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## Introduction

Uniform color and texture are optimal characteristics of quality turfgrass. Broadleaf weeds, such as Virginia buttonweed (*Diodia virginiana* L.), disrupt uniformity due to differences in color, leaf width and/or growth habit (6, 8). Broadleaf weeds also compete with turfgrass for soil nutrients, moisture, and light (3).

Virginia buttonweed is a warm-season dicot belonging to the Rubiaceae family (1). It is a herbaceous perennial with a prolific growth habit, rapidly forming dense mats (7, 8). It grows from late spring to early frost and is commonly found along savannahs, wet ditches, ponds, marshes, and roadsides (10). It also has been observed surviving well under severe drought conditions (2). Virginia buttonweed is native to the Western Hemisphere, with largest United States populations inhabiting the warmer southeastern regions (1).

Virginia buttonweed is a strong competitor in common bermudagrass [Cynodon dactylon (L.) Pers.] and other warm season turfgrasses, and has become a serious pest in the southern United States (5, 7). Increased establishment in turfgrasses may be related to increased water application and improved irrigation systems (2). This weed possesses a high degree of tolerance to commonly used herbicides, which places it in the "problem weed" category (5).

Broadleaf weed herbicides commonly used in warm season turfgrasses do not provide adequate control of Virginia buttonweed (2). Control of Virginia buttonweed with phenoxy herbicides has been somewhat inconsistent (6, 7). Generally, a single application of a phenoxy herbicide or mixture of two or three hormone-type herbicides maintained control for 30 to 45 days, but regrowth occurred from both seed and fleshy root (7). Combinations of 2,4-D + dichlorprop + clopyralid, 2,4-D ester + triclopyr + clopyralid, or clopyralid alone provided consistent control of Virginia buttonweed (4). The objective of this study was to determine if addition of a surfactant enhances the efficacy of two-way or three-way herbicide combinations or single herbicide applications for extended control of Virginia buttonweed under greenhouse conditions.

## Materials and Methods

### *General Greenhouse Procedures*

Studies were conducted in the greenhouse at Mississippi State University. Thirty-two-ounce Styrofoam cups were uniformly filled with a mixture (2:1, by volume) of sand and topsoil from a Freestone sandy loam (fine-loamy, siliceous, thermic Aquic Paleudalf). Soil pH was 8.2 and organic matter content was 0.47%.

Plants were grown under natural light and fertilized with 3.9 lb/A each of N-P-K at time of planting and then every 3 months. Temperatures were maintained at 30 + 3°C during the day and 25 + 3°C at night. Benomyl (methyl-1-(butylcarbamoyl)-2-benzimidazolecarbamate) was sprayed in a solution of 6.8 grams/gal to the point of runoff every 2 weeks. All pots were surface-irrigated as needed to maintain the moisture level at or near field capacity. Herbicide treatments were applied using a continuous belt-sprayer pressurized with $CO_2$ that delivered 25 gal/A (gallons per acre) at 19 psi. The sprayer was equipped with a 8002E fan nozzle set 18 inches above the target. Visual ratings of Virginia buttonweed control were made utilizing a scale of 0 to 100; where 0 equals no phytotoxicity and 100 equals total necrosis. Data were combined over experiments and means were separated at the 5% level of significance according to Fisher's Protected LSD following analyses of variance.

## Herbicide Combinations and Surfactants

Plant material was collected near Mississippi State Univsity campus and transplanted as a 1-inch to 2-inch long fleshy root into Styrofoam cups (1 plant/pot) in September 1990. Perennial plants were treated at the 15-stem stage. Herbicide combinations were 57 + 30 + 46 grams acid equivalent per acre (g ae/A) dimethylamine (DMA) salt of 2,4-D + mecoprop DMA + dicamba; 56 + 56 + 14 g ae/A isooctyl ester (IOE) of 2,4-D + dichlorprop IOE + dicamba; 52 + 52 g/A diethanolamine (DOA) of 2,4-D + dichlorprop DOA; and butoxyethyl ester (BOE) of 2,4-D + dichlorprop BOE. Herbicides were applied in 0.25 or 0.5% (v/v) nonionic surfactant[1] solution and compared to herbicide treatments applied without surfactant. The experimental design was a randomized complete block with a factorial arrangement of herbicides and surfactant rates, with six replicates. Experiments were conducted twice. Control ratings were made weekly for 4 weeks. At 4 weeks after treatment (WAT), shoots were removed and plants were allowed to regrow for 4 weeks to evaluate regrowth.

