

Effect of Glyphosate Rate and Spray Volume on Control of Giant Salvinia

LINDA S. NELSON¹, L. M. GLOMSKI² AND D. N. GLADWIN³

INTRODUCTION

Giant salvinia (*Salvinia molesta* (D. S. Mitchell)) is a free-floating, aquatic fern native to Brazil that has established and become a nuisance in many lakes, rivers, irrigation canals, and reservoirs of the United States (Jacono 1999, Jacono and Pitman 2001, McFarland et al. 2004). Outside its native range, giant salvinia is considered one of the world's worst weeds due to its prolific growth habit, effective means of dispersal, tolerance to adverse growing conditions, and difficulty of control (Oliver 1993, Jacono and Pitman 2001, McFarland et al. 2004). Heavy infestations not only limit human use of water resources (fishing, boating, irrigation) but can also negatively impact the ecology of aquatic systems by restricting light penetration, degrading water quality (decreased dissolved oxygen and pH), and reducing valuable native plant and animal habitat and biodiversity (Thomas and Room 1986, Oliver 1993, McFarland et al. 2004).

Since its discovery in South Carolina in 1995 (Johnson 1995), giant salvinia has spread to more than 90 locations in 41 freshwater drainages of 12 states (Jacono and Richerson 2005, 2003). According to recent estimates by Jacono and Richerson (2003), giant salvinia can be expected to establish wherever waterhyacinth (*Eichhornia crassipes* (Mart.) Solms.) persists. This would include aquatic habitats throughout the Atlantic Coastal Plain, from southeastern Virginia through Florida, west across the Gulf Coast states to Arizona, and north through central California. Although giant salvinia is listed as a Federal Noxious Weed by the U.S. Department of Agriculture (<http://www.aphis.usda.gov/ppq/weeds/>), expansion will likely continue since quarantines and the sale and distribution of this plant by the nursery industry have been difficult to enforce nationwide. In a recent survey of mail-order catalogs and on-line commercial websites, Kay and Hoyle (2001) found that giant salvinia was among the many noxious aquatic plants readily available for purchase over the Internet.

The systemic herbicide, glyphosate (*N*-(phosphonomethyl)glycine), is an effective chemical treatment for managing giant salvinia. Results of outdoor herbicide trials showed that 8.97 kg ae ha⁻¹ glyphosate mixed with a nonionic surfactant, controlled 99% of giant salvinia 42 days after treatment (Nel-

son et al. 2001). In laboratory studies, Fairchild et al. (2002) reported significant control of giant salvinia following glyphosate application over a broad range of rates (0.45 to 3.60% solution mixed v:v). Currently, the efficacy of low-rate glyphosate applications has not been evaluated on giant salvinia grown under outdoor conditions. Reducing the rate of application would be more economical and reduce chemical inputs to the aquatic environment.

Since giant salvinia frond surfaces are covered with numerous trichomes which can impede herbicide deposition and penetration, it has been suggested that adjuvant selection and ample wetting of frond surfaces could be critical factors for maximizing herbicide efficacy. Observations of outdoor tank experiments, demonstrated that adjuvant type (non-ionic, organosilicone, silicone blends, and combinations of these products) did not affect glyphosate performance against giant salvinia (L. Nelson, unpublished data). Fairchild et al. (2002) reported that glyphosate, with or without adjuvant addition, exhibited activity against giant salvinia. However, complete plant mortality using low glyphosate rates (0.45% solution) was achieved only when mixed with Optima® (Helena Chemical Company, Collierville, TN), a specialized adjuvant blend of wetting and buffering agents. This data suggests that adjuvant choice may be critical for enhancing glyphosate performance when low application rates are used. Variability among surfactant effects on glyphosate efficacy has been reported for other plant species (O'Sullivan et al. 1981, Nalewaja and Matysiak 1992, Riechers et al. 1995). Spray volume also affects herbicide deposition on leaf surfaces and can impact herbicide performance. Previous research has demonstrated that post-emergent herbicides, such as glyphosate, control weeds better when applied in low volumes of water than when applied in high volumes (Buhler and Burnside 1983, 1987). Low spray volumes are preferred by applicators because of savings in time when filling sprayer tanks and traveling to and from treatment sites. Excluding aerial applications, aquatic herbicides are typically delivered in total spray volumes between 468 to 1870 L water ha⁻¹ (50 to 200 gal water A⁻¹). Information concerning the effect of spray volume on glyphosate performance in relation to floating aquatic plants like giant salvinia, should be investigated. Therefore, the objectives of these studies were to determine the effect of glyphosate rate and spray volume on control of giant salvinia grown under outdoor conditions.

