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Efficacy of Glyphosate and Five Surfactants for Controlling Giant Salvinia

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ABSTRACT

Giant salvinia (*Salvinia molesta* Mitchell) is a non-native, invasive aquatic fern that was recently introduced to the southern United States. The aggressive nature of the species has led to concerns over its potential adverse impacts to native plants, fish, and invertebrates. We conducted a study to determine the efficacy of glyphosate [isopropylamine salt of N-(phosphono-methyl)glycine] and several surfactants for control of giant salvinia. Studies were conducted over a 42-day period using static renewals (twice weekly) with 4% Hoagland's medium (10 mg/L N equivalent) in replicated 2-L containers. Five concentrations of glyphosate (0, 0.45, 0.91, 1.82, and 3.60% v:v) and five surfactants (0.25% concentration, v:v; Optima™, Kinetic™, Mon 0818™, Cygnet Plus™, and LI-700™) were applied with a pressurized sprayer as a single surface application in a fully nested experimental design. Untreated giant salvinia grew rapidly and exhibited an increase of 800% wet weight biomass over the 42-day test duration. Glyphosate, with and without surfactants, exhibited efficacy at concentrations as low as 0.45% of the commercial formulation. Glyphosate with Optima was the only mixture that resulted in complete mortality of plants with no regrowth.

Key words: herbicides, aquatic, weeds, control, invasive species, *Salvinia molesta.*

INTRODUCTION

Giant salvinia (*Salvinia molesta* Mitchell) is a free-floating aquatic fern native to Southeastern Brazil (Forno and Harley 1979; Forno 1983). Giant salvinia has been exported to many countries around the world via the aquarium and ornamental trade and has recently become established in the U.S. states of Alabama, Arizona, California, Florida, Georgia, Hawaii, Louisiana, Mississippi, North Carolina, and Texas.

Mitchell and Thomas (1972) and Oliver (1993) have provided extensive reviews on the biology of giant salvinia. Mitchell and Tur (1975) have demonstrated that the species can double in biomass every 2.5 to 10 days under optimum growth conditions. Giant salvinia can out-compete native plant species due to robust life history characteristics such as vegetative reproduction, high growth rates, ability to survive under variable environmental conditions, and wind-blown mobility. Excessive growth of giant salvinia results in complete coverage of water surfaces that can shade desirable native vegetation, alter gaseous exchange across the air-water interface, and remove available nutrients (Oliver 1993). Mats

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of dead giant salvinia sink to the bottom to decay and consume dissolved oxygen needed by fish and other aquatic life (Thomas and Room 1986, Oliver 1993).

Numerous studies have been conducted throughout the world using herbicides to control giant salvinia. Control efforts with diquat [(1,1'-Ethylene-2,2'-bipyridylium ion; CAS 2764-72-9) (Kam-Wing and Furtado 1977, Mitchell 1979, Thayer and Haller 1985)], paraquat [(1,1'-Dimethyl-4-4'bipyridium ion; CAS 4685-14-7) (Mitchell 1979)], 2,4-D [(2,4-dichlorophenoxyacetic acid; CAS 94-75-7) (Thomas 1979, Thayer and Haller 1985, Miller and Pickering 1988)] and endothall [(7-Oxabicyclo(2,2,1)heptane-2,3-dicarboxylic acid; CAS 129-67-9) (Thayer and Haller 1985)] have met with some success; however fluridone [(1-methyl-3-phenyl-5-(3-(trifluoromethyl)phenyl)-4(1H)-pyridinone; CAS 59756-60-4) (Wells et al. 1986)] was reported as ineffective.

Thayer and Haller (1985) treated *S. rotundifolia* with glyphosate [(isopropylamine salt of N-(phosphono-methyl)glycine; CAS 1071-83-6)] at 2.2 to 6.7 L/ha and observed approximately 80% control within 15 days after treatment. Glyphosate is formulated as a 53.8% solution (Rodeo™) and is approved in the United States for emergent aquatic weed control in all bodies of fresh and brackish water. Glyphosate is a foliar-applied contact herbicide that inhibits the synthesis of several essential amino acids during periods of active plant growth (Franz et al. 1997). Glyphosate is relatively non-toxic to fish and invertebrates (LC50 > 100 mg/L) (Henry et al. 1994, Beyers 1995) and is readily inactivated on contact with soil or water. Glyphosate has undergone extensive ecological risk assessments (Giesy et al. 2000) and is frequently used in agricultural practices and in ecological restorations due to its high efficacy and low non-target toxicity.

