Herbicide Tank Mixtures for Broad-Spectrum Weed Control in Florida Citrus

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Weed control in Florida citrus is primarily based on herbicides. Saflufenacil, a POST-applied herbicide is recently registered for broadleaf weed control in citrus. Saflufenacil has very limited grass activity; therefore, it should be tank mixed with graminicides or broad-spectrum herbicides to increase the spectrum of weed control. Greenhouse and field experiments were conducted at two locations (Polk County and Orange County, FL) to evaluate the efficacy and potential antagonism or synergy of saflufenacil and sethoxydim applied alone or tank mixed, and various two- and three-way mixes with glyphosate or pendimethalin. The results suggested that tank mixing saflufenacil and sethoxydim had neither synergistic nor antagonistic effect on broadleaf and grass weed control, respectively. Tank mixing pendimethalin with saflufenacil and sethoxydim improved broadleaf and grass weed control and reduced weed density and biomass, compared with saflufenacil or sethoxydim applied alone or tank mixed at 45 and 60 d after treatment (DAT). Glyphosate tank mixed with saflufenacil and sethoxydim provided $> 90\%$ control of broadleaf and grass weeds at 15 DAT, reduced density ≤ 8 plants m^{-2}, and reduced biomass < 95 g m^{-2} at 60 DAT. Glyphosate applied alone was less effective than it was when tank mixed with saflufenacil and sethoxydim or pendimethalin for broadleaf and grass weed control, indicating an additive effect of tank mixture on glyphosate efficacy. It is concluded that saflufenacil can be tank mixed with sethoxydim for control of broadleaf and grass weeds without antagonism on the efficacy of either herbicide; however, tank mixing saflufenacil and sethoxydim with glyphosate or pendimethalin provided long-term, broad-spectrum weed control in Florida citrus.
Nomenclature: Glyphosate; pendimethalin; saflufenacil; sethoxydim; citrus, *Citrus* spp.
Key words: Broadleaf weeds, grass weeds, herbicides, percent control, tank mixture, weed biomass, weed density.

El control de malezas en cítricos en Florida está basado principalmente en herbicidas. Saflufenacil, un herbicida aplicado POST, fue registrado recientemente para el control de malezas de hoja ancha en cítricos. Saflufenacil tiene actividad muy limitada sobre gramíneas; por lo que debe ser mezclado en tanque con graminicidas o herbicidas de amplio espectro para incrementar el espectro de control de malezas. Se realizaron estudios de invernadero y de campo en dos localidades (condados Polk y Orange en Florida) para evaluar la eficacia y el antagonismo o sinergismo potencial de saflufenacil y sethoxydim aplicados solos o en mezcla en tanque, y varias mezclas en dos y tres formas con glyphosate o pendimethalin. Los resultados sugirieron que mezclar en tanque saflufenacil y sethoxydim no tuvo efectos sinérgicos ni antagónicos en el control de malezas de hoja ancha o gramíneas, respectivamente. El mezclar en tanque pendimethalin con saflufenacil y sethoxydim mejoró el control de malezas de hoja ancha y gramíneas y redujo la densidad y biomasa de malezas a 45 y 60 días después del tratamiento (DAT), en comparación con saflufenacil o sethoxydim aplicados individualmente o en mezcla en tanque. Glyphosate mezclado en tanque con saflufenacil y sethoxydim brindó $>$90% de control de malezas de hoja ancha y gramíneas a 15 DAT, redujo la densidad $\leq$8 plantas m^{-2} y redujo la biomasa $<$95 g m^{-2} a 60 DAT. Glyphosate aplicado solo fue menos efectivo que cuando se aplicó en mezcla en tanque con saflufenacil y sethoxydim o pendimethalin para el control de malezas de hoja ancha y gramíneas indicando un efecto aditivo de la mezcla en tanque sobre la eficacia de glyphosate. Se concluye que saflufenacil puede ser mezclado en tanque con sethoxydim para el control de malezas de hoja ancha y gramíneas sin causar antagonismo sobre la eficacia de ninguno de estos herbicidas. Sin embargo, el mezclar en tanque saflufenacil y sethoxydim con glyphosate o pendimethalin brindó un control de amplio espectro de malezas de larga duración en cítricos en Florida.

The United States is the second largest producer of citrus, including grapefruit [*Citrus paradisi* Macfad. (pro sp.)(*maxima* × *sinensis*)], sweet orange [*Citrus sinensis* (L.) Osbeck (pro sp.)(*maxima* × *sinesis*)], mandarin tree (*Citrus reticulata* Blanco), and mandarin hybrid cultivars in the world (USDA 2006). The Florida citrus industry represents more than 65% of the commercial citrus produced in the United States. In 2010, citrus was grown on more than 223,000 ha in Florida (USDA 2010a), with a total production of more than 159 million boxes (USDA 2010b). Because of high temperature and frequent rainfall in Florida, weed management programs require considerable attention by citrus growers to reduce weed competition as well as to minimize weed interference with horticultural operations (Futch and Singh 2007). Citrus growers use a combination of mechanical, chemical, and cultural methods to control weeds; however, use of herbicides is the most-commonly adopted method by citrus growers. Herbicides are applied either as strip applications within the crop row or as broadcast applications to the grove floor (Sharma et al. 2008). Newly transplanted citrus trees (< 3 yr old) require greater attention to herbicide selection and application rates compared with older trees because the area around young citrus trees is

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more exposed to sunlight and usually has greater weed pressure compared with the area around older trees (Futch and Singh 2000).