### *Single Herbicides and Surfactants*

Plant material used in this experiment was grown as described in the previous experiment. Herbicides used were 114 g ae/A triethylamine (TEA) salt of triclopyr, triclopyr BOE, monoethanolamine salt of clopyralid, and dicamba; 58 g ae/A methylheptyl ester of fluroxypyr; and 454 g/A of 2,4-D DMA. Herbicides were used in 0.25 or 0.5% (v/v) nonionic surfactant solution and compared to herbicides applied without surfactant.

The experimental design was a randomized complete block with a factorial arrangement of herbicides and surfactant rates, with six replicates. Experiments were conducted twice. Control ratings were made weekly for 4 weeks. At 4 WAT, shoots were removed to determine shoot fresh weight and plants were allowed to regrow for 4 weeks to evaluate regrowth. Because of an experiment-by-herbicide interaction, data are presented by experiment.

### *Herbicide Rates*

Virginia buttonweed seeds were collected near Mississippi State University campus, germinated in sand for 3 weeks, then transplanted into Styrofoam cups (one plant/pot). Plants were treated at the four-stem stage as previously described. Herbicides used were

[1]Valent X-77 Spreader (Principal agent: alkylarylopyoxyethylene glycols, free fatty acids, and isopropanol: 90%). Valent USA, Corp., 1333 N. California Blvd., Walnut Creek, CA 94596.

**Table 1. Effect of surfactant on control and regrowth of Virginia buttonweed following applications of postemergence herbicide combinations.**

| | | | Virginia buttonweed control and regrowth by WAT | | | | |
|---|---|---|---|---|---|---|---|
| | | | Control | | | | Regrowth* |
| Herbicide | Rate | Surfactant rate | 1 | 2 | 3 | 4 | 8 |
| | g ae/A | % | % | | | | g/pot |
| 2,4-D (DMA) | 57 | | | | | | |
| + mecoprop (DMA) | 30 | | | | | | |
| + dicamba | 6 | . . .** | 38 | 43 | 54 | 58 | 13.2 |
| | | 0.25 | 30 | 33 | 51 | 58 | 12.9 |
| | | 0.50 | 30 | 38 | 55 | 58 | 17.1 |
| 2,4-D (IOE) | 56 | | | | | | |
| + dichlorprop (IOE) | 56 | | | | | | |
| + dicamba | 14 | . . . | 33 | 45 | 58 | 56 | 16.3 |
| | | 0.25 | 37 | 47 | 57 | 59 | 15.0 |
| | | 0.50 | 38 | 48 | 58 | 64 | 14.2 |
| 2,4-D (DOA) | 52 | | | | | | |
| + dichlorprop (DOA) | 52 | . . . | 30 | 33 | 43 | 44 | 19.0 |
| | | 0.25 | 24 | 32 | 42 | 46 | 17.7 |
| | | 0.50 | 26 | 34 | 50 | 49 | 15.0 |
| 2,4-D (BOE) | 52 | | | | | | |
| + dichlorprop (BOE) | 52 | . . . | 23 | 31 | 43 | 50 | 14.1 |
| | | 0.25 | 32 | 33 | 50 | 58 | 17.3 |
| | | 0.50 | 27 | 33 | 41 | 44 | 14.4 |
| No herbicide | . . . | . . . | 0 | 0 | 0 | 0 | 13.8 |
| | | 0.25 | 6 | 0 | 5 | 5 | 18.0 |
| | | 0.50 | 7 | 2 | 10 | 8 | 16.4 |
| LSD (0.05) | | | 9 | 8 | 10 | 11 | 4.1 |

* Shoot fresh weight.

** Dots indicate no surfactant and/or herbicide.

7, 14, 28, 56, and 112 g/A monethanolamine salt of clopyralid and methylheptyl ester of fluroxypyr; and 28, 57, 113, 226, and 454 g/A of 2,4-D DMA.

The experimental design was a randomized complete block with six replicates. Experiments were conducted twice. Ratings were made weekly for 2 weeks. At 2 WAT, shoots were removed to determine shoot fresh weight and regrowth was determined 4 WAT. Because of an experiment-by-herbicide interaction, data are presented by experiment.

