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Effect of PRE and POST-Directed Herbicides for Season-Long Nutsedge (*Cyperus* spp.) Control in Bell Pepper

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Fomesafen and imazosulfuron are two recently registered herbicides for use in Florida bell pepper. Field studies were conducted in 2012 and 2013 to evaluate PRE, POST-directed (POST-DIR), and PRE followed by (fb) POST-DIR control programs utilizing these new herbicides for nutsedge control in Florida bell pepper. PRE treatments included: *S*-metolachlor at 0.71 and 1.07 kg ai ha^{-1}, fomesafen at 0.28 and 0.42 kg ai ha^{-1}, *S*-metolachlor at 0.71 kg ha^{-1} + fomesafen 0.28 kg ha^{-1}, and *S*-metolachlor at 1.07 kg ha^{-1} + fomesafen at 0.42 kg ha^{-1}. POST-DIR treatments included imazosulfuron at 0.21 and 0.34 kg ai ha^{-1}. PRE fb POST-DIR treatments included *S*-metolachlor at 0.71 or 1.07 kg ha^{-1} fb imazosulfuron at 0.21 kg ha^{-1} and fomesafen at 0.28 or 0.42 kg ha^{-1} fb imazosulfuron at 0.21 kg ha^{-1}. Nutsedge control in both years at 28 d after planting was similar among all PRE treatments providing ≤ 60% control. The addition of imazosulfuron POST-DIR following *S*-metolachlor or fomesafen PRE provided greater control compared to *S*-metolachlor or fomesafen alone 14, 21, and 28 d after the POST-DIR application. Plots treated with *S*-metolachlor resulted in lower marketable weight and marketable fruit count compared to fomesafen in 2012; however, this was not observed in 2013. The results for these studies indicate the importance of a PRE fb POST-DIR herbicide for nutsedge control and that fomesafen or *S*-metolachlor PRE fb imazosulfuron POST-DIR provides growers with a viable tool capable of achieving season-long control of nutsedge in bell pepper.

Nomenclature: Fomesafen; imazosulfuron; *S*-metolachlor; nutsedge, *Cyperus* spp.; bell pepper, *Capsicum annuum* L.

Key words: Methyl bromide alternative, vegetable weed management, weed control in bell pepper.

Fomesafen e imazosulfuron son dos herbicidas recientemente registrados para uso en pimentón en Florida. Se realizaron estudios de campo en 2012 y 2013 para evaluar programas de control PRE, POST-dirigido (POST-DIR), y PRE seguido por (fb) POST-DIR utilizando estos nuevos herbicidas para el control de *Cyperus* spp. en pimentón en Florida. Los tratamientos PRE incluyeron: *S*-metolachlor a 0.71 y 1.07 kg ai ha^{-1}, fomesafen a 0.28 y 0.42 kg ai ha^{-1}, *S*-metolachlor a 0.71 kg ha^{-1} + fomesafen 0.28 kg ha^{-1}, y *S*-metolachlor a 1.07 kg ha^{-1} + fomesafen 0.42 kg ha^{-1}. Los tratamientos POST-DIR incluyeron imazosulfuron a 0.21 y 0.34 kg ai ha^{-1}. Los tratamientos PRE fb POST-DIR incluyeron *S*-metolachlor a 0.71 ó 1.07 kg ha^{-1} fb imazosulfuron a 0.21 kg ha^{-1}, y fomesafen a 0.28 ó 0.42 kg ha^{-1} fb imazosulfuron a 0.21 kg ha^{-1}. El control de *Cyperus* spp. en ambos años a 28 d después de la siembra fue similar entre todos los tratamientos PRE siendo ≤ 60% de control. El agregar imazosulfuron POST-DIR después de *S*-metolachlor o de fomesafen PRE brindó mayor control al compararse con *S*-metolachlor o fomesafen solos 14, 21, y 28 d después de la aplicación POST-DIR. Los lotes tratados con *S*-metolachlor resultaron en menor peso y número de fruto comercializable al compararse con fomesafen en 2012, sin embargo esto no se observó en 2013. Los resultados de estos estudios indican la importancia de herbicidas PRE fb POST-DIR para el control de *Cyperus* spp. y que fomesafen o *S*-metolachlor PRE fb imazosulfuron POST-DIR brindan a los productores una herramienta viable capaz de alcanzar control de *Cyperus* spp. a lo largo de toda la temporada de crecimiento del pimentón.

