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Full length Research paper

Response of Yellow Nutsedge (*Cyperus esculentus* L.) to Preemergence Herbicides and Nonionic Surfactants Applied Through Drip Irrigation Under Low-Density Polyethylene Mulch

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Preemergence (PRE) herbicide applications through drip-irrigation is a novel approach for controlling nutsedge spp. under low-density polyethylene (LDPE) mulch. However, achieving acceptable movement of PRE herbicides under LDPE mulch is difficult. Nonionic surfactants are used in agriculture to enhance the dispersion, spreading, sticking and penetration of pesticides. With this in mind, field experiments were conducted to evaluate nonionic surfactants applied with PRE herbicides through drip-irrigation on yellow nutsedge (*Cyperus esculentus* L.) punctures in LDPE-mulched beds. The objective of this experiment was to increase herbicide movement under the mulch thus improving nutsedge control. The experiment was a factorial treatment arrangement of the nonionic surfactants Integrate™ 20 (2.8 kg ai ha^{-1}), Tween® 20 (2.8 kgha^{-1}) and no surfactant, and the PRE-applied herbicides halosulfuron (54 gha^{-1}), *S*-metolachlor (1.4 gha^{-1}), and fomesafen (280 gha^{-1}). A non-treated control (LDPE mulch alone) was included for comparison. Tween® 20 and Integrate™ 20 nonionic surfactants applied with fomesafen, halosulfuron, and *S*-metolachlor through drip-irrigation did not reduce nutsedge punctures through LDPE mulch compared to application of these herbicides without surfactants. Combinations of nonionic surfactants and PRE herbicides not evaluated in this experiment may elicit different results and warrant further investigation.

Keywords: Chemigation, fomesafen, halosulfuron, methyl bromide alternatives, nutsedge, *S*-metolachlor, surfactants.

INTRODUCTION

Yellow nutsedge (*Cyperus esculentus* L.) is one of the most challenging and common weed species found in plasticulture production systems (Webster, 2010). Low-density polyethylene (LDPE) mulch used in these systems provides suitable control of most weed species; however, yellow nutsedge can penetrate the mulch resulting in premature degradation and competition with desirable crops for water, nutrients and light (Williams, 1976; McCraw and Motes, 2000).

To control weeds under LDPE mulch, fumigants or preemergence herbicides are traditionally applied to pre-formed beds prior to mulch application. This

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process is time consuming requiring multiple passes through the field with equipment, or purchase of expensive specialized equipment not practical for smaller producers. A potential solution for reducing time and expense for these applications is use of drip-applied herbicides. Using a combination bedder and mulch layer implement, beds are formed, and mulch is applied concurrently. Herbicides are then applied through the drip irrigation system where they are distributed throughout the beds. In addition to reducing field preparation time, drip application of herbicides can increase movement of some chemicals into the target root zone, reduce compaction, improve applicator safety and eliminate drift compared to sprayed applications (Thomas et al., 2003; Wang et al., 2009). Previous research evaluating drip-applied herbicides for nutsedge control under LDPE mulch has been favorable. Dittmar et al., (2012a) reported improved nutsedge control using drip-applied halosulfuron compared to untreated plots. Monday et al., (2015) reported drip-applied fomesafen, halosulfuron, and *S*-metolachlor yielded similar control of yellow nutsedge when compared to applications of *S*-metolachlor sprayed to the bed surface prior to mulch application. Additionally, drip-applied fomesafen provided good suppression of yellow nutsedge when compared to an untreated control (Yu and Boyd, 2017). While results have been promising, the limited wetting pattern and low volume of water used for drip irrigation systems often results in poor herbicide movement (Coolong, 2013). In studies evaluating drip-applied herbicides under LDPE mulch, yellow nutsedge control was reduced as distance from drip emitters increased (Candole et al., 2007, Chase et al., 2006, Fennimore et al., 2003). Additionally, Dittmar et al. (2012b) noted that two drip tapes may be needed to ensure uniform application of drip-applied herbicides across beds.

To overcome pesticide water solubility issues, adjuvants were developed (Czarnota and Thomas, 2013). Surfactants are the most widely used adjuvant in agriculture and are formulated to improve the emulsifying, dispersing, spreading, sticking and penetration of liquids by lowering surface and interfacial tension (Miller and Westra, 1998; Wang, 2008). Research examining the effect of surfactants on the dispersion of drip-applied herbicides is very limited. However, Santos et al. (2013) investigated the performance of the fumigant metam potassium on nutsedge density when applied with the nonionic soil surfactant Integrate™ 20 (15.25% tri block co-polymer and 4.75% glucoethers; Engage Agro USA, Prescott, AZ) through a single drip-irrigation line. The addition of Integrate™ 20 increased lateral movement of the moisture field by 68% (in a 1-h irrigation period) resulting in a 25 to 30% improvement in nutsedge control. Fumigants move more freely in soil than most herbicides due to their volatile nature.