## Results and Discussion

### *Herbicide Combinations and Surfactants*

The addition of surfactant did not increase Virginia buttonweed control with any herbicide combination at any rating date (Table 1). Virginia buttonweed control increased over time, peaking at 3 WAT. Maximum control was s 64% with all treatments. By 4 WAT, plants exhibited visible regrowth from shoots and/or fleshy roots in all treatments. The addition of surfactant had no influence on regrowth (Table 1).

### *Single Herbicides and Surfactants*

In Experiment 1, control with all treatments peaked at 3 WAT, and by 4 WAT plants exhibited visible regrowth from shoots and/or fleshy roots (Table 2). There were no differences in control with the addition of surfactant to clopyralid or dicamba. Clopyralid treatments provided ≤ 30% control. The addition of surfactant enhanced Virginia buttonweed control at 3 WAT with triclopyr TEA to 58% and triclopyr BOE to 53% from 25% and 37%, respectively, when applied without surfactant. Highest Virginia buttonweed control (65%) was achieved with 2,4-D 3 WAT.

Shoot fresh weight at 4 WAT was significantly less with all herbicide treatments compared to the control (Table 3). Triclopyr TEA applied in nonionic surfactant solution resulted in less shoot fresh weight compared to triclopyr TEA applied alone. However, at 8 WAT, there were no differences in regrowth in any treatment (Table 3).

Many responses observed in Experiment 1 were also

**Table 2. Effect of surfactant on control of Virginia buttonweed with herbicides.**

| | | | Virginia buttonweed control by WAT | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Experiment 1 | | | | Experiment 2 | | | |
| Herbicide | Rate | Surfactant rate | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| | g ae/A | % | % | | | | | | | |
| Triclopyr (TEA) | 114 | . . .* | 13 | 27 | 25 | 25 | 10 | 18 | 27 | 17 |
| | | 0.25 | 30 | 57 | 60 | 50 | 2 | 0 | 12 | 0 |
| | | 0.50 | 30 | 57 | 58 | 47 | 18 | 40 | 40 | 40 |
| Triclopyr (BOE) | 114 | . . . | 13 | 35 | 37 | 27 | 8 | 15 | 18 | 17 |
| | | 0.25 | 23 | 43 | 47 | 40 | 15 | 32 | 38 | 30 |
| | | 0.50 | 22 | 45 | 53 | 43 | 17 | 35 | 40 | 30 |
| Fluroxypyr | 58 | . . . | 20 | 42 | 52 | 47 | 10 | 12 | 22 | 8 |
| | | 0.25 | 18 | 27 | 33 | 25 | 10 | 18 | 18 | 17 |
| | | 0.50 | 22 | 38 | 37 | 38 | 12 | 12 | 25 | 10 |
| Clopyralid | 114 | . . . | 10 | 15 | 15 | 15 | 8 | 13 | 15 | 10 |
| | | 0.25 | 10 | 30 | 25 | 27 | 7 | 12 | 15 | 5 |
| | | 0.50 | 12 | 22 | 20 | 15 | 10 | 15 | 25 | 17 |
| Dicamba | 114 | . . . | 23 | 47 | 48 | 37 | 12 | 27 | 28 | 15 |
| | | 0.25 | 28 | 47 | 42 | 30 | 17 | 33 | 33 | 28 |
| | | 0.50 | 30 | 57 | 55 | 42 | 15 | 38 | 33 | 23 |
| 2,4-D (DMA) | 454 | . . . | 27 | 55 | 65 | 45 | 12 | 43 | 48 | 40 |
| | | 0.25 | 20 | 47 | 43 | 37 | 12 | 50 | 52 | 45 |
| | | 0.50 | 27 | 60 | 62 | 50 | 15 | 40 | 42 | 37 |
| No herbicide | . . . | . . . | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 0.25 | 3 | 8 | 5 | 7 | 2 | 2 | 10 | 2 |
| | | 0.50 | 0 | 2 | 2 | 2 | 5 | 2 | 10 | 2 |
| LSD (0.05) | | | 7 | 13 | 14 | 12 | 5 | 10 | 12 | 13 |

* Dots indicate no surfactant and/or herbicide.

observed in Experiment 2. Control peaked with all treatments 3 WAT, and by 4 WAT plants exhibited visible regrowth from shoots and/or fleshy roots (Table 2). Addition of surfactant had no influence on control with dicamba or clopyralid, which was similar to that observed in Experiment 1. Control with clopyralid was less than 25% throughout the rating period. In Experiment 2, control with fluroxypyr was ≤ 25% with or without surfactant. Addition of surfactant enhanced Virginia buttonweed control with triclopyr BOE to 40% 3 WAT, compared to 18% control without surfactant. On the other hand, control with triclopyr TEA increased only when applied in 0.5% nonionic surfactant solution compared to applications without surfactant 3 WAT. Virginia buttonweed control 3 WAT was highest with 2,4-D (52%), similar to that observed in Experiment 1.