Many POST-applied herbicides are registered for weed control in Florida citrus; however, choice is limited when compared with the PRE-applied herbicides (Futch and Singh 2011). Fortunately, a few new POST herbicides are either in the process of registration or have recently been registered for weed control in citrus. For example, saflufenacil was registered for broadleaf weed control in bearing and nonbearing citrus trees in 2010 (Anonymous 2010a). Saflufenacil is a potent inhibitor of protoporphyrinogen oxidase (PPO)(Grossman et al. 2010). This herbicide competitively inhibits PPO by occupying the binding site for protogen IX, which causes a rapid loss of membrane integrity and tissue necrosis (Duke et al. 1991). Saflufenacil is primarily a contact herbicide, translocated mainly in the xylem, with limited mobility in the phloem (Liebl et al. 2008). The labeled rate of saflufenacil applied POST in citrus is 0.05 kg ai ha^{-1} in a single application with a maximum cumulative annual amount of 0.15 kg ha^{-1} (Anonymous 2010a). It can be applied as a single application or sequentially up to three times in a year. Knezevic et al. (2009a, 2010) reported that the addition of adjuvants greatly improved the efficacy of saflufenacil to control broadleaf weeds. Saflufenacil is also registered for broadleaf weed control in annual crops, such as chickpea (*Cicer arietinum* L.), corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), soybean (*Glycine max* L.), and some other crops (Anonymous 2010b); however in annual crops, it is applied pre-plant or PRE.

Sethoxydim, a cyclohexanedione herbicide is a POST-applied graminicide that controls annual and perennial grasses, not only in broadleaf annual crops but also in several perennial crops, including citrus. Sethoxydim rapidly enters the target plants through foliage and translocates throughout the plant. It inhibits the acetyl-coenzyme A carboxylase (ACCase) enzyme and disrupts fatty acid biosynthesis in susceptible grasses (Marshall et al. 1992). The labeled rate of sethoxydim in citrus is ranges from 0.31 to 0.51 kg ai ha^{-1}, with a maximum, cumulative, annual amount of 2.1 kg ha^{-1} (Anonymous 2009a). Because most citrus groves have a mixed stand of grass and broadleaf weeds, it is desirable to tank mix sethoxydim with a broadleaf herbicide for broad-spectrum weed control. Several studies report tank mixing sethoxydim with grass and broadleaf herbicides improved the weed control spectrum. For example, when sethoxydim was tank mixed with fluazifop, the mixture controlled more than 90% green foxtail [*Setaria viridis* (L.) Beauv.], wild oat (*Avena fatua* L.), wheat (*Triticum aestivum* L.), and barley (*Hordeum vulgare* L.)(Harker et al. 1991). Several studies reported that tank mixing sethoxydim with broadleaf herbicides resulted in antagonistic effects (Campbell and Penner 1982; Corkern et al. 1998; Grichar 1991; Young et al. 1996); however, there is a lack of information on tank mixing sethoxydim with saflufenacil, and the effect the tank mix may have on weed species commonly found in Florida citrus.

Because of its broad-spectrum weed activity, relative low cost, and favorable environmental profile, glyphosate is applied extensively for weed control in Florida citrus (Sharma and Singh 2007). Although glyphosate is a broad-spectrum herbicide, not all weeds are equally susceptible to it (Culpepper and York 2000). For example, barnyardgrass [*Echinochloa crus-galli* (L.) Beauv] is more sensitive to glyphosate than is velvetleaf (*Abutilon theophrasti* Medik.) (Taylor 1996). Many weed species common to Florida citrus, including Brazil pusley [*Richardia brasiliensis* (Moq.) Gomez], common ragweed (*Ambrosia artemisiifolia* L.), Benghal dayflower (*Commelina benghalensis* L.), and common beggar-ticks [*Bidens alba* (L) D.C.] are not controlled with the recommended rate of glyphosate (Singh et al. 2011b). Therefore, herbicides with different modes of action or a tank-mix partner is required to improve the efficacy of glyphosate (Duke and Powles 2008). Waggoner et al. (2011) reported a tank mix of saflufenacil with glyphosate provided excellent control of glyphosate-resistant horseweed [*Conyza canadensis* (L.) Cronq.] in no-till cotton. Knezevic et al. (2009b) also reported a synergy between the two herbicides for control of several weed species.