Bell pepper is an important economic commodity for fresh market vegetable production in Florida. In 2012, Florida bell pepper production was valued at $247 million and grown on 7,082 ha, making Florida the second largest national producer behind California (USDA 2013). Florida's bell pepper production is concentrated in the central and southern areas of the state due to the warm winter growing conditions, allowing growers a competitive market advantage over areas with shorter pepper production seasons.

Fresh market bell peppers are currently produced in a plasticulture production system, which involves

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the application of polyethylene mulch over a raised bed (Lament 1993). The polyethylene serves multiple purposes, by trapping fumigants during preplant treatment, reducing water loss, and providing weed suppression during the production season. Furthermore, bell pepper grown in plasticulture has a greater water-use efficiency and marketable yield per plant compared to bareground production (Morales-Garcia et al. 2010). There are many advantages of plasticulture production; among them is the suppression of broadleaf and grass weeds. However, purple and yellow nutsedge (*Cyperus rotundus* L. and *C. esculentus* L.) can pierce through the polyethylene mulch (Lament 1993; Webster 2005a).

Purple and yellow nutsedge remain two of the world's most problematic weeds (Hauser 1962; Gilreath et al. 2005; Gilreath and Santos 2005). Nutsedge is a member of the Cyperaceae (Sedge) family, although nutsedge can be mistaken for a grass species due to its narrow grass-like leaves. *Cyperus* species develop a solid triangular stem, which extends through the apex of the plant and bears a seed head at its tip. The two species are commonly found growing in mixed stands (Wills 1987). Yellow nutsedge is typically found in moist areas, whereas purple nutsedge is more commonly found on well-drained soils (Holm et al. 1977). Webster (2005b) reported that polyethylene mulch suppressed yellow nutsedge more than purple nutsedge, resulting in a higher population of purple nutsedge than yellow nutsedge in a plasticulture system. Control of these weeds is difficult due to their vigorous growth habits, adaptibility to multiple environmental conditions, and highly efficient C_4 photosynthetic pathway (Wills 1987). However, a weakness of nutsedge includes their relatively short stature (30 to 40 cm) and intolerance to shade (Wills 1987).

Nutsedge species have been found to reduce pepper yield. A population of 63 purple nutsedge plants m^{-2} reduced pepper yield 10% and a population of 200 plants m^{-2} decreased pepper yield up to 32% (Morales-Payan et al. 1997). Similar research has also found season-long interference of 5 yellow nutsedge plants m^{-2} to reduce pepper yield 10% (Motis et al. 2003). The critical nutsedge-free period for bell pepper has been determined to be 3 to 5 wk after planting (Motis et al. 2004).

Until recent years, Florida vegetable growers relied heavily on the use of the soil fumigant, methyl bromide, for control of nutsedge; however, the EPA required a phase out of methyl bromide (EPA 2011). Since then, growers have transitioned to the use of herbicides to effectively and efficiently remove weeds. In bell pepper, herbicides can be applied during the preplant fallow period, PRE under the polyethylene mulch, POST-directed (POST-DIR) to the crop, POST over the top of the crop, and PRE or POST to the row middle. Although several herbicide options are available in Florida bell pepper, few provide control of nutsedge. Prior to the registration of fomesafen and imazosulfuron, herbicides registered for nutsedge control in bell pepper were restricted to glyphosate preplant burndown, *S*-metolachlor preplant under the polyethylene mulch, and halosulfuron to the row middles only (Santos et al. 2013). With the addition of fomesafen preplant under the polyethylene mulch and imazosulfuron POST-DIR, new in-season nutsedge control programs could possibly be developed for Florida bell pepper.

Fomesafen is a member of the diphenylether family and is registered for PRE and POST control of weeds in snap bean (*Phaseolus vulgaris* L.), cotton (*Gossypium hirsutum* L.), potato (*Solanum tuberosum* L.), and soybean [*Glycine max* (L.) Merr.] (Anonymous 2011a). A recent registration in bell pepper allows for use of fomesafen PRE under the polyethylene mulch only. Previous research has reported that fomesafen PRE has the potential to suppress or control yellow nutsedge growth (Dowler 1987).