All herbicide treatments (except triclopyr TEA) applied in 0.25% nonionic surfactant solution resulted in significant shoot fresh weight reduction when compared to the control at 4 WAT (Table 3). The addition of surfactant to herbicide treatments had no effect on regrowth (Table 3).

Herbicide treatments in both experiments followed the same trends but with enough differences to cause interactions between experiments. Greenhouse watering methods and decreasing day lengths may contribute to differences in control, shoot fresh weights, and regrowth. In Experiment 1 (14-hour daylength), applications were made in July 1991, and in Experiment 2 (12-hour daylength), applications were made in late August. Other work on Virginia buttonweed showed that differences in control may be caused by the amount of plant material in each pot and/or regrowth potential between pots (9). More mature plants would be more difficult to control, and have a greater potential for regrowth than less mature plants.

### *Herbicide Rates*

In Experiment 1, greatest control was with 112 g/A fluroxypyr (77%) at 2 WAT (Table 4). All clopyralid treatments controlled ≤25% by 2 WAT. The highest rate of 2,4-D DMA resulted in ≤60% control of Virginia buttonweed by 2 WAT. Control significantly increased following 112 g/A fluroxypyr or 454 g/A 2,4-D

**Table 3. Effect of surfactant on shoot fresh weight and regrowth of Virginia buttonweed with herbicides.**

| Herbicide | Rate | Surfactant rate | Shoot fresh weight 4 WAT Exp. 1 | Shoot fresh weight 4 WAT Exp. 2 | Regrowth 8 WAT Exp. 1 | Regrowth 8 WAT Exp. 2 |
|---|---|---|---|---|---|---|
| | g ae/A | % | g/pot | | | |
| Triclopyr (TEA) | 114 | . . .* | 28.4 | 20.1 | 6.5 | 3.2 |
| | | 0.25 | 17.6 | 38.7 | 6.3 | 4.0 |
| | | 0.50 | 15.2 | 15.1 | 8.2 | 3.2 |
| Triclopyr (BOE) | 114 | . . . | 19.2 | 16.2 | 6.6 | 2.1 |
| | | 0.25 | 18.0 | 16.9 | 5.4 | 3.3 |
| | | 0.50 | 15.4 | 16.4 | 6.0 | 2.7 |
| Fluroxypyr | 58 | . . . | 23.7 | 23.2 | 5.1 | 1.3 |
| | | 0.25 | 24.4 | 19.9 | 2.1 | 0.6 |
| | | 0.50 | 25.6 | 21.1 | 4.7 | 0.5 |
| Clopyralid | 114 | . . . | 31.2 | 22.6 | 5.7 | 1.6 |
| | | 0.25 | 36.0 | 24.8 | 8.6 | 0.8 |
| | | 0.50 | 27.1 | 20.7 | 4.8 | 1.1 |
| Dicamba | 114 | . . . | 21.4 | 25.3 | 8.2 | 4.2 |
| | | 0.25 | 22.8 | 16.2 | 8.1 | 2.8 |
| | | 0.50 | 14.3 | 19.1 | 7.0 | 4.6 |
| 2,4-D (DMA) | 454 | . . . | 14.8 | 16.8 | 6.7 | 2.7 |
| | | 0.25 | 16.4 | 12.5 | 7.3 | 3.0 |
| | | 0.50 | 15.2 | 14.0 | 8.6 | 1.6 |
| No herbicide | . . . | . . . | 51.9 | 39.0 | 7.1 | 2.0 |
| | | 0.25 | 35.4 | 39.7 | 5.8 | 3.6 |
| | | 0.50 | 45.9 | 33.9 | 5.8 | 2.4 |
| LSD (0.05) | | | 8.7 | 6.7 | 2.9 | 1.7 |

* Dots indicate no surfactant and/or herbicide.