The impact of soil-applied surfactants on herbicide movement needs to be investigated.
This experiment was conducted to evaluate the effect of soil-applied surfactants mixed, and applied with PRE herbicides, on yellow nutsedge punctures through LDPE-mulched beds.

MATERIALS AND METHODS

Field studies were conducted in the summer of 2013 and 2014 at the E.V. Smith Research Center (EVS), Shorter, AL (32°26'N, 85°53'W) and the Old Agronomy Farm (OAF), Auburn, AL (32°35'N, 85°29'W). Soil type at both locations was a Marvyn sandy loam (fine-loamy, kaolinitic, thermic-type Kanhapludults) comprised of 75.6, 6.8, and 17.5% sand, silt and clay respectively, with pH 5.8 (EVS)and 76.3, 5.0, and 18.8% sand, silt and clay, respectively, with pH 6.2 (OAF). Fields at both locations had a history of heavy yellow nutsedge infestation. In both years, the soil was prepared and formed (91 cm bedder; Reddick fumigants, Williamston, N.C.) into 4 raised beds 21m long, 91cm wide (46cm wide at OAF location), 13 cm high, and covered with white LDPE mulch (1.25mil, black on white embossed; Berry Plastics Corp., Evansville, IN). Each row (spaced 6.1 m apart) contained 13, 5.5m long plots with a 0.60m buffer between plots. Prior to applying mulch, a single drip tape (Aqua-Traxx; Toro Ag., Bloomington, MN) was placed in the center of each bed and buried 5 cm deep. Drip tape emitters were 30.5 cm apart delivering 1.02 Lhr^{-1}. Integrate™ 20 is a nonionic, soil surfactant used to improve initial wetting and rewetting of agricultural soils. It is formulated to provide uniform penetration and lateral movement of water for improved rooting and nutrient uptake by plants (Anonymous, 2013). Tween® 20 (polyoxyethylene sorbitan monolaurate; Croda International, Yorkshire, England) is a nonionic polysorbate surfactant used as a detergent and emulsifier in a number of domestic, scientific, and pharmacological applications. Tween® 20 is inexpensive, chemically inert, pH neutral, water soluble, and highly efficient at decreasing surface tension at low concentrations, making it an ideal candidate for use as an irrigation-applied adjuvant (Colwell and Rixon, 1961). Tween® 20 has shown promising results for increasing herbicide mobility (Helling, 1971) and longevity (Johnson and Dureja, 2002) in soils. Halosulfuron (Sandea®; Gowan Co., Yuma, AZ) is a systemic sulfonylurea herbicide that inhibits acetolactate synthase. Movement of halosulfuron in soil is considered relatively low and half-life is approximately 14-18 days for a sandy loam soil (Senseman,2007). Halosulfuron has PRE activity on yellow nutsedge (Anonymous, 2012). *S*-metolachlor (Dual Magnum®; Syngenta Crop Protection, Greensboro, NC) is a systemic chloroacetamide herbicide which inhibits synthesis of fatty acids, lipids, proteins, isoprenoids, and flavonoids in plants. Movement of *S*-metolachlor in soil is considered low to moderate and half-life is approximately 15 days to 5 months (Senseman, 2007).

S-metolachlor is labeled in numerous vegetable crops for control of yellow nutsedge (Anonymous, 2011). *S*-metolachlor is often applied to beds prior to LDPE mulch application for control of weeds in vegetable crops. Additionally, Santos et al. (2008) reported improved weed control in tomatoes (*Solanum lycopersicum* L.) produced on LDPE mulch using drip-applied *S*-metolachlor. Fomesafen (Reflex®; Syngenta Crop Protection) is a systemic diphenyl ether herbicide that inhibits protoporphyrinogen oxidase.

Movement of fomesafen in soils is moderate and half-life is approximately 100 days (Senseman, 2007). Fomesafen is primarily a row crop herbicide that has recently been evaluated and received indemnified labels for some vegetable crops (Culpepper, 2012). Fomesafen has a similar weed species control spectrum as *S*-metolachor.

The experiment was conducted in a randomized complete block design with 4 replications.

The treatment design was a factorial consisting of the surfactants Integrate™ 20 (2.8 kg ai ha^{-1}), Tween® 20 (2.8 $kgha^{-1}$) and no surfactant, and the PRE-applied herbicides halosulfuron (54 gha^{-1}), *S*-metolachlor (1.4 gha^{-1}), and fomesafen (280 gha^{-1}) with comparison to a non-treated control (LDPE mulch without herbicides or surfactants) for a total of 10 treatments.