S-metolachlor, another PRE herbicide, is in the chloroacetamide family and is applied PRE to preformed beds before laying the polyethylene mulch (Bangarwa et al. 2009). Currently, *S*-metolachlor (Dual Magnum® Syngenta crop protection, Greensboro, NC) is registered for use under a third-party registration in Florida and allows for use PRE in the crop row and post-transplant in the row middles (Santos et al. 2013). Previous research has reported *S*-metolachlor applied PRE provided control of yellow nutsedge but was inconsistent in the control of purple nutsedge (Anonymous 2007; Bangarwa et al. 2009).

Imazosulfuron is a sulfonylurea herbicide that provides PRE and POST weed control. In 2012, imazosulfuron was registered for use PRE in the row

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middles and POST-DIR in Florida bell pepper and tomato for the control of broadleaf and sedge weeds (Anonymous 2011b). Label restrictions state that when applied POST-DIR, bell pepper should be at least 25 cm in height and the spray should be directed towards the base of the stem to avoid contact with fruit (Anonymous 2011b). Research found imazosulfuron at 224 or 336 g ha^{-1} provided up to 93% control of yellow nutsedge (Riar and Norsworthy 2011). Further research reported imazosulfuron at 560 g ha^{-1} to have up to 94% control of purple nutsedge at 4 wk after treatment in bermudagrass [*Cynodon dactylon* (L.) Pers.] turf (Henry et al. 2012).

There is need for more in-season nutsedge control options in Florida bell pepper. Furthermore, previous research suggests that fomesafen and imazosulfuron are capable of achieving some level of nutsedge control. With the recent registration of each of these herbicides in Florida bell pepper, research should be conducted utilizing these herbicides to evaluate their fit in an in-season nutsedge management program. The specific objectives of the study were to: (1) determine the effect of *S*-metolachlor, fomesafen, and imazosulfuron on bell pepper height, injury, and yield; and (2) evaluate herbicide programs containing *S*-metolachlor, fomesafen, and imazosulfuron for in-season nutsedge control in bell pepper.

Materials and Methods

The experiment was conducted during the fall of 2012 and spring of 2013 at the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) Plant Science Research and Education Unit in Citra, FL. The soil type was Hague sand (loamy, sliceous, semiactive, hyperthermic Arenic Hapludalfs) with a pH of 7. In both years, fields were prepared using standard tillage and plasticulture production practices typical for the region (Santos et al. 2013). Beds were formed on 1.8 m centers with a bed height of 20 cm and width of 91 cm. Soil fumigants were not used in this study. Some fumigants suppress nutsedge and the purpose of this study was to evaluate stand-alone herbicide programs. Planting beds were covered with a 1.25-ml plastic mulch (Intergro, Berry Plastics Corporation, Evansville, IN). One drip tape per bed was laid in the center of each bed at a depth of 4 cm while the beds were being covered with the plastic mulch. Recommended irrigation and fertigation practices were applied according to the UF/IFAS Florida Vegetable Production Handbook (Santos et al. 2013). Plots measured 6 m long with the center 4.5 m planted. A 30.4 cm offset double-row plant spacing was used, resulting in 30 plants per plot. The fields contained a mixed, natural stand of yellow (60%) and purple (40%) nutsedge species with an average density of 100 shoots m^{-2}. Bell pepper 'TomCat' was transplanted on August 22, 2012 (Fall 2012) and 'Aristotle' was transplanted on March 28, 2013 (Spring 2013).

