSION

Water temperatures ranged from 20.8 to 24.5°C in the first experiment and from 13.2 to 16.1 in the second experiment. These values reflect the range of temperatures that are conducive for healthy grow of Eurasian watermilfoil and parrotfeather (Barko and Smart 1981, Sutton 1985, Madsen 1997b, Moreira et al. 1999).

In the first experiment, Eurasian watermilfoil control 1 WAT was >90% for all treatments containing a combination of carfentrazone and 2,4-D (Table 1). At this time interval, control was significantly lower for carfentrazone or 2,4-D alone at 82 and 78%, respectively. Eurasian watermilfoil control was 100% 3 WAT for all treatments except carfentrazone alone (70%). Shoot biomass was reduced by nearly 50% compared to the untreated control. These results are comparable to those found by Glomski et al. (2006), where rates of 50 to 200 µg ai L^{-1} carfentrazone provided 54 to 71% control at 28 days after treatment (DAT) when applied to Eurasian watermilfoil.

Parrotfeather control 1 WAT was ≥90% for all treatments except for the 72% control from 2,4-D alone (Table 1). At 3

[5]Osmocote® Slow Release Plant Food, Scotts-Sierra Horticultural Products Company, 14111 Scottslawn Road, Marysville, OH 43041.

[6]Aim®, FMC Corporation, 1735 Market Street, Philadelphia, PA 19103.

[7]Hardball®, Helena Chemical Company, 225 Schilling Blvd., Collierville, TN 38017.

[8]HOBO Water Temp Pro, Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532.

TABLE 1. EURASIAN WATERMILFOIL AND PARROTFEATHER PERCENT CONTROL AND BIOMASS REDUCTION USING CARFENTRAZONE ALONE AND IN COMBINATION WITH 2,4-D FOR EXPERIMENT #1.

		Control[a]						Biomass	
		Eurasian watermilfoil			Parrotfeather				
Herbicide treatment	Rate[b]	1 WAT[c]	2 WAT	3 WAT	1 WAT	2 WAT	3 WAT	Eurasian watermilfoil	Parrotfeather
	µg/L	%						g/pot	
Carfentrazone	100	82 bc[d]	78 b	70 b	90 b	73 b	70 b	0.9 b	1.8 b
2,4-D	1000	78 c	98 a	100 a	72 c	100 a	100 a	0.0 c	0.0 c
Carfentrazone + 2,4-D	100 + 250	93 a	100 a	100 a	95 ab	100 a	100 a	0.0 c	0.0 c
Carfentrazone + 2,4-D	100 + 500	97 a	100 a	100 a	100 a	100 a	100 a	0.0 c	0.0 c
Carfentrazone + 2,4-D	100 + 1000	97 a	100 a	100 a	100 a	100 a	100 a	0.0 c	0.0 c
Carfentrazone + 2,4-D	100 + 2000	92 ab	100 a	100 a	98 a	100 a	100 a	0.0 c	0.0 c
Untreated Control		0 d	0 c	0 c	0 d	0 c	0 c	1.7 a	10.0 a

[a]Visual ratings were assessed based on a scale of 0 (no control) to 100% (death of plant).
[b]Carfentrazone (in µg ai/L): 2,4-D (in µg ae/L).
[c]WAT = weeks after treatment.
[d]Means within a column followed by the same letter are equivalent according to Fisher's protected LSD test P = 0.05.

WAT, parrotfeather control was 100% for all treatments with the exception of carfentrazone alone (70%). Glomski et al. (2006) also found limited control of parrotfeather (29 to 54%) in outdoor mesocosms in Texas, when carfentrazone alone was applied from 50 to 200 µg ai L^{-1}. Parrotfeather shoot biomass for carfentrazone alone (1.8 g/pot) was significantly lower compared to the untreated control (10 g/pot).