Use of herbicide tank mixes to control broadleaf, grass, and sedge weeds is common among citrus producers in Florida. A tank mix of herbicides with different sites of action is one of the methods used to reduce herbicide rates while maintaining weed control at acceptable levels (Shaw and Arnold 2002). In addition, a tank mix of herbicides is also useful for control of herbicide resistant weeds (Beckie 2006; Green and Owen 2011). Saflufenacil is a broadleaf herbicide; therefore, it is essential that it be tank mixed with a grass herbicide to expand the weed control spectrum. Saflufenacil has been premixed with dimethenamid-P for PRE control of annual grasses and broadleaf and sedge weeds in corn, sorghum [*Sorghum bicolor* (L.) Moench ssp. *bicolor*], and soybean (Anonymous 2010b). Saflufenacil has also been premixed with imazethapyr for use in imidazolinone-resistant corn, soybean, and field pea (*Pisum sativum* L.)(Anonymous 2010c).

Citrus growers can benefit from new herbicides and their tank mixes. To develop weed management programs involving saflufenacil in citrus, requires a greater understanding about its interactions with commonly used herbicides. Therefore, the objective of this research was to evaluate tank mixes of saflufenacil with sethoxydim and glyphosate or pendimethalin for broad-spectrum weed control in Florida citrus.

Materials and Methods

Greenhouse Experiments. Experiments were conducted under greenhouse conditions at the Citrus Research and Education Center (University of Florida, Lake Alfred, FL) in 2011. Seeds of barnyardgrass, yellow foxtail [*Setaria pumila* (Poir.) Roem. & J.A. Schultes], and spanishneedles (*Bidens bipinnata* L.) were collected from a citrus grove in 2010 and stored at 5 C until used in this study. About seven to eight seeds of each weed species were planted in plastic pots (15 cm in diameter and 15 cm in height) at a depth of 1 to 2 cm in a commercial potting mix (Sun Gro Metro-mix, Sun Gro Horticulture Distribution Inc., Bellevue, WA). The soil was tamped lightly to ensure adequate seed-to-soil contact and watered to near field capacity upon seeding. Seedlings of

Table 1. Effects of herbicide treatments on weed control and biomass at 14 d after treatment (DAT) in a greenhouse study.

Herbicide	Rate	Control[a,b]						Biomass[a,b]					
		Barnyardgrass	Yellow foxtail	Spanishneedles	Brazil pusley	Dogfennel	Purple nutsedge	Barnyardgrass	Yellow foxtail	Spanishneedles	Brazil pusley	Dogfennel	Purple nutsedge
	kg ae or ai ha^{-1}	%						g pot^{-1}					
Nontreated control	—	0 f	0 f	0 f	0 h	0 f	0 d	5.2 a	6.7 a	6.0 a	7.5 a	8.0 a	14.5 a
Saflufenacil	0.037	14 e	30 e	75 d	63 f	66 d	1 d	5.1 a	6.5 ab	5.9 a	6.5 b	6.0 c	13.5 a
Saflufenacil	0.05	17 e	32 e	90 c	84 bc	86 b	2 d	5.2 a	6.1 b	4.6 b	5.6 cde	5.1 e	13.5 a
Sethoxydim	0.245	88 d	86 d	9 e	6 g	11 e	0 d	3.5 c	5.1 c	6.0 a	7.5 a	8.0 a	14.5 a
Sethoxydim	0.315	90 cd	94 abc	8 e	7 g	12 e	11 c	3.0 de	4.1 d	6.5 a	7.5 a	7.0 b	13.5 a
Saflufenacil + sethoxydim	0.037 + 0.245	91 cd	92 bcd	89 c	83 bc	71 d	18 b	3.6 c	5.0 c	5.9 a	6.1 bc	5.8 cd	13.5 a
Saflufenacil + sethoxydim	0.05 + 0.315	93 bc	91 cd	94 bc	83 bc	85 b	17 bc	2.9 e	4.0 d	4.6 bc	5.7 cd	5.1 e	14.5 a
Saflufenacil + sethoxydim + pendimethalin	0.037 + 0.245 + 2	91 cd	90 cd	94 bc	84 bc	86 b	14 bc	2.9 e	4.0 d	4.5 bc	5.6 cde	5.1 e	13.5 a
Saflufenacil + sethoxydim + pendimethalin	0.05 + 0.315 + 2.5	94 bc	92 bcd	93 bc	88 b	87 b	14 bc	2.9 e	4.0 d	4.5 bc	5.3 de	5.0 e	13.5 a
Saflufenacil + sethoxydim + pendimethalin	0.05 + 0.315 + 3.0	87 d	92 bcd	89 c	88 b	87 b	11 c	2.9 e	3.6 d	4.1 bc	5.1 e	4.9 e	12.4 ab
Saflufenacil + sethoxydim + glyphosate	0.05 + 0.315 + 2.24	99 a	99 a	100 a	95 a	95 a	65 a	0 g	0 f	0 e	1.6 g	2.8 g	7.5 c
Saflufenacil + glyphosate + pendimethalin	0.05 + 2.24 + 3.0	87 d	86 d	100 a	95 a	95 a	63 a	2.3 f	3.1 e	0 e	1.7 g	2.5 g	7.6 c
Glyphosate	2.52	90 cd	91 cd	94 bc	78 cd	87 b	64 a	3.4 cd	3.0 e	2.75 d	3.8 f	3.7 f	7.7 c

[a] The treatment by experiment interaction among greenhouse studies was nonsignificant; therefore, data from both experiments were pooled, and the combined data were presented. The data were arcsine square-root transformed for homogenous variance before analysis; however, data presented are the means of actual values based on interpretation from the transformed data.