Treatments were arranged in a randomized complete block design with each treatment replicated four times. All herbicide treatments were sprayed with a CO_2-pressurized backpack sprayer calibrated to deliver 284 L ha^{-1}. PRE treatments included *S*-metolachlor at 0.71 and 1.07 kg ha^{-1}, fomesafen at 0.28 and 0.42 kg ha^{-1}, *S*-metolachlor at 0.71 kg ha^{-1} + fomesafen 0.28 kg ha^{-1}, and *S*-metolachlor at 1.07 kg ha^{-1} + fomesafen at 0.42 kg ha^{-1}. PRE treatments were applied to preformed beds prior to laying the plastic mulch on August 7, 2012 and on March 21, 2013. POST-DIR treatments included imazosulfuron at 0.21 and 0.34 kg ha^{-1}. POST-DIR applications were applied on September 26, 2012 and on May 6, 2013 (35 and 39 d after planting [DAP], respectively). POST-DIR treatments were applied with a single nozzle boom directed to the base of the stem when the bell pepper plant were 25 to 38 cm in height, with four to five flowers, and with fruit measuring 1.2 to 3.8 cm in diam. In both years, the nutsedge measured 20 to 38 cm tall, with a majority of plants bearing a seed head when the POST-DIR application was made. PRE followed by (fb) POST-DIR treatments included *S*-metolachlor at 0.71 or 1.07 kg ha^{-1} fb imazosulfuron at 0.21 kg ha^{-1} and fomesafen at 0.28 or 0.42 kg ha^{-1} fb imazosulfuron at 0.21 kg ha^{-1}. Weed-free treatments were hand-weeded once per week, whereas weedy plots remained undisturbed throughout the growing season.

Nutsedge control, crop injury, plant heights, and marketable yield data were collected in each year. In both years, PRE nutsedge control and crop injury ratings were performed 7, 14, 21, and 28 DAP. POST-DIR nutsedge control and crop injury ratings were performed 7, 14, 21, and 28

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Table 1. Effect of *S*-metolachlor and fomesafen applied PRE for nutsedge (mixture of yellow and purple) control in bell pepper.[a]

			Nutsedge control							
			7 DAP		14 DAP		21 DAP		28 DAP	
Treatment	Rate	Timing	2012	2013	2012	2013	2012	2013	2012	2013
	kg ha^{-1}		%							
Weed-free	—	—	100 a[b]	100	100 a	100 a	100 a	100 a	100 a	100 a
S-metolachlor	0.71	PRE	40 bc	88	43 bcd	80 b	53 bc	66 b	59 bc	60 b
S-metolachlor	1.07	PRE	38 bc	89	54 bc	84 b	61 b	69 b	60 bc	60 b
Fomesafen	0.28	PRE	16 bc	78	18 d	74 b	24 c	58 b	29 c	53 b
Fomesafen	0.42	PRE	13 c	80	21 cd	73 b	30 bc	69 b	48 bc	50 b
S-metolachlor + fomesafen	0.71 + 0.28	PRE	51 b	84	56 b	78 b	61 b	53 b	65 b	49 b
S-metolachlor + fomesafen	1.07 + 0.42	PRE	43 bc	88	46 bcd	83 b	50 bc	66 b	63 b	55 b
Contrasts[c]										
S-metolachlor vs. fomesafen			*	*	**	*	**	NS	*	NS
S-metolachlor alone vs. + fomesafen			NS	NS	NS	NS	NS	NS	NS	NS
Fomesafen alone vs. + *S*-metolachlor			**	NS	**	NS	**	NS	*	NS

[a] Abbreviation: DAP, d after planting.

[b] Means within columns followed by different letters are significantly different using Fisher's protected LSD ($\alpha = 0.05$).

[c] Contrasts were nonsignificant (NS) or significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**), or $P \leq 0.001$ (***).

d after the POST-DIR treatment (DAPD). Estimates of nutsedge control were based on a scale of 0 to 100% with 0% representing no nutsedge control and 100% representing complete control. Crop injury included irregular growth malformations such as misshapen or stunted leaves, stems, or fruit. Crop injury was estimated based on ratings of 0% = no crop injury and 100% =c omplete crop death. Plant heights were determined by measuring 5 plants plot^{-1} located within the center 0.9 m of the plot at 14 and 28 DAP and 14 and 28 DAPD.