In the second experiment, Eurasian watermilfoil control 1 WAT was 95% for all treatments with the exception of 2,4-D alone (55%) (Table 2). At 3 WAT treatment, Eurasian watermilfoil control with 2,4-D alone decreased to 43%, while control with respect to all other treatments ranged from 88 to 100%. Shoot biomass was significantly less than the untreated control for both treatments using carfentrazone alone. The remaining biomass in these treatments was attributed to defoliated stems that had not yet decayed. Eurasian watermilfoil biomass was not decreased with 2,4-D alone when compared to the untreated control. This decrease in 2,4-D control may be attributed to the low rate used (100 µg ai L^{-1}). Rates of 2,4-D used for controlling Eurasian watermilfoil in the field typically exceed 1000 µg ai L^{-1} and the rate used in this evaluation is below threshold levels (500 to 750 µg ai L^{-1}) required to achieve acceptable control (Green and Westerdahl 1990, Parsons et al. 2001).

Parrotfeather control 1 WAT was ≥90% for all treatments except for the 62% control from 2,4-D alone (Table 2). Parrotfeather control with 2,4-D 3 WAT decreased to 53% while all other treatments were statistically the same, with control ranging from 88 to 100%. Parrotfeather shoot biomass was reduced for all treatments compared to the untreated control, and only carfentrazone plus 2,4-D completely reduced shoot biomass. Moreira et al. (1999) suggested the most effective active ingredient for parrotfeather control was 2,4-D at 6.5 kg ai/ha, yielding 640 µg ai L^{-1} in the water column immediately after treatment.

Parrotfeather shoot recovery was visible with carfentrazone applied alone and evident in shoot biomass (Tables 1 and 2). The combination of the visual control ratings and biomass results showed that parrotfeather, although initially suppressed, can recover and survive applications of carfen-

TABLE 2. EURASIAN WATERMILFOIL AND PARROTFEATHER PERCENT CONTROL AND BIOMASS REDUCTION USING CARFENTRAZONE ALONE AND IN COMBINATION WITH 2,4-D FOR EXPERIMENT #2.

		Control[a]						Biomass	
		Eurasian watermilfoil			Parrotfeather				
Herbicide treatment	Rate[b]	1 WAT[c]	2 WAT	3 WAT	1 WAT	2 WAT	3 WAT	Eurasian watermilfoil	Parrotfeather
	µg/L	%						g/pot	
Carfentrazone	150	95 a[d]	97 a	98 a	90 a	78 b	88 a	0.3 b	3.4 b
Carfentrazone	200	95 a	100 a	100 a	90 a	85 b	88 a	0.0 b	2.4 bc
Carfentrazone + 2,4-D	100 + 100	95 a	100 a	100 a	97 a	99 a	100 a	0.0 b	0.0 c
2,4-D	100	55 b	47 b	43 b	62 b	45 c	53 b	2.0 a	3.1 b
Untreated Control		0 c	0 c	0 c	0 c	0 d	0 c	2.6 a	6.4 a

[a]Visual ratings were assessed based on a scale of 0 (no control) to 100% (death of plant).
[b]Carfentrazone (in µg ai/L): 2,4-D (in µg ae/L).
[c]WAT = weeks after treatment.
[d]Means within a column followed by the same letter are equivalent according to Fisher's protected LSD test P = 0.05.

trazone alone. The herbicide treatment was applied evenly throughout the water column, rather than over the top of emergent shoots, an application technique that is commonly used in the field. Therefore, over-the-top broadcast applications of carfentrazone for the control of parrotfeather need to be studied further.

Results from these studies suggest carfentrazone applied with low rates of 2,4-D will completely control both Eurasian watermilfoil and parrotfeather. Eurasian watermilfoil control may be obtained using a carfentrazone rate of 150 µg ai L^{-1} or greater. Carfentrazone applied alone initially controlled parrotfeather; however, tissue viability at 3 WAT indicated that plant recovery was likely.

ACKNOWLEDGMENTS

This research was supported by the Aquatic Ecosystem Restoration Foundation and the FMC Corporation. Permission was granted by the Chief of Engineers to publish this information. This manuscript has been approved for publication as Journal Article No. J-0000 of the Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

LITERATURE CITED

Barko, J. W. and R. M. Smart. 1981. Comparative influences of light and temperature on the growth and metabolism of selected submersed freshwater macrophytes. Ecol. Monogr. 51:219-236.