**Table 4. Effect of herbicide rate on control of Virginia buttonweed.**

| | | Virginia buttonweed control by WAT | | | |
|---|---|---|---|---|---|
| | | Exp. 1 | | Exp. 2 | |
| Herbicide | Rate | 1 | 2 | 1 | 2 |
| | g ae/A | | % | | |
| Clopyralid | 7 | 3 | 0 | 8 | 8 |
| | 14 | 2 | 0 | 13 | 15 |
| | 28 | 3 | 2 | 27 | 18 |
| | 56 | 12 | 8 | 35 | 38 |
| | 112 | 10 | 25 | 33 | 35 |
| Fluroxypyr | 7 | 0 | 0 | 28 | 35 |
| | 14 | 10 | 2 | 33 | 30 |
| | 28 | 10 | 8 | 50 | 53 |
| | 56 | 25 | 53 | 42 | 47 |
| | 112 | 35 | 77 | 77 | 88 |
| 2,4-D (DMA) | 28 | 2 | 0 | 22 | 13 |
| | 57 | 8 | 5 | 32 | 22 |
| | 113 | 18 | 7 | 48 | 48 |
| | 226 | 22 | 25 | 47 | 72 |
| | 454 | 35 | 60 | 62 | 77 |
| Untreated | . . .* | 0 | 0 | 0 | 0 |
| LSD (0.05) | | 7 | 10 | 14 | 20 |

* Dots indicate no herbicide.

**Table 5. Effect of herbicide rate on shoot fresh weight and regrowth of Virginia buttonweed.**

| | | Shoot fresh weight 2 WAT | | Regrowth 4 WAT | |
|---|---|---|---|---|---|
| Herbicide | Rate | Exp. 1 | Exp. 2 | Exp. 1 | Exp. 2 |
| | g ae/A | | g/pot | | |
| Clopyralid | 7 | 9.5 | 9.6 | 3.8 | 0.3 |
| | 14 | 7.9 | 7.1 | 2.6 | 0.2 |
| | 28 | 6.1 | 5.1 | 2.3 | 0 |
| | 56 | 5.0 | 3.2 | 1.7 | 0 |
| | 112 | 3.5 | 4.0 | 1.6 | 0 |
| Fluroxypyr | 7 | 8.9 | 6.5 | 3.4 | 0.1 |
| | 14 | 4.5 | 4.9 | 2.1 | 0.6 |
| | 28 | 3.1 | 2.9 | 1.8 | 0 |
| | 56 | 2.1 | 5.6 | 0 | 0 |
| | 112 | 0.7 | 1.2 | 0 | 0 |
| 2,4-D (DMA) | 28 | 6.3 | 4.4 | 3.2 | 0.4 |
| | 57 | 4.7 | 4.2 | 2.4 | 0.3 |
| | 113 | 3.3 | 2.3 | 2.9 | 0.1 |
| | 226 | 3.6 | 2.1 | 2.1 | 0 |
| | 454 | 1.7 | 1.8 | 1.9 | 0 |
| Untreated | . . .* | 9.8 | 10.1 | 1.3 | 1.0 |
| LSD (0.05) | | 2.3 | 3.0 | 1.3 | 0.4 |

*Dots indicate no herbicide.

DMA compared to the lower rates by 2 WAT. All herbicide treatments reduced shoot fresh weight when compared to the control except for 7 g/A fluroxypyr and ≤ 14 g/A clopyralid (Table 5). Fluroxypyr applied at ≥ 56 g/A resulted in no plant regrowth.

Many responses apparent in Experiment 1 were observed in Experiment 2. All clopyralid treatments achieved < 40% control of Virginia buttonweed at 2 WAT (Table 4). Control significantly increased with the highest rate of fluroxypyr and 2,4-D DMA by 2 WAT. Best control in Experiment 2 followed treatments of 112 g/A fluroxypyr (85%) and 226 g/A 2,4-D DMA (77%) at 2 WAT. Shoot fresh weights were significantly less in all treatments except the two lowest rates of clopyralid (Table 5). Unlike Experiment 1, less regrowth occurred compared to the control in all herbicide treatments, except fluroxypyr at 7 g/A 4 WAT. Clopyralid or fluroxypyr applied at 28 g/A or greater, and 2,4-D DMA applied at 226 g/A or greater, prevented regrowth at 8 WAT.

Differences in control and regrowth may be due to application timing. In Experiment 1 (14-hour day length), applications were made in July, 1991 and in Experiment 2 (12-hour day length) applications were made in September, 1991. Baird (1) found that light and temperature play a major role in Virginia buttonweed development. Shortened day length during Experiment 2 may explain differences in control and regrowth response. Further research is needed on Virginia buttonweed to determine if applying herbicides late in the season could be advantageous.

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