Bell peppers were harvested and graded according to USDA grade and standard guidelines (USDA 2005). Harvest data included marketable yield and marketable fruit count, including U.S. No.1, No.2, and Fancy grades according to USDA guidelines. In both years, a single harvest was performed. Harvest occurred 69 DAP on October 30, 2012 and 75 DAP on June 11, 2013. At the time of harvest, fruit measuring less than 5 cm diam were not harvested. Data were subjected to ANOVA using PROC GLM in SAS (version 9.2, SAS Institute Inc., P.O. Box 8000, Cary, NC 25712) and means were separated with Fisher's protected LSD ($\alpha = 0.05$). Orthogonal contrasts were used for treatment comparison.

Results and Discussion

Nutsedge Control. An application timing by nutsedge control interaction was observed for PRE and POST-DIR applications; thus, PRE and POST-DIR applications were analyzed separately. A year-by-treatment interaction was observed for PRE nutsedge control; thus ,years were analyzed separately. In 2012, all PRE herbicide treatments had poor nutsedge control (13 to 56%) at 7 and 14 DAP (Table 1). At 7 DAP, all PRE treatments provided equivalent levels of control in the range of 13 to 51%. At 14 DAP, *S*-metolachlor at 0.71 kg ha^{-1} + fomesafen at 0.28 kg ha^{-1} had the highest control of nutsedge (56%), whereas the lowest control was observed with fomesafen at 0.28 kg ha^{-1} (18%). PRE herbicides exhibited higher nutsedge control at 21 DAP, ranging from 24 to 61%. At 28 DAP, PRE herbicide nutsedge control ranged from 29 to 65%. Orthogonal contrast statements indicated that either rate of *S*-metolachlor alone provided greater nutsedge control than either rate of fomesafen alone across all rating dates in 2012. Furthermore, the combination of *S*-metolachlor + fomesafen had higher nutsedge control compared to fomesafen alone across all rating dates in 2012; *S*-metolachlor alone did not gain any additional nutsedge control when combined with fomesafen.

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Table 2. Effect of *S*-metolachlor and fomesafen applied PRE followed by imazosulfuon POST-DIR for nutsedge (mixture of yellow and purple) control in bell pepper with years combined.[a]

Treatment	Rate	Timing	Nutsedge control							
			7 DAPD		14 DAPD		21 DAPD		28 DAPD	
	kg ha^{-1}		%							
Weed-free	—	—	100	a[b]	100	a	100	a	100	a
S-metolachlor	0.71	PRE	45	bcde	47	ef	53	defg	46	de
S-metolachlor	1.07	PRE	45	bcde	54	cdef	53	defg	50	de
Fomesafen	0.28	PRE	31	de	39	f	43	g	42	e
Fomesafen	0.42	PRE	39	cde	48	def	56	defg	52	de
Imazosulfuron	0.21	POST-DIR	32	cde	51	def	51	efg	49	de
Imazosulfuron	0.34	POST-DIR	36	cde	46	ef	48	gf	45	de
S-metolachlor fb imazosulfuron	0.71 fb 0.21	PRE fb POST-DIR	62	b	76	b	74	b	73	b
S-metolachlor fb imazosulfuron	1.07 fb 0.21	PRE fb POST-DIR	49	bcd	69	bc	72	bc	69	bc
Fomesafen fb imazosulfuron	0.28 fb 0.21	PRE fb POST-DIR	28	e	51	cde	57	defg	59	bcd
Fomesafen fb imazosulfuron	0.42 fb 0.21	PRE fb POST-DIR	45	bcde	64	bcd	67	bcd	69	bc
S-metolachlor + fomesafen	0.71 + 0.28	PRE	51	bcd	58	cde	64	bcde	58	cd
S-metolachlor + fomesafen	1.07 + 0.42	PRE	52	bc	59	cde	59	cdef	56	cde
Contrasts[c]										
S-metolachlor vs. fomesafen			NS		NS		NS		NS	
S-metolachlor alone vs. *S*-metolachlor fb imazosulfuron			NS		***		***		***	
Fomesafen alone vs. fomesafen fb imazosulfuron			NS		*		*		***	
Imazosulfuron alone vs. PRE herbicide fb imazosulfuron			NS		**		***		***	

[a] Abbreviations: POST-DIR, POST-directed; DAPD, d after post-directed application; fb, followed by.

[b] Means within columns followed by different letters are significantly different using Fisher's protected LSD ($\alpha = 0.05$).