[b] Means within columns with no common letter or letters are significantly different according to Fisher's Protected LSD test, where $P \leq 0.05$.

Brazil pusley, dogfennel [*Eupatorium capillifolium* (Lam.) Small], and purple nutsedge (*Cyperus rotundus* L.) were collected from a citrus grove near Winter Garden, FL, and immediately transplanted at five seedlings per pot (15 cm in diameter and 15 cm in height) containing commercial potting mix. Two weeks after seeding or transplanting, plants were thinned to three plants per pot. All pots were surface watered as needed throughout the experiment to maintain adequate soil moisture for plant growth. The greenhouse was maintained at a day/night temperature of 25/16 C (± 0.5 C), 70% (± 5%) relative humidity, and normal photoperiod. The fertilizer solution (Tractite 20-20-20 [N–P–K], Helena Chemical Company, Collierville, TN) was applied with irrigation water for better plant growth.

The experiment was conducted in a randomized complete-block design with four replications. Herbicide treatments included saflufenacil (herbicide Treevix, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC) applied alone at 0.037 or 0.05 kg ha^{-1}; sethoxydim (herbicide Poast Plus, BASF) applied alone at 0.245 or 0.315 kg ha^{-1}; tank mixing saflufenacil (0.037 or 0.05 kg ha^{-1}) and sethoxydim (0.245 or 0.315 kg ha^{-1}); tank mixing saflufenacil and sethoxydim with either pendimethalin (herbicide Prowl H_2O BASF)(2.0, 2.5 or 3 kg ai ha^{-1}) or glyphosate (herbicide Roundup WeatherMax, Monsanto Company, St Louis, MO) at 2.24 kg ae ha^{-1}; saflufenacil (0.05 kg ai ha^{-1}) plus glyphosate (2.24 kg ae ha^{-1}) plus pendimethalin (3 kg ai ha^{-1}), and glyphosate applied alone at 2.52 kg ae ha^{-1} (Table 1). An untreated control was included for comparison. To improve the efficacy of herbicides, saflufenacil and glyphosate treatments were mixed with ammonium sulfate (DSM Chemicals North America Inc., Augusta, GA) at 1.2 kg 100 L^{-1} and crop oil concentrate (Agri-Dex, Helena) at 1% v/v. All sethoxydim treatments were mixed with crop oil concentrate at 1% v/v. Herbicide treatments were applied when weeds were 10 to 13 cm tall. The herbicides were applied using a chamber track-bench sprayer (Spraying System Company, Wheaton, IL) fitted with 8002 nozzle (TeeJet, Spraying Systems Co., Wheaton, IL) calibrated to deliver 187 L ha^{-1} at 279 kPa. Control of weeds was recorded at 14 d after treatment (DAT) on a scale of 0 to 100%, with 0% being no control and 100% being complete control of weeds at the time of observation, compared with the nontreated control. The aboveground biomass was harvested at 14 DAT, dried in an oven at 60 C for 7 d, weighed, and the biomass was recorded. The experiment was repeated.

Field Experiments. Field experiments were conducted in citrus groves in Polk and Orange counties, FL, in 2011. The soil at the experimental site in Polk County, FL, is a Florida Candler fine sand (hyperthermic, uncoated, Typic Quartzipsamment) with a pH of 6.5, 91.7% sand, 4.5% silt, 4.0% clay, and 0.5% organic matter. The soil of the experimental site in Orange County, FL, had a pH of 6.3, 91.0% sand, 4.8% silt, 3.8% clay, and 0.4% organic matter. Experiments were conducted in a randomized complete-block design with four replications. Herbicide treatments were the same as discussed in greenhouse studies. An untreated control was included for comparison. At both the sites, the plot size was 2 m by 10 m, arranged between the tree rows (middles).

Herbicides were applied on July 7, 2011, at the Polk County, FL, site and on July 18, 2011, at Orange County, FL, site using a tractor-mounted computerized boom sprayer fitted with 8002 nozzles calibrated to deliver 188 L ha^{-1} at 279 kPa. Citrus species were 3- and 7-yr-old 'Valencia' sweet orange at Polk County and Orange County sites, respectively.