MATERIALS AND METHODS

These studies were conducted at the Lewisville Aquatic Ecosystem Research Facility (LAERF), Lewisville, TX, and the U.S. Army Engineer Research and Development Center,

¹U.S. Army Engineer Research and Development Center, Environmental Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; e-mail: Linda.S.Nelson@erd.c.usace.army.mil

²SpecPro, Inc., U.S. Army Engineer Research and Development Center, Environmental Laboratory, Lewisville Aquatic Ecosystem Research Facility, Lewisville, TX 75057.

³U.S. Geological Survey, MidContinent Ecological Science Center, 4512 McMurry Ave., Fort Collins, CO 80524. Received for publication June 18, 2006, and in revised form November 1, 2006.

Vicksburg, MS. Giant salvinia plants used in these experiments were obtained from outdoor cultures maintained at the LAERF. Equal amounts of fresh plant material (enough to cover 75% of the water surface; approximately 300 g fresh weight) were transferred from these cultures to 76-L plastic containers (approximately 49.5 cm diameter by 58.4 cm height). The containers were filled with water that was amended with Stearns Miracle-Gro™ lawn fertilizer (36% N; 6% P; 6% K; 0.325% Fe) at a rate to provide 10 mg N L⁻¹ in the water column. In addition, the inert, light-quenching dye Aquashade™ (Applied Biochemists, Milwaukee, WI), was added to the water in each tank at a rate of 1 mg L⁻¹ to reduce light penetration and algal growth in the water column. Controlling algae was necessary to prevent a potential nutrient depletion and/or variation in nutrient concentration among experimental tanks and to prevent epiphytic algae from colonizing submersed salvinia fronds. Epiphytic algal growth on submersed frond surfaces was shown to be phytostatic to lethal to salvinia grown in laboratory culture (Jim F. Fairchild¹, pers. comm.). These culture techniques have proven to be successful for maintaining healthy salvinia growth in previous studies (Nelson et al. 2001).

Plants were allowed to acclimate to container conditions for seven days prior to chemical treatment. The acclimation period allowed formation of a dense, single layer of mature salvinia that covered 100% of the water surface. Four rates of glyphosate, 0, 2.24, 4.48, and 8.96 kg ae ha⁻¹ were applied at two spray volumes: 935 and 1870 L ha⁻¹ (100 and 200 gal A⁻¹). The glyphosate formulation used in these studies was Aqua-Master™ (Monsanto Company, St. Louis, MO). The non-ionic surfactant, CideKick™ (Brewer International, Vero Beach, FL) was added at a rate of 0.5% v:v to all treatments. Treatments were applied using a CO₂-pressurized sprayer (R&D Sprayers, Opelousas, LA) equipped with a hand-held, single-nozzle spray header fitted with a TeeJet™ solid-cone spray tip (Spraying Systems Co., Nuevo, CA). Shielding was placed around each experimental container during application to prevent drift and cross-contamination of spray material between treatments. Treatments were uniformly applied across plant surfaces.

Visual ratings of plant control and injury were recorded 7, 14, and 28 days after treatment (DAT). Salvinia control was assessed on a scale of 0 to 100, where 0 = no control; and 100 = complete plant mortality. A reading of 95% control or greater was regarded as an "acceptable" treatment response, however 100% plant control is ideal to prevent recurrence of salvinia populations. Injury was rated on a scale of 1 to 9 where 1 = total destruction to the plant stand (necrotic, collapsing tissues); 3 = severe damage on 50% of plant tissues; 6 = visible injury but not plant death; and 9 = no visible effect, green healthy tissues. In addition, salvinia biomass (all living plant material) was harvested by hand at the conclusion of the study (28 DAT), dried at 70°C to a constant weight, and dry weights recorded.