Soil surfactants were mixed with PRE herbicides prior to application using Dosatron® D14MZ2 injectors (Dosatron International Inc., Clearwater, FL) and a custom injection manifold. Surfactants were applied at a rate of 2.8 $kgha^{-1}$(or 0.2% v/v) along with 2240 Lha^{-1} of water per Integrate™ 20 label recommendations.

The amount of herbicide applied to each treatment was based on bedded plot area. Plots were 5.5 m long and 0.6 m wide at EVS and 5.5 m long and 0.3 m wide at OAF. At EVS, treatments were applied on 30 July and 14 May in 2013 and 2014, respectively. At OAF, treatments were applied on 21 Aug. and 21 May in 2013 and 2014, respectively.

Nutsedge punctures were counted 28 and 56 d after treatment (DAT) in a randomly selected 1.0m^2 section of each plot.

Data were analyzed with generalized linear models using the GLIMMIX procedure of SAS (version 9.2; SAS Institute, Cary, N.C.) with the binomial distribution and log link. Block and year were included in the models as random factors. Data were analyzed separately by study location due to significant interactions (P <0.10) of treatment combinations with locations.

Herbicide-by-surfactant interactions were not significant; therefore, levels within main effects were examined. Least-squares means for punctures were compared to those for the non treated control using two-tailed *t*-tests. All *p* values for tests of differences between least squares means were adjusted using the Shaffer-Simulated method (α = 0.10).

RESULTS

Both Locations: Nutsedge punctures were not affected by the interaction of surfactant and herbicide at either location (P = 0.37 at EVS; P = 0.47 at OAF); therefore, only main effects were examined (Tables 1 and 2). Separately, individual treatments were compared to the non-treated control.

EVS. Nutsedge punctures counted 28 DAT were influenced by surfactant and herbicide (Table 1). Herbicide treatments applied without a surfactant had less punctures compared to herbicide treatments applied with Tween® 20 (3.0 m^{-2} vs. 3.9 m^{-2}, respectively).

Puncture counts were similar between herbicide treatments applied with Integrate™ 20 and herbicide treatments applied without a surfactant. Additionally, treatments containing fomesafen (2.3 m^{-2}) had less punctures compared to treatments containing halosulfuron or *S*-metolachlor (3.6 m^{-2} and 4.4 m^{-2}, respectively).

Nutsedge punctures counted 56 DAT were influenced by herbicide only (Table 1). Punctures were much lower in treatments containing fomesafen (4.6 m^{-2}) compared to treatments containing halosulfuron or *S*-metolachlor (10.6 m^{-2} and 10.5 m^{-2}, respectively).

Comparing individual treatments to the non treated revealed all treatments reduced yellow nutsedge punctures compared to the non-treated (Table 1). *OAF.* Nutsedge punctures counted 28 DAT were influenced by both surfactant and herbicide (Table 2). Herbicide treatments applied without a surfactant (4.0 m^{-2}) had less punctures compared to herbicide treatments applied with a surfactant (5.6 m^{-2} with Integrate™ 20 and 5.5 m^{-2}

Table 1. Yellow nutsedge punctures in LDPE-mulched beds following treatment with herbicides applied with and without surfactants at the E.V. Smith Research Center (EVS) in Shorter, AL. Data for 2013 and 2014 are pooled.

Treatment			Punctures			
Surfactant[1]	Herbicide	Rate	28 DAT[2]		56 DAT	
Comparisons within main effects:						
		g ha^{-1}	no. m^{-2}			
Integrate 20		2,800	3.4	ab[3]	8.6	ns
Tween 20		2,800	3.9	a	9.2	
None			3.0	b	7.9	
	Fomesafen	280	2.3	b	4.6	b
	Halosulfuron	54	3.6	a	10.6	a
	S-metolachlor	1,400	4.4	a	10.5	a
Comparisons of individual treatments with the nontreated:						
Integrate 20	Fomesafen	280	2.4	*[4]	5.0	*
	Halosulfuron	54	3.9	*	8.5	*
	S-metolachlor	1,400	3.9	*	12.4	*
Tween 20	Fomesafen	280	2.9	*	5.3	*
	Halosulfuron	54	4.4	*	12.1	*
	S-metolachlor	1,400	4.6	*	10.4	*
None	Fomesafen	280	1.5	*	3.6	*
	Halosulfuron	54	2.6	*	11.3	*
	S-metolachlor	1,400	4.8	*	8.8	*
	Nontreated		17.9		45.5	

[1]Interactions between surfactant and herbicide were not significant for nutsedge punctures at 28 or 56 DAT.
[2]Abbreviations: DAT, days after treatment.
[3]Means followed by the same letter are not significantly different according to the Shaffer-Simulated test (α = 0.10).
[4]Individual treatment means followed by an asterisk (*) are significantly different from the nontreated according to the Shaffer-Simulated test (α = 0.10).