Control of weeds was recorded at 15, 30, 45, and 60 DAT on a scale 0 to 100%, where 0% means no control and 100% means complete control of weeds at the time of observation, compared with the nontreated control. The weed densities and biomass were assessed during the growing season within 0.5-m^2 quadrats (two quadrats per plot) at 60 DAT. The weed species (broadleaf or grass weeds separately) that survived were cut at the stem base close to the soil surface from two randomly selected 0.5-m^2 quadrats per plot; placed in paper bags, dried in an oven for 7 d at 60 C, and the biomass was recorded.

Statistical Analysis. Data were subjected to ANOVA using the SAS version 9.2 (SAS Institute Inc, Cary, NC). Normality, homogeneity of variance, and interactions of treatments in greenhouse repeat experiments were tested. The percentage of weed control data, weed density, and weed biomass were arcsine square-root transformed before analysis to meet assumptions of variance analysis. However, non-transformed data are presented based on interpretation from the transformed data. Where the ANOVA indicated that treatment effects were significant, means were separated at $P \leq 0.05$ with Fisher's Protected LSD test.

Results and Discussion

Greenhouse Experiments. The treatment by experiment interaction among greenhouse studies was nonsignificant; therefore, data of both experiments were pooled, and the combined data are presented. Results suggested that all herbicide treatments were effective for control of broadleaf and grass weeds, compared with the nontreated control (Table 1). Saflufenacil applied alone at all rates was not effective for control of barnyardgrass ($\leq$ 17%) and yellow foxtail ($\leq$ 32%) at 14 DAT. This was due to the saflufenacil being a broadleaf herbicide, with very limited grass activity (Anonymous 2010a). Sethoxydim applied alone at the lower rate was as effective as the recommended rate for control of barnyardgrass; however, yellow foxtail control was less with the lower rate (86% control) compared with the recommended rate (94% control; Table 1). Tank mixing saflufenacil with sethoxydim did not reduce control of barnyardgrass or yellow foxtail compared with sethoxydim applied alone at 0.315 kg ha^{-1}. This indicated that saflufenacil had no antagonistic effect on performance of sethoxydim in controlling grass weeds. Similarly, a greenhouse study reported no antagonism between a tank mixture of sethoxydim and chlorimuron on goosegrass [*Eleusine indica* (L.) Gaertn.] control compared with sethoxydim applied alone (Holshouser and Coble 1990). In contrast to this, several studies reported that sethoxydim efficacy was reduced when tank mixed with bentazon (Campbell and Penner 1982), bromoxynil (Corkern et al. 1998), pyridate (Grichar 1991), and 2,4-D (Young et al. 1996).

Tank mixing pendimethalin with sethoxydim usually did not improve control of barnyardgrass and yellow foxtail, compared with sethoxydim applied alone at 0.315 kg ha^{-1}. This was because pendimethalin is a soil-applied herbicide and provides most effective weed control when applied before weed seedling emergence (Anonymous 2009b), whereas in this study, herbicides were applied POST when weeds were 10 to 13 cm tall; therefore, it was expected that pendimethalin would not improve weed control. Control of barnyardgrass and yellow foxtail was the highest (99%) with glyphosate tank mixed with sethoxydim and saflufenacil. Glyphosate applied alone provided 90 and 91% control of barnyardgrass and yellow foxtail, respectively. This indicated that tank mixing glyphosate with sethoxydim improved control of grass weeds compared with the efficacy of either herbicide alone.

Saflufenacil applied alone at the recommended rate of 0.05 kg ha^{-1} provided 90, 84, and 86% control of spanishneedles, Brazil pusley, and dogfennel, respectively, compared with the lower rate (0.037 kg ha^{-1}) that resulted in $\leq$ 75% control at 14 DAT (Table 1). Similarly, Frihauf et al. (2010) reported 55% control of henbit (*Lamium amplexicaule* L.) with saflufenacil applied at 13 g ha^{-1} compared with 78% control at 50 g ha^{-1} at 7 DAT. Sethoxydim applied alone at all rates was poor (< 15%) for control of broadleaf weeds. A tank mix of sethoxydim with saflufenacil neither reduced nor improved control of broadleaf weeds compared with saflufenacil applied alone, indicating there was no antagonistic effect. Holshouser and Coble (1990) reported that control of entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray) or tall morningglory [*Ipomoea purpurea* (L.) Roth.] did not differ by tank mixing sethoxydim with any of the five broadleaf herbicides (acifluorfen, bentazon, fomesafen, imazaquin and chlorimuron) compared with the broadleaf herbicides applied alone.

The treatments containing glyphosate as a tank-mix partner were the most effective and resulted in 100, 95, and 95% control of spanishneedles, Brazil pusley, and dogfennel, respectively. In the absence of glyphosate, purple nutsedge control was < 20%, indicating failure of sethoxydim or saflufenacil applied alone or in tank mixes to control this weed problem. Glyphosate applied alone was less effective than it was when tank mixed with sethoxydim and saflufenacil for control of grass and broadleaf weeds.