This study presents data from a controlled outdoor laboratory study that determined the efficacy of glyphosate for control of giant salvinia. The study had two objectives: 1) to investigate the efficacy of glyphosate for controlling giant salvinia over a range of five concentrations, and 2) to determine if any of five selected surfactants would increase the efficacy of glyphosate for controlling giant salvinia.

MATERIALS AND METHODS

Giant salvinia plants were obtained from Linda Nelson, U.S. Army Corps of Engineers, Vicksburg, MS under USDA APHIS Permit Number 45296. Studies were conducted at the U.S. Geological Survey's Columbia Environmental Research Center, Columbia, MO. Plants were cultured and tested under outdoor conditions of ambient temperature and lighting using 4% Hoagland's medium (10 mg/L N equivalent) prepared in deionized water (ASTM 2000). This medium was selected from several media combinations tested in preliminary screening because it contributed to robust growth of giant salvinia but minimized growth of nuisance algae on root surfaces.

The culture medium was prepared and renewed twice weekly on Tuesdays and Fridays. Each test container was prepared by adding 1800 ml of media to a round 2-L polyethylene container (10-cm water depth; 15-cm diameter) followed by addition of plants. A single plant was transferred to each test container; plants weighed approximately 5 g wet weight and covered approximately 10% of the water surface. Plants were allowed to acclimate for 7 days prior to treatment.

On Day 0 of the test, the plants were removed, individually weighed to the nearest 0.01 g wet weight, and placed back into the container for treatment. Wet weights were used as the measurement endpoint because it is non-destructive and is highly correlated with dry weight biomass. In addition, this approach allowed repeated measurements on individual plants which increases statistical sensitivity.

Plants were treated using a single spray dose (1.10 ml) with a CO_2-powered Model SS Meterjet Spray Pump (R&D Sprayers, Inc., Opelousas, LA) and a conical spray tip. The sprayer was mounted 40 cm above the plant to deliver a 15-cm diameter circular spray area (equivalent to 630 L spray/ha). We tested the effects of glyphosate in aqueous solutions at 0, 0.45 (2.8 L/ha), 0.91 (5.7 L/ha), 1.82 (11.5 L/ha), and 3.6% (22.9 L/ha) with and without surfactants (0.25% surfactant concentration; 1.6 L/ha surfactant equivalent). Surfactants tested are presented in Table 1. Each glyphosate: surfactant mixture was replicated five times.

Effects of glyphosate on plant growth were determined weekly over a 42-day test duration (September 5 to October 17). Plants were weighed weekly for wet weight biomass as described above. The media solutions were totally exchanged twice weekly (Tuesdays and Fridays). Air and water temperatures were continuously recorded using HOBO Temperature Monitors™ (Onset Computer Corp, Bourne, MA).

Glyphosate concentrations were verified at test initiation using nine quality assurance samples: 1) triplicate negative controls; 2) triplicate positive spiked controls; and 3) tripli-

TABLE 1. CONCENTRATIONS OF SURFACTANTS TESTED IN GLYPHOSATE TRIALS WITH GIANT SALVINIA.

Surfactant	Type	Recommended rate (%)[a]	Tested conc. (%)[b]	Aquatic label[c]
Kinetic™	Silicone-based nonionic	0.09-1.0%	0.25	Yes
Optima™	Combination	0.50-1.00%	0.25	Yes
LI-700™	Nonionic	0.125-0.5%	0.25	Yes
Mon 0818™	Ethoxylated tallow amine	0.125%	0.25	No
Cygnet Plus™	Citrus oil	0.125%	0.25	Yes

[a]Manufacturer's recommended range of rates.
[b]Manufacturer's recommended application rate for Kinetic (Helena Corp), Optima (Helena Corp), and LI-700 (Loveland Industries), but may fall outside recommended range of Mon 0818 (Monsanto Co.) and Cygnet Plus (Brewer Chemical Corp).
[c]Registered for aquatic use with U.S. Environmental Protection Agency.

cate positive sprayed controls (e.g., glyphosate sprayed into 100 ml well water using the Meterjet Sprayer). Samples were analyzed using gas chromatography.