The study was a completely randomized design with a factorial (4 by 2) arrangement of treatments. Treatments were replicated five times and the study was conducted twice.

¹Fairchild, Jim F., U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO.

Plant control and injury ratings were transformed by arcsine square root before analyses, however non-transformed data are presented. Data were subjected to analyses of variance (ANOVA) procedures using the Statistical Analysis System (SAS Institute, Inc., Cary, NC); where a significant F test was found, means were separated using Fisher's Least Significant Difference (LSD) at the P = 0.05 level of probability. Since there was no statistical interaction between the two repeat experiments, the data for both experiments were pooled.

RESULTS AND DISCUSSION

For plant injury and control, the analysis of variance indicated there were significant effects of rate and time (days after treatment) but not due to spray volume. For both of these parameters, the interaction between rate and spray volume was not significant however, the interaction between rate, volume, and time was significant.

All glyphosate-treated plants displayed herbicide injury symptoms following chemical application (Table 1). Yellowing and burning of frond edges, were noted on 25 to 50% of plant tissues as early as 7 DAT, and was similar among glyphosate rates. Symptoms progressed over time for all glyphosate treatments as indicated by a decrease in injury ratings. The only measurable difference among glyphosate rates was noted 14 DAT where plants treated with the lower spray volume of 4.48 and 8.96 kg ha⁻¹ glyphosate, showed severe tissue damage and plant fragmentation, whereas symptoms on plants treated with 2.24 kg ha⁻¹ glyphosate were less pronounced. Despite early differences, by 28 DAT, the injury response for all glyphosate rates at both spray volumes was similar.

Similar to herbicide injury, plant control ratings progressed with time with higher treatment rates resulting in better plant control. By 14 DAT, treatment with either 4.48 or 8.96 kg ha⁻¹ glyphosate controlled 82.5 to 94% of giant salvinia, whereas 2.24 kg ha⁻¹ glyphosate controlled only 65 to 68% of sprayed plants. Although all rates of glyphosate provided significant control of giant salvinia compared to untreated plants, the high rate was the most effective treatment. Twenty-eight days after application of 8.96 kg ha⁻¹ glyphosate, giant salvinia control was greater than 97%. Plants treated with 2.24 kg ha⁻¹ glyphosate were controlled 93 to 95%.

All glyphosate treatments significantly reduced plant dry weight (Table 1). There were significant effects of rate but not due to spray volume. Compared to untreated plants, all glyphosate treatments reduced salvinia biomass ≥95%. For all glyphosate treatments, surviving plants were small in size and may have survived as a result of fragmented rhizomes and a subsequent reduction in herbicide translocation.

Results from these studies agree with findings by Fairchild et al. (2002) that glyphosate is effective on giant salvinia over a wide range of application rates. In addition, the data also demonstrated that giant salvinia was sensitive to a lower rate of glyphosate (2.24 kg ha⁻¹) than was previously examined under similar experimental conditions (Nelson et al. 2001). In smaller-scale studies, Fairchild et al. (2002) also demonstrated excellent control of giant salvinia following application of glyphosate at 1.33 kg ha⁻¹ (reported as a 0.45% solution). We can conclude from these and other studies, that giant salvinia is very sensitive to glyphosate. Herbicide activity over a wide

TABLE 1. EFFECT OF SPRAY VOLUME AND GLYPHOSATE RATE ON INJURY, CONTROL, AND FINAL DRY WEIGHT OF GIANT SALVINIA.