[c] Contrasts were nonsignificant (NS) or significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**), or $P \leq 0.001$ (***).

In 2013, all PRE treatments were similar to the weed-free treatment at 7 DAP (Table 1). At 14 DAP, all PRE treatments were similar and provided nutsedge control ranging from 73 to 83%. Nutsedge control steadily declined 21 and 28 DAP with all PRE treatments. Orthogonal contrasts indicated that at 14, 21, and 28 DAP, all PRE-applied herbicides provided a similar level of nutsedge control. However, no treatment was similar to the weed-free treatment at 14, 21, or 28 DAP. Furthermore, orthogonal contrast indicated that *S*-metolachlor provided greater nutsedge control compared to fomesafen at 7 and 14 DAP; however, no difference was observed between *S*-metolachlor and fomesafen treatments at 21 and 28 DAP. No additional nutsedge control was observed with the tank mix of fomesafen + *S*-metolachlor compared to fomesafen or *S*-metolachlor applied alone in 2013.

When comparing years for early PRE ($\leq$ 28 DAP) nutsedge control ratings, potential differences in the ratio of nutsedge species within plots might have contributed to the inadequate level of control observed in early 2012 ratings. As reported by Webster (2005b), a higher population of purple nutsedge than yellow nutsedge is likely in a plasticulture system. The nutsedge control provided by the herbicides used herein is typically lower with purple nutsedge compared to yellow nutsedge, likely resulting in the lower control levels observed in this experiment. Likewise, a year-by-treatment interaction for early PRE control might also have been attributed to seasonal changes such as rainfall, resulting in lower activation of the herbicides. For example, the 2012 study was conducted in the fall, which is typically the dry season in Florida, but the 2013 study was conducted in the spring, normally a wetter season. However, in both years, the nutsedge control ratings at 21 and 28 DAP demonstrated that high nutsedge stands ($>$ 100 shoots m^{-2}) might be difficult to reduce when relying on a PRE herbicide alone. Furthermore, achieving the critical

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Table 3. Influence of *S*-metolachlor and fomesafen PRE and imazosulfuron POST-DIR on bell pepper plant height 28 DAP.[a]

Treatment	Rate	Timing	Plant height	
			2012	2013
	ka ha^{-1}		cm	
Weed-free	—	—	30 ab[b]	23
Weedy	—	—	30 ab	23
S-metolachlor	0.71	PRE	25 e	22
S-metolachlor	1.07	PRE	27 bcde	22
Fomesafen	0.28	PRE	30 ab	24
Fomesafen	0.42	PRE	29 abcd	23
Imazosulfuron	0.21	PRE	29 abcd	24
Imazosulfuron	0.34	PRE	30 ab	24
S-metolachlor fb imazosulfuron	0.71 fb 0.21	PRE fb POST-DIR	25 e	22
S-metolachlor fb imazosulfuron	1.07 fb 0.21	PRE fb POST-DIR	29 abcd	23
Fomesafen fb imazosulfuron	0.28 fb 0.21	PRE fb POST-DIR	32 a	24
Fomesafen fb imazosulfuron	0.42 fb 0.21	PRE fb POST-DIR	30 ab	24
S-metolachlor + fomesafen	0.71 + 0.28	PRE	26 de	24
S-metolachlor + fomesafen	1.07 + 0.42	PRE	26 cde	23
Contrasts[c]				
S-metolachor vs. fomesafen			*	*
S-metolachlor alone vs. *S*-metolachlor fb imazosulfuron			NS	NS
Fomesafen alone vs. fomesafen fb imazosulfuron			NS	NS
Imazosulfuron alone vs. PRE herbicide fb imazosulfuron			NS	NS

[a] Abbreviations: DAP, d after planting; POST-DIR, POST-directed; fb, followed by.

[b] Means within columns followed by different letters are significantly different using Fisher's protected LSD ($\alpha = 0.05$).

[c] Contrasts were nonsignificant (NS) or significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**), or $P \leq 0.001$ (***).

nutsedge-free period in bell pepper (21 to 35 DAP) (Motis et al. 2004) in areas where high nutsedge populations exist will be challenging when relying on a nutsedge management program that utilizes only PRE herbicides.