Statistical comparisons were conducted using the Statistical Analysis System™ (SAS 2000; Cary, NC). Analysis of raw data indicated that the data were not normally distributed. Therefore, we transformed the data (log_{10} transformation) to normalize the distribution. Main effects of concentration, surfactant, date, and their interactions were tested using the Proc Mixed Procedure ($p \leq 0.05$ level of significance).

RESULTS AND DISCUSSION

Negative control samples contained no detectable levels of glyphosate. Both positive spiked controls (102.9 ± 1.8% of nominal) and positive sprayed controls (106.9 ± 0.1% of nominal) were within 7% of the nominal target concentrations. Therefore, treatment concentrations were not corrected for recovery and are presented as nominal concentrations.

Air and water temperatures averaged 20.5 ± 9.1C and 20.6 ± 6.9C, respectively, during the 42-day study period. Temperature extremes, measured as the 5th and 95th percentiles, ranged from 8 to 37C in air and from 10 to 35C in water.

Giant salvinia exhibited good growth under control conditions over the 42-day outdoor study and increased in wet weight biomass by over 800% (Figure 1; Table 2). Similarly, growth of giant salvinia was good in the surfactant controls (e.g., surfactant but no glyphosate) and increased from 657 to 880% wet weight biomass over the course of the study (Table 2).

All concentrations of glyphosate resulted in significant control of giant salvinia; degree of control was directly related to concentration (Figure 1; Table 2). An analysis of variance indicated that there were significant main effects of time ($p \leq 0.001$) and glyphosate concentration ($p \leq 0.001$) but not due to presence or absence of surfactant ($p = 0.0923$).

Optima was the only surfactant that increased the efficacy of glyphosate compared to the glyphosate control (Figure 2; Table 2). In addition, Optima was the only 0.45% glyphosate:surfactant combination that resulted in complete mortality of giant salvinia with no regrowth. Complete mortality was indicated by the combined indicators of total loss of pigment; linear loss of weight over time; and a decrease in average stan-