Spray volume	Rate ⁴	Plant injury ¹			Plant control ²			Dry weight ³	
		7 DAT	14 DAT	28 DAT	7 DAT	14 DAT	28 DAT	28 DAT	
L ha ⁻¹	kg ha ⁻¹	-----% control-----							g-----
935	0.00	8.6 a ⁵	8.6 a	8.6 a	0.0 a	0.5 c	0.0 c	38.61 a	
	2.24	4.0 b	3.1 b	2.0 b	21.5 a	65.0 b	93.3 b	2.05 b	
	4.48	3.5 b	2.0 c	1.9 b	27.0 a	82.5 a	94.3 b	0.59 b	
	8.96	3.1 b	1.9 c	1.9 b	32.0 a	87.5 a	97.7 a	0.48 b	
LSD (0.05)		0.92	0.90	0.31	NS	14.0	2.16	1.80	
1870	0.00	8.8 a	7.7 a	8.3 a	0.0 d	9.0 c	2.0 c	38.55 a	
	2.24	3.9 b	2.6 b	2.0 b	18.0 c	68.0 b	95.3 b	1.27 b	
	4.48	3.5 b	1.9 b	2.0 b	27.0 c	85.5 a	97.8 ab	0.67 b	
	8.96	3.2 b	1.9 b	1.7 b	35.0 a	94.0 a	99.1 a	0.18 b	
LSD (0.05)		0.91	1.01	0.74	7.81	11.82	3.56	2.47	

¹Plant injury was evaluated on a visual scale of 1 to 9 where 1 = total destruction to the plant stand (necrotic, collapsing tissues); 3 = severe damage on 50% of plant tissues; 6 = visible injury but not plant death; and 9 = no visible effect, green healthy tissues.

²Plant control is expressed on a visual scale of 0 to 100% where 0% equals no control and 100% equals complete control.

³Dry weight is expressed as the mean dry weight (g) of living plant material per 76-L plastic container.

⁴Glyphosate applied as the formulation AquaMaster™ (480 g L⁻¹ or 4 lbs gal⁻¹ of the acid, glyphosate). The non-ionic surfactant, CideKick™ was added to all treatments at a rate of 0.5% v/v.

⁵Values in a column for each spray volume followed by the same letter do not statistically differ (P = 0.05, Fisher's Protected Least Significant Difference (LSD) test, N = 10).

DAT = days after treatment, NS = not significant.

range of rates allows for greater flexibility in terms of application and reduces the risk of failed treatment. Furthermore, dense infestations of giant salvinia often require multiple applications of herbicide to insure that underlying plants receive treatment. Using lower rates will make multiple applications an economical practice. While it is well documented that glyphosate efficacy increases as spray volume decreases (Ramsdale et al. 2003, Ramsdale and Messersmith 2002, Buhler and Burnside, 1983), we did not observe differences in performance when glyphosate was applied in 935 versus 1870 L water ha⁻¹. It is possible that enhanced efficacy was not realized with the spray volumes tested here, and that diluent volumes lower than 935 L water ha⁻¹ may exhibit differences in herbicide performance. The use of lower chemical rates and carrier volume would be more economical, increase treatment efficiency, and minimize chemical inputs into the environment.

Since this study was performed, a low-rate glyphosate treatment (4.6 kg ha⁻¹) was utilized in conjunction with mechanical harvesting to successfully control a 121-ha giant salvinia infestation in Lake Wilson, Oahu, Hawaii (Larry Nakahara⁵, pers. comm.). Overall, the results of these studies and the successful use of lower rates of this product on an operational-scale demonstrates the wide range of effectiveness, reliability, and flexibility of glyphosate against this target plant.

ACKNOWLEDGMENTS

Technical assistance provided by Chetta Owens was greatly appreciated. The AquaMaster™ formulation was provided by Dr. Ron Crockett, Monsanto Corporation, St. Louis, MO.

⁵Larry Nakahara, (retired) Plant Pest Control Branch, Hawaii Dept. of Agriculture, Honolulu, HI.

This research was funded by the U.S. Geological Survey (USGS), MidContinent Ecological Science Center under the joint USGS/U.S. Fish and Wildlife Service Quick Response Program and the U.S. Army Corps of Engineers Aquatic Plant Control Research Program. Permission was granted by the Chief of Engineers and the USGS to publish this information. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

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