For POST-DIR treatments, no year-by-treatment interaction was observed for nutsedge control at 7, 14, 21, or 28 DAPD; thus, data were pooled across years. The nutsedge control 7 DAPD ranged between 28 and 62% (Table 2). At 7 DAPD, no differences were observed with orthogonal contrasts when comparing imazosulfuron alone to a PRE alone. Like other sulfonylurea herbicides, imazosulfuron requires several weeks to kill a plant when applied POST-DIR. Thus, improved nutsedge control was observed with imazosulfuron at 14, 21, and 28 DAPD. Nutsedge control at 14, 21, and 28 DAPD was greatest with *S*-metolachlor at 0.71 kg ha^{-1} fb imazosulfuron at 0.21 kg ha^{-1}, *S*-metolachlor at 1.07 kg ha^{-1} fb imazosulfuron at 0.21 kg ha^{-1}, and fomesafen at 0.42 kg ha^{-1} fb imazosulfuron. Orthogonal contrasts revealed no differences between *S*-metolachlor and fomesafen at 7, 14, 21, or 28 DAPD. However, at 14, 21, and 28 DAPD, *S*-metolachlor or fomesafen PRE fb imazosulfuron provided higher nutsedge control compared to imazosulfuron alone, and the addition of imazosulfuron consistently improved nutsedge control when following a PRE herbicide.

Crop Injury and Height. Crop injury was not observed in either year (data not shown). The absence of crop injury was expected and is likely attributed to the use of registered rates.

A year-by-treatment interaction for plant heights was observed; thus, years were analyzed separately. In 2012, no differences in plant heights were observed 14, 42, or 56 DAP (data not shown). At 28 DAP, *S*-metolachlor at 0.71 kg ha^{-1}, *S*-metolachlor 0.71 kg ha^{-1} + fomesafen at 0.28 kg ha^{-1}, and *S*-metolachlor 0.71 kg ha^{-1} fb imazosulfuron 0.21 kg ha^{-1} had lower plant heights than the weedy and weed-free treatments (Table 3). All other herbicide treatments were similar to the weed-free. According to orthogonal contrasts, treatments that included *S*-metolachlor had lower plant heights

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Table 4. Effect of *S*-metolachlor and fomesafen PRE and imazosulfuron POST-DIR on bell pepper marketable yield.[a,b]

Treatment	Rate	Timing	2012				2013	
	kg ha^{-1}		—kg ha^{-1}—		—fruit ha^{-1}—		kg ha^{-1}	fruit ha^{-1}
Weed-free	—	—	2,858	a[c]	17,560	a	4,983	21,683
Weedy	—	—	2,509	abcd	16,843	ab	4,896	21,102
S-metolachlor	0.71	PRE	1,586	f	11,035	f	5,541	23,522
S-metolachlor	1.07	PRE	2,152	cde	14,617	bcd	4,495	19,399
Fomesafen	0.28	PRE	2,692	ab	16,301	abc	5,306	23,038
Fomesafen	0.42	PRE	2,335	bcd	14,462	cd	5,628	23,852
Imazosulfuron	0.21	PRE	2,361	bcd	14,617	bcd	5,271	22,980
Imazosulfuron	0.34	PRE	2,614	abc	16,262	abc	5,724	22,942
S-metolachlor fb imazosulfuron	0.71 fb 0.21	PRE fb POST-DIR	2,065	de	13,841	de	4,957	21,296
S-metolachlor fb imazosulfuron	1.07 fb 0.21	PRE fb POST-DIR	2,431	abcd	15,333	abcd	5,567	23,948
Fomesafen fb imazosulfuron	0.28 fb 0.21	PRE fb POST-DIR	2,858	a	17,076	a	5,828	24,529
Fomesafen fb imazosulfuron	0.42 fb 0.21	PRE fb POST-DIR	2,710	ab	16,398	abc	6,247	25,284
S-metolachlor + fomesafen	0.71 + 0.28	PRE	1,786	ef	11,752	ef	4,704	20,270
S-metolachlor + fomesafen	1.07 + 0.42	PRE	2,152	cde	13,552	de	5,149	22,554
Contrasts[d]								
S-metolachlor vs. fomesafen			***		**		NS	NS
S-metolachlor alone vs. *S*-metolachlor fb imazosulfuron			*		*		NS	NS
Fomesafen alone vs. fomesafen fb imazosulfuron			NS		NS		NS	NS
Imazosulfuron alone vs. PRE herbicide fb imazosulfuron			NS		NS		NS	NS

[a] Harvest data included marketable yield and marketable fruit count including U.S. No.1, No.2, and Fancy grades (USDA).