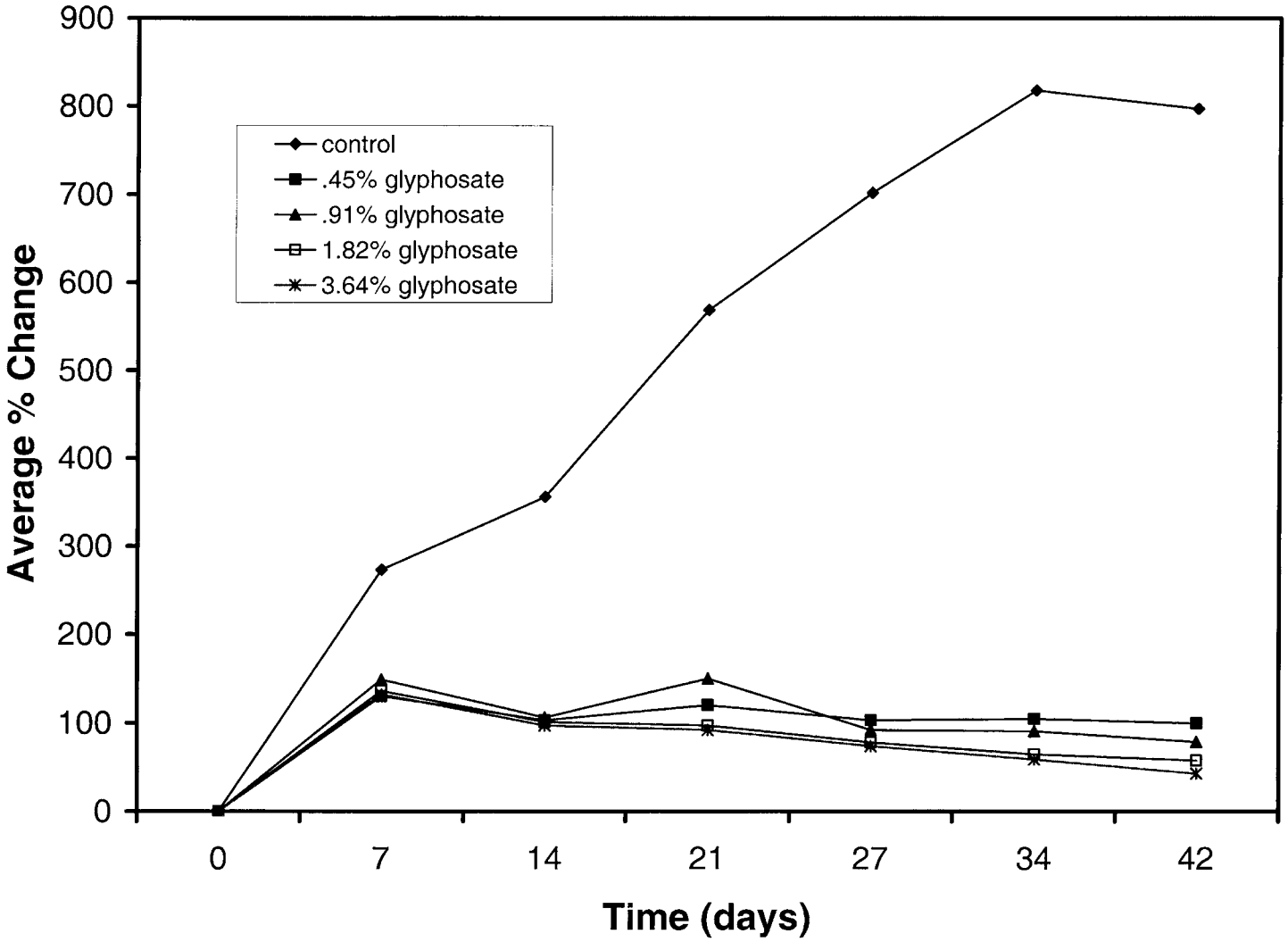

Figure 1. Response of giant salvinia to various concentrations of glyphosate with no surfactants. Each point represents mean of five replicates.

TABLE 2. PERCENT WEIGHT GAIN OF GIANT SALVINIA EXPOSED TO VARIOUS CONCENTRATIONS OF GLYPHOSATE ALONE AND IN COMBINATION WITH FIVE SURFACTANTS. ALL SURFACTANTS TESTED AT 0.25% (V:V). NUMBERS REPRESENT MEAN (±1 SD) OF FIVE REPLICATES. AN (*) REPRESENTS A NUMBER SIGNIFICANTLY DIFFERENT ($P \leq 0.05$) FROM THE CONTROL WITHIN A ROW FOR EACH GLYPHOSATE:SURFACTANT COMBINATION.