Similar results were reflected in weed biomass. For example, sethoxydim or saflufenacil applied alone resulted in higher broadleaf and grass weed biomass, respectively. The lowest biomass (0 g pot^{-1}) was observed for barnyardgrass and yellow foxtail with glyphosate tank mixed with sethoxydim and saflufenacil, and, similarly, the least biomasses of 0, 1.6, and 2.8 g pot^{-1} were reported for spanishneedles, Brazil pusley, and dogfennel, respectively, with this treatment. The highest control ($\leq$ 65%) and the least biomass (< 8.0 g pot^{-1}) of purple nutsedge was noticed in treatments with glyphosate applied alone or in tank mix, compared with other treatments (Table 1).

Field Experiments. Weed species at the Polk and Orange County sites were different, thus weed control, weed density

Table 2. Efficacy of herbicide treatments for weed control at 15 and 45 d after treatment (DAT) in a field experiment conducted in Polk County, FL.

		15 DAT[a,b]						45 DAT[a,b]					
Herbicide	Rate	Brazil pusley	Jamaica feverplant	Eclipta	Bermudagrass	Guineagrass	Southern sandbur	Brazil pusley	Jamaica feverplant	Eclipta	Bermudagrass	Guineagrass	Southern sandbur
	kg ae or ai ha^{-1}	%											
Nontreated control	—	0 d	0 f	0 f	0 g	0 g	0 f	0 e	0 f	0 f	0 e	0 f	0 f
Saflufenacil	0.037	64 c	70 d	70 d	1 gf	4 f	1 f	49 d	52 e	50 e	0 e	0 f	0 f
Saflufenacil	0.05	82 b	89 ab	87 b	3 f	3 f	6 e	58 c	60 d	58 d	0 e	0 f	0 f
Sethoxydim	0.245	0 d	0 ef	1 e	66 e	74 de	1 d	0 e	0 f	0 f	49 d	52 e	50 e
Sethoxydim	0.315	1 d	3 e	0 f	88 ab	89 b	87 ab	0 e	0 f	0 f	58 c	60 d	59 d
Saflufenacil + sethoxydim	0.037 + 0.245	73 c	70 d	70 d	68 e	66 e	67 d	50 d	52 e	50 e	49 d	52 e	50 e
Saflufenacil + sethoxydim	0.05 + 0.315	88 b	89 ab	88 b	82 bcd	78 cd	75 cd	59 c	60 d	60 d	58 c	60 d	59 d
Saflufenacil + sethoxydim + pendimethalin	0.037 + 0.245 + 2	88 b	86 ab	77 c	79 cd	79 cd	82 bc	72 b	68 c	70 c	73 b	72 c	73 b
Saflufenacil + sethoxydim + pendimethalin	0.05 + 0.315 + 2.5	88 b	86 ab	88 b	88 ab	86 bc	82 bc	71 b	67 c	70 c	73 b	73 bc	73 b
Saflufenacil + sethoxydim + pendimethalin	0.05 + 0.315 + 3.0	86 b	83 bc	86 b	86 abc	79 bcd	79 c	70 b	67 c	70 c	73 b	74 b	73 b
Saflufenacil + sethoxydim + glyphosate	0.05 + 0.315 + 2.24	96 a	92 a	98 a	92 a	98 a	91 a	79 a	79 a	79 a	80 a	79 a	79 a
Saflufenacil + glyphosate + pendimethalin	0.05 + 2.24 + 3.0	88 b	89 ab	90 b	89 ab	89 b	87 ab	79 a	79 a	78 a	79 a	79 a	79 a
Glyphosate	2.52	72 c	73 cd	71 cd	74 de	71 ed	70 d	71 b	71 b	72 b	72 b	71 c	70 c

[a] The data were arcsine square-root transformed for homogenous variance before analysis; however, data presented are the means of actual values for comparison, based on interpretation from the transformed data.

[b] Means within columns with no common letter or letters are significantly different according to Fisher's Protected LSD test, where $P \leq 0.05$.

and biomass data were analyzed and presented separately for each site.