with Tween® 20). Moreover, punctures were lower in treatments containing fomesafen (3.5 m^{-2}) compared to treatments containing halosulfuron or *S*-metolachlor (6.0 m^{-2} and 5.4 m^{-2}, respectively). Nutsedge punctures counted 56 DAT were also influenced by both surfactant and herbicide (Table 2). Punctures were lower in treatments without a surfactant (7.1 m^{-2}) compared to treatments with Integrate™ 20 and Tween® 20 (9.5 m^{-2} and 9.6 m^{-2}, respectively). As observed throughout the study, treatments containing fomesafen had less punctures (7.1 m^{-2}) compared to treatments containing halosulfuron or *S*-metolachlor (10.2 m^{-2} and 8.9 m^{-2}, respectively). Comparing individual treatments with the non-treated revealed all treatments reduced yellow nutsedge punctures compared to the non treated (Table 2).

DISCUSSION

The primary objective of these field experiments was to evaluate the effect of nonionic surfactants mixed, and applied with selected PRE herbicides, on yellow nutsedge punctures through LDPE-mulched beds. Previous research (Santos et al., 2013) evalut-

Table 2. Yellow nutsedge punctures in LDPE-mulched beds following treatment with herbicides applied with and without surfactants at the Old Agronomy Farm (OAF) in Auburn, AL. Data for 2013 and 2014 are pooled.

Treatment			Punctures			
Surfactant[1]	**Herbicide**	**Rate**	**28 DAT[2]**		**56 DAT**	
Comparisons within main effects:						
		g ha^{-1}	no. m^{-2}			
Integrate 20		2,800	5.6	a[3]	9.5	a
Tween 20		2,800	5.5	a	9.6	a
None			4.0	b	7.1	b
	Fomesafen	280	3.5	b	7.1	a
	Halosulfuron	54	6.0	a	10.2	b
	S-metolachlor	1,400	5.4	a	8.9	b
Comparisons of individual treatments with the nontreated:						
Integrate 20	Fomesafen	280	4.8	*[4]	8.3	*
	Halosulfuron	54	6.4	*	10.4	*
	S-metolachlor	1,400	5.6	*	9.8	*
Tween 20	Fomesafen	280	3.6	*	6.3	*
	Halosulfuron	54	6.5	*	11.3	*
	S-metolachlor	1,400	6.3	*	11.1	*
None	Fomesafen	280	2.6	*	6.6	*
	Halosulfuron	54	5.1	*	8.8	*
	S-metolachlor	1,400	4.3	*	5.9	*
	Nontreated		13.3		36.9	

[1]Interactions between surfactant and herbicide were not significant for nutsedge punctures at 28 or 56 DAT.
[2]Abbreviations: DAT, days after treatment.
[3]Means followed by the same letter are not significantly different according to the Shaffer-Simulated test (α = 0.10).
[4]Individual treatment means followed by an asterisk (*) are significantly different from the nontreated according to the Shaffer-Simulated test (α = 0.10).

ting nonionic surfactants applied with drip-applied fumigants reported improvement in nutsedge control; however, movement of fumigants within the soil is typically much greater than movement of herbicides. The impact of nonionic surfactants on drip-applied PRE herbicides is not widely understood as research is severely lacking. However, results from some older research has been promising. Koren (1972) reported nonionic surfactants increased both depth of water movement and herbicide movement in soil when applied along with trifluralin and oryzalin in a sandy soil. Results from this experiment indicated the application of Tween® 20 and Integrate™ 20 nonionic surfactants failed to reduce yellow nutsedge punctures relative to application of these herbicides without surfactants. Conversely, nutsedge punctures were often higher in plots treated with surfactants combined with PRE herbicides, an indication of potential leaching. Helling (1971) also reported increased leaching of 2,4-D with the addition of nonionic surfactants. These studies were conducted on sandy loam soils with low (<1%) organic matter content. Studies performed on soils with higher clay or organic matter content may elicit different results. Foy (1992) found that surfactants caused variable effects on water movement and herbicide movement, depending on the herbicide, surfactant and its concentration, soil type, and preleaching conditions. Alternative practices to increase lateral movement of herbicides must be devised to improve yellow nutsedge control at bed edges.

Future research should include spatial information on punctures within the mulch as well as a determination of the coefficient of uniformity to better understand movement of drip-applied herbicides.

CONCLUSION

Tween® 20 and Integrate™ 20 nonionic surfactants applied with fomesafen, halosulfuron, and *S*-metolachlor through drip-irrigation did not reduce nutsedge punctures through LDPE mulch compared to application of these herbicides without surfactants. Alternatively, herbicide leaching may be increased resulting in reduced yellow nutsedge control.

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