		Glyphosate concentration (%)				
Surfactant	Day	Control	0.45	0.91	1.82	3.64
Glyphosate only	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	7	273 (41)	130 (8)*	149 (19)*	136 (16)*	132 (6)*
	14	356 (70)	103 (6)*	106 (11)*	101 (6)*	97 (4)*
	21	569 (185)	120 (14)*	150 (66)*	97 (11)*	92 (19)*
	28	702 (159)	103 (8)*	92 (43)*	78 (17)*	74 (12)*
	35	818 (191)	105 (20)*	91 (70)*	65 (14)*	59 (11)*
	42	797 (206)	100 (28)*	79 (62)*	59 (14)*	43 (5)*
Cygnet Plus	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	7	241 (88)	149 (15)*	136 (7)*	142 (23)*	125 (11)*
	14	280 (114)	117 (9)*	107 (9)*	101 (9)*	99 (11)*
	21	436 (200)	118 (13)*	113 (13)*	99 (15)*	92 (13)*
	28	616 (318)	121 (25)*	101 (24)*	84 (18)*	78 (16)*
	35	729 (412)	107 (38)*	88 (22)*	75 (39)*	68 (14)*
	42	682 (378)	108 (46)*	85 (30)*	72 (50)*	52 (9)*
Kinetic	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)*
	7	261 (37)	154 (15)*	153 (18)*	138 (8)*	116 (44)*
	14	286 (60)	136 (11)*	118 (12)*	105 (7)*	88 (32)*
	21	500 (175)	171 (21)*	138 (29)*	110 (25)*	79 (40)*
	28	615 (216)	193 (30)*	120 (17)*	92 (12)*	71 (33)*
	35	763 (289)	230 (41)*	101 (18)*	69 (10)*	56 (27)*
	42	657 (257)	315 (115)*	113 (34)*	70 (15)*	52 (24)*
LI-700	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	7	260 (30)	146 (13)*	147 (2)*	140 (6)*	143 (20)*
	14	291 (31)	111 (12)*	103 (21)*	105 (10)*	105 (10)*
	21	466 (92)	118 (38)*	88 (36)*	90 (10)*	97 (16)*
	28	600 (201)	103 (37)*	67 (15)*	82 (58)*	66 (25)*
	35	693 (250)	82 (32)*	48 (12)*	50 (12)*	49 (15)*
	42	695 (280)	91 (38)*	57 (22)*	54 (22)*	35 (12)*
Mon 0818	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	7	180 (23)	163 (125)*	128 (53)*	121 (9)*	103 (8)*
	14	234 (43)	175 (181)*	116 (52)*	99 (4)*	78 (6)*
	21	424 (87)	236 (338)*	104 (51)*	94 (12)*	62 (15)*
	28	695 (225)	270 (453)*	94 (59)*	72 (14)*	42 (8)*
	35	851 (291)	277 (513)*	100 (118)*	46 (15)*	22 (7)*
	42	880 (271)	267 (509)*	125 (196)*	28 (15)*	14 (5)*
Optima	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	7	210 (36)	99 (12)*	85 (18)*	110 (7)*	109 (9)*
	14	258 (43)	89 (12)*	75 (18)*	92 (12)*	93 (11)*
	21	423 (93)	78 (16)*	64 (21)*	70 (13)*	70 (17)*
	28	644 (239)	64 (18)*	48 (11)*	41 (7)*	53 (12)*
	35	835 (330)	57 (18)*	41 (10)*	26 (3)*	34 (13)*
	42	788 (328)	46 (11)*	33 (10)*	19 (8)*	22 (11)*

dard deviation of wet weight biomass over time. Wet weights did not reach zero in cases of total mortality due to the gradual decomposition of plants and concomitant retention of water.

Regrowth generally appeared as growth of isolated fronds (as opposed to whole-plant recovery) which may have been due to fragmentation of untreated fronds during post-spray handling and weighing. This regrowth is evident in some cases after Day 14 where the standard deviation of mean weights exceeds 20% (Table 2). For example, on Day 42 the 0.45% glyphosate-only treatment exhibited good control (i.e., no average weight increase over time after day 7); however, regrowth occurred in one beaker that is revealed in the increased standard deviation (28% on Day 42). Regrowth is evident in both the mean and standard deviation of the 0.45% treatments with Kinetic and Mon 0818 surfactants (Figure 2; Table 2). Thus, it should be recognized that there is potential for survival of the population due to regrowth if there is an uneven spray pattern and loss of untreated, viable fronds.

In this study we applied all of the surfactants at the same concentration (0.25%) to remove bias; however, each manu-