Polk County Experiment. Major broadleaf weeds present at the Polk County site were Brazil pusley, Jamaica feverplant (*Tribulus cistoides* L.), and eclipta [*Eclipta prostrata* (L.) L.]. All herbicide treatments provided better control of broadleaf weeds, compared with the nontreated control, except for sethoxydim applied alone at 15 and 45 DAT (Table 2). Saflufenacil applied alone at the lower rate (0.037 kg ha^{-1}) provided $\leq$ 70% control of broadleaf weeds, compared with $\geq$ 82% at the recommended rate at 15 DAT (Table 2). Owen et al. (2011) reported > 90% control of glyphosate-resistant horseweed with a labeled rate of saflufenacil applied alone before planting no-till cotton. Glyphosate tank mixed with saflufenacil provided the highest control of Brazil pusley (96%) and eclipta (98%), compared with other treatments at 15 DAT. Pendimethalin at 2.5 or 3.0 kg ha^{-1} tank mixed with saflufenacil and sethoxydim provided $\geq$ 70%, $\geq$ 67%, and 70% control of Brazil pusley, Jamaica feverplant, and eclipta, compared with saflufenacil applied alone ($\leq$ 60% control), at 45 DAT, indicating residual activity of pendimethalin as a tank-mix partner to control broadleaf weeds (Table 2). A similar trend was observed later in the season; for example, treatments with pendimethalin provided relatively higher control of broadleaf weeds than did saflufenacil applied alone. Overall, weed control was reduced ($\leq$ 80%) because of weed emergence after rainfall at $\geq$ 45 DAT (Table 2). Among herbicide treatments, the greatest control of broadleaf weeds was observed with tank mixes of glyphosate with saflufenacil or pendimethalin or both, compared with other treatments at 60 DAT (data not shown). Similarly, Singh et al. (2011a) reported the greatest control of Brazil pusley, spanishneedles, and cutleaf evening-primrose (*Oenothera laciniata* Hill) with tank mixing of saflufenacil, glyphosate, and pendimethalin, compared with either saflufenacil or glyphosate applied alone in Florida citrus at 60 DAT.

Major grass weeds present at the Polk County site were bermudagrass [*Cynodon dactylon* (L.) Pers.], guineagrass [*Panicum maximum* (Jacq.) R. Webster], and southern sandbur (*Cenchrus echinatus* L.). Saflufenacil applied alone did not provide control of grass weeds (e.g., < 5% control at 15 and 45 DAT; Table 2). Sethoxydim applied alone at a recommended rate of 0.315 kg ha^{-1} provided 88, 89, and 87% control of bermudagrass, guineagrass, and southern sandbur, respectively, at 15 DAT; however, control was reduced to $\leq$ 60% at 45 DAT (Table 2). Tank mixes of saflufenacil with sethoxydim provided the same high level of control of bermudagrass, guineagrass, and southern sandbur as sethoxydim applied alone at the recommended rate, indicating no antagonistic effect of saflufenacil on sethoxydim efficacy. Similarly, a study by Young et al. (1996) reported no reduction in control of giant foxtail (*Setaria faberi* Herm.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], or shattercane [*Sorghum bicolor* (L.) Moench ssp. *arundinaceum* (Desv.) de Wet & Harlan] when sethoxydim was tank mixed with atrazine. In contrast, Chen and Penner (1985) found a synergistic response with a tank mix of sethoxydim with acifluorfen on barnyardgrass. Glyphosate tank mixed with sethoxydim provided 92, 98, and 91% control of bermuda-

Table 3. Effects of herbicide treatments on weed density and biomass at 60 d after treatment in a field experiment conducted in Polk County, FL.

Herbicide	Rate	Weed density[a,b] Brazil pusley	Jamaica feverplant	Eclipta	Bermudagrass	Guineagrass	Southern sandbur	Biomass[a,b] Broadleaf weeds	Grass weeds
	kg ae or ai ha^{-1}	No. m^{-2}						g m^{-2}	
Nontreated control	—	24 a	23 a	16 a	15 a	14 a	16 a	362 a	355 a
Saflufenacil	0.037	15 b	13 b	12 b	13 a	14 a	15 a	272 b	347 a
Saflufenacil	0.05	12 cde	10 cd	11 b	15 a	13 a	15 a	194 d	347 a
Sethoxydim	0.245	24 a	23 a	16 a	11 b	10 b	9 b	361 a	261 b
Sethoxydim	0.315	22 a	21 a	16 a	9 cd	8 bc	8 bc	361 a	204 c
Saflufenacil + sethoxydim	0.037 + 0.245	14 bc	12 bc	11 b	10 bc	9 b	9 bc	272 b	265 b
Saflufenacil + sethoxydim	0.05 + 0.315	12 cde	10 cd	10 bc	10 bc	9 b	9 b	203 c	201 c
Saflufenacil + sethoxydim + pendimethalin	0.037 + 0.245 + 2.0	9 ef	9 d	8 c	8 de	6 d	7 cd	175 e	177 d
Saflufenacil + sethoxydim + pendimethalin	0.05 + 0.315 + 2.5	9 ef	9 d	6 d	7 ef	6 d	6 def	171 e	173 d
Saflufenacil + sethoxydim + pendimethalin	0.05 + 0.315 + 3.0	8 f	9 d	8 c	6 f	3 e	5 f	160 f	95 e
Saflufenacil + sethoxydim + glyphosate	0.05 + 0.315 + 2.24	4 g	4 e	4 d	3 g	3 e	4 f	73 h	82 f
Saflufenacil + glyphosate + pendimethalin	0.05 + 2.24 + 3.0	5 g	5 e	4 d	7 f	10 b	7 cd	75 h	92 e
Glyphosate	2.52	13 bcd	10 cd	10 bc	10 bc	9 b	8 bc	206 c	203 c

[a] The data were arcsine square-root transformed for homogenous variance before analysis; however, data presented are the means of actual values for comparison based on interpretation from the transformed data.