[b] Abbreviations: DAP, d after planting; POST-DIR, POST-directed; fb, followed by.

[c] Means within columns followed by different letters are significantly different using Fisher's LSD ($\alpha = 0.05$).

[d] Contrasts were nonsignificant (NS) or significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**), or $P \leq 0.001$ (***).

compared to treatments with fomesafen at 28 DAP; however, this was not observed at any other rating in 2012.

In 2013, no differences in plant heights were observed at 14, 28, 46, or 60 DAP among any of the treatments when compared to the weed-free treatment (data not shown). However, contrast statements indicated that herbicide treatments that included *S*-metolachlor had lower plant heights than treatments with fomesafen at 28 DAP, but this was not observed at any other measurement date in 2013 (Table 3). Additionally, treatments consisting of *S*-metolachlor fb imazosulfuron had taller plants compared to *S*-metolachlor alone at 60 DAP.

Differences in plant heights between years are likely due to the different bell pepper cultivars used and time of year. Tomcat, the variety used in 2012, has a more compact growth habit whereas Aristotle, the variety used in 2013, is known for being a vigorous pepper plant. The low plant heights observed 28 DAP in both years with treatments containing *S*-metolachlor might be attributed to environmental factors and was not observed at any other measurement date.

Marketable Yield. A year-by-treatment interaction was observed for marketable yield; thus, years were analyzed separately. In 2012, orthogonal contrasts revealed that treatments containing fomesafen had higher yield compared to treatments with *S*-metolachlor (Table 4). The lowest marketable fruit weight and fruit count was observed with *S*-metolachlor at 0.71 kg ha^{-1}, which similar to *S*-metolachlor at 0.71 kg ha^{-1} + fomesafen at 0.28 kg ha^{-1} (Table 4). The highest marketable yield in 2012 was observed with fomesafen 0.28 kg ha^{-1}, imazosulfuron 0.34 kg ha^{-1}, *S*-metolachlor 1.07 kg ha^{-1} fb imazosulfuron 0.21 kg ha^{-1}, fomesafen 0.28 kg ha^{-1} fb imazosulfuron 0.21 kg ha^{-1}, and fomesafen 0.42 kg ha^{-1} fb imazosulfuron 0.21 kg ha^{-1}, and were similar to the weedfree.

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In 2013, no differences in marketable yield were observed among any of the treatments when compared to the weed-free treatment. Orthogonal contrasts indicated that treatments containing *S*-metolachlor at 0.71 or 1.07 kg ha^{-1} reduced fruit weight and fruit count when compared to fomesafen treatments in 2012; however, this did not occur in 2013. Differences in market fruit weight and market fruit count between years were likely due to the use of different bell pepper cultivars in each year.

In summary, a PRE or POST-DIR herbicide alone are not capable of achieving season-long control of nutsedge in Florida bell pepper. Bangarwa et al. (2009) reported that by the end of the season *S*-metolachlor and halosulfuron PRE fb trifloxysulfuron and halosulfuron POST-DIR provided greater nutsedge control than treatments relying on a PRE or a POST-DIR treatment alone. Although differences in marketable yield were only observed in 2012, nutsedge control in Florida bell pepper remains important due the ability of weeds to host plant pathogens such as fungal diseases and nematodes. The overall results from this study support previous research findings and exhibit the importance of a PRE fb POST-DIR herbicide program to control nutsedge in the bell pepper crop. Furthermore, *S*-metolachlor or fomesafen PRE fb imazosulfuron POST-DIR demonstrated excellent crop safety and might be a viable tool for Florida growers to achieve season-long control of nutsedge in bell pepper.

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