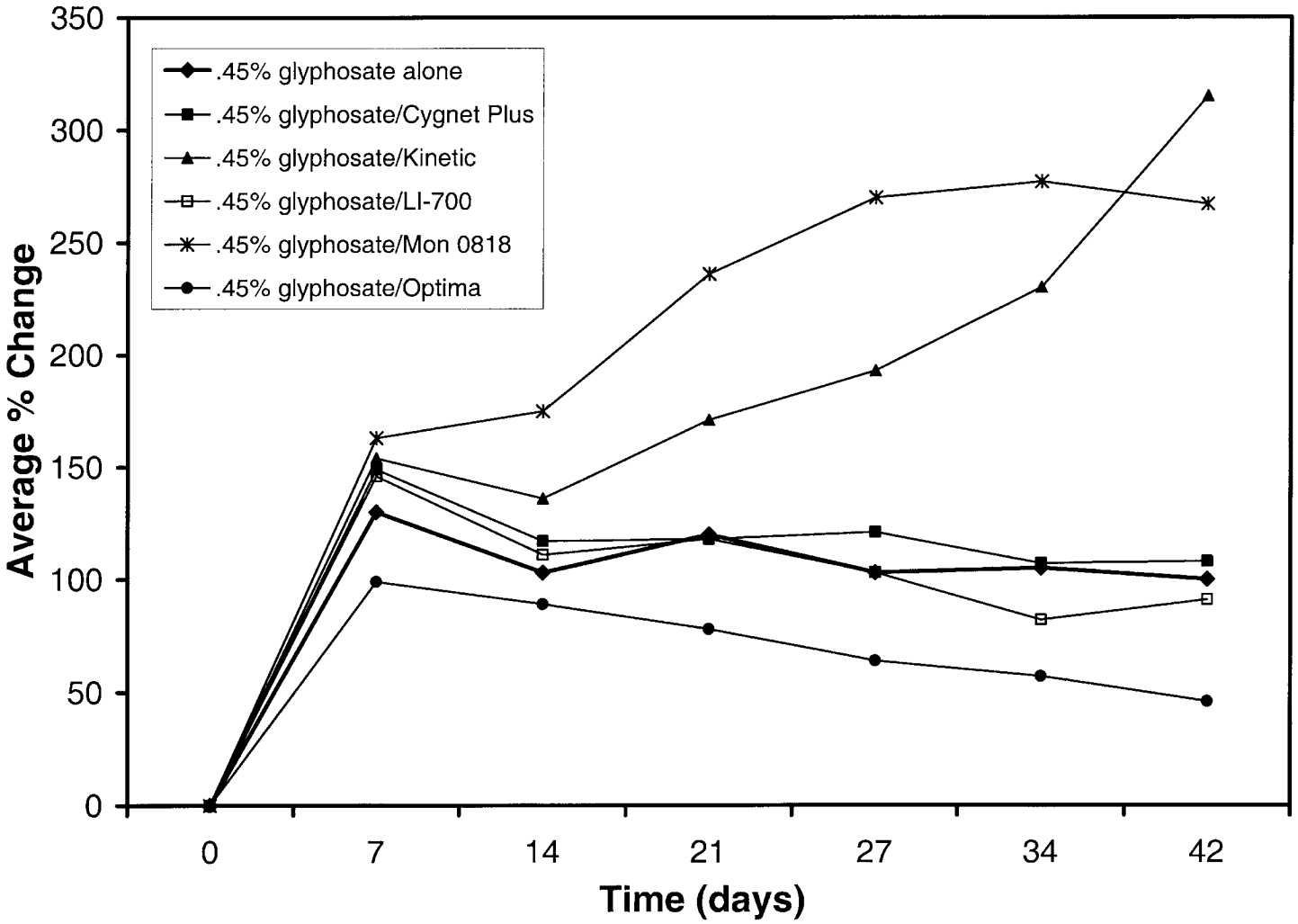

Figure 2. Response of giant salvinia to 0.45% glyphosate with and without various surfactants. Each point represents mean of five replicates.

facturer provided a range of recommended rates (Table 1). In some cases our application rate was above the recommended rates (e.g., Mon 0818, Cygnet Plus), below the recommended rates (e.g., Optima), or within the recommended range of rates (e.g., Kinetic and LI-700). Poorest surfactant performance occurred with Kinetic and Mon 0818 as indicated by the significant regrowth that occurred in the 0.45% glyphosate concentration (Figure 2). Although Optima was applied below the manufacturers recommended rate it resulted in complete mortality of giant salvinia (Table 2, Figure 2). Our data indicates that Optima may be the most promising surfactant for use with glyphosate for control of giant salvinia.

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