Boydston, R. A. 2004. Managing volunteer potato (*Solanum tuberosum*) in field corn (*Zea mays*) with carfentrazone-ethyl and dicamba. Weed Technol. 18:83-87.

Dayan, F. E., S. O. Duke, J. D. Weete and H. G. Hancock. 1997. Selectivity and mode of action of carfentrazone-ethyl, a novel phenyl triazolinone herbicide. Pestic. Sci. 51:65-73.

Elmarakby, S. A., D. Supplee and R. Cook. 2001. Degradation of [^{14}C]carfentrazone-ethyl under aerobic aquatic conditions. J. Agric. Food Chem. 49:5285-5293.

FMC 2005. FMC receives federal approval for new herbicide Stingray™. http://pestsolutions.fmc.com/Pest_Solutions/NewsDetail/0,1663,2840,00.html. FMC Corporation. Philadelphia, PA. 1 March 2005.

Glomski, L. A. M., A. G. Poovey and K. D. Getsinger. 2006. Effect of carfentrazone-ethyl on three submersed macrophytes. J. Aquat. Plant Manage. 44:67-69.

Green, W. R. and H. E. Westerdahl. 1990. Response of Eurasian watermilfoil to 2,4-D concentrations and exposure times. J. Aquat. Plant Manage. 28:27-32.

Koschnick, T. J., W. T. Haller and A. W. Chen. 2004. Carfentrazone-ethyl pond dissipation and efficacy on floating plants. J. Aquat. Plant Manage. 42:103-108.

Madsen, J. D. 1997a. Ch. 12. Methods for management of nonindigenous aquatic plants. *In:* J. O. Luken and J.W. Thieret, eds. Assessment and Management of Plant Invasions Springer, New York. pp. 145-171.

Madsen, J. D. 1997b. Seasonal biomass and carbohydrate allocation in a southern population of Eurasian watermilfoil. J. Aquat. Plant Manage. 35:15-21.

Madsen, J. D. and D. H. Smith. 1997. Vegetative spread of Eurasian watermilfoil colonies. J. Aquat. Plant Manage. 35:63-68.

Manning, G. R. and S. A. Fennimore. 2001. Evaluation of low-rate herbicides to supplement methyl bromide alternative fumigants to control weeds in strawberry. Hort. Technol. 11:603-609.

Moreira, I., A. Monteira and T. Ferreira. 1999. Biology and control of parrotfeather (*Myriophyllum aquaticum*) in Portugal. Ecol. Env. & Cons. 5:171-179.

Nandula, V. K. and F. A. Manthey. 2002. Response of kochia (*Kochia scoparia*) inbreds to 2,4-D and dicamba. Weed Technol. 16:50-54.

Netherland, M. D., K. D. Getsinger and D. R. Stubbs. 2005. Aquatic plant management: Invasive species and chemical control. Outlooks on Pest Management 16(3):100-104.

Parsons, J. K., K. S. Hamel, J. D. Madsen and K. D. Getsinger. 2001. The use of 2,4-D for selective control of an early infestation of Eurasian watermilfoil in Loon Lake, Washington. J. Aquat. Plant Manage. 39:117-125.

Steel, R. G. D., J. H. Torrie and D. A. Dickey. 1997. Principles and Procedures of Statistics: A Biometrical Approach, 3rd edition. McGraw-Hill Companies, New York.

Sutton, D. L. 1985. Biology and ecology of *Myriophyllum aquaticum*. Proceeding of 1st International Symposium on Watermilfoil (*Myriophyllum spicatum*) and Related Haloragaceae Species. Vancouver, Canada.

Thompson, W. M. and S. J. Nissen. 2000. Absorption and date of carfentrazone-ethyl in *Zea mays*, *Glycine max*, and *Abutilon theophrasti*. Weed Sci. 48:15-19.

Vencill, W. K. (ed.). 2002. Herbicide handbook. 8th ed. Weed Sci. Soc. Amer., Lawrence, KS.