[b] Means within columns with no common letter or letters are significantly different according to Fisher's Protected LSD test, where $P \leq 0.05$.

grass, guineagrass, and southern sandbur, respectively, at 15 DAT (Table 2); however, at 60 DAT control was reduced to 79, 76, and 71%, respectively, and control was comparable to glyphosate tank mixed with pendimethalin (data not shown). Similarly, Affeldt and Rice (2009) reported that tank mixing pendimethalin and glyphosate provided $\geq$ 94% control of witchgrass (*Panicum capillare* L.) and yellow foxtail, compared with $\leq$ 65% when pendimethalin was applied alone, at 45 DAT in glyphosate-resistant alfalfa (*Medicago sativa* L.). Knezevic et al. (2009b) also reported synergy with saflufenacil and glyphosate on a variety of weed species.

The highest density of broadleaf weeds (16 to 24 plants m^{-2}) was observed in plots treated with sethoxydim alone, and that control was comparable to the nontreated control at 60 DAT (Table 3). Saflufenacil applied alone at a recommended rate of 0.05 kg ha^{-1} reduced broadleaf weed density compared with the lower rate (0.037 kg ha^{-1}). Geier et al. (2009) reported that saflufenacil applied POST at 6 to 30 g ha^{-1} reduced population density of broadleaf weeds by 63 to 93%. A tank mix of pendimethalin at a higher rate (3 kg ha^{-1}) with saflufenacil resulted in a lower density of Brazil pusley, Jamaica feverplant, and eclipta compared with the saflufenacil applied alone (Table 3). This might be due to the residual activity of pendimethalin that reduced emergence of weed seedlings. The lowest density of broadleaf weeds ($\leq$ 5 plants m^{-2}) was reported in treatments with glyphosate as a tank mix partner. Waggoner et al. (2011) reported that a tank mix of saflufenacil with glyphosate reduced the density of glyphosate-resistant horseweed to as low as $\leq$ 3 plants m^{-1}. Saflufenacil applied alone was not effective for control of grass weeds, and the grass-weed density was comparable to that of the nontreated control. Tank mixing pendimethalin at the higher rate (3 kg ha^{-1}) with sethoxydim reduced the density of guineagrass and southern sandbur to as low as 3 and 5 plants m^{-2}, respectively, and was comparable to tank mixing glyphosate and sethoxydim (Table 3).

Broadleaf and grass weed biomass was affected by herbicide treatments. Pendimethalin as a tank-mix partner reduced broadleaf weed biomass compared with saflufenacil applied alone (Table 3). The lowest broadleaf weed biomass was recorded in treatments with glyphosate as tank-mix partner. A similar trend was observed for grass weed biomass. Glyphosate tank mixed with sethoxydim reduced grass weed biomass as low as 82 g m^{-2}.

Orange County Experiment. Major broadleaf weeds present at the Orange County, FL, site were Brazil pusley, Benghal dayflower, and cutleaf evening-primrose, and the major grass weeds were barnyardgrass, goosegrass, and johnsongrass [*Sorghum halepense* (L.) Pers.]. All herbicide treatments were effective for better control of broadleaf and grass weeds than provided by the nontreated control at 15 DAT (Table 4). Glyphosate tank mixed with saflufenacil and sethoxydim provided $\geq$ 92% control of broadleaf and grass weeds at 15 DAT. Residual weed control was reduced later in the season. Pendimethalin tank mixed with glyphosate and saflufenacil provided 69 and 67% control of Brazil pusley and Benghal dayflower, respectively, whereas control of grass weeds was significantly less, because of the absence of sethoxydim, than

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Table 4. Efficacy of herbicide treatments for weed control at 15 and 45 d after treatment (DAT) in a field experiment conducted in Orange County, FL.

		15 DAT[a,b]						45 DAT[a,b]					
Herbicide	Rate	Brazil pusley	Benghal dayflower	Cutleaf evening-primrose	Barnyard grass	Goose grass	Johnson grass	Brazil pusley	Benghal dayflower	Cutleaf evening-primrose	Barnyard grass	Goose grass	Johnson grass
	kg ae or ai ha^{-1}	%											
Nontreated control	—	0 g	0 j	0 i	0 f	0 f	0 f	0 i	0 g	0 g	0 g	0 g	0 g
Saflufenacil	0.037	63 e	70 g	67 f	6 e	3 e	3 e	44 h	46 f	49 f	0 g	0 g	0 g
Saflufenacil	0.05	75 d	79 edf	79 cde	9 e	3 e	3 e	56 fg	58 de	57 de	0 g	0 g	0 g
Sethoxydim	0.245	8 f	7 i	6 h	64 d	66 d	71 d	0 i	0 g	0 g	55 ef	52 f	54 f
Sethoxydim	0.315	12 f	17 h	21 g	75 bc	77 bc	79 bcd	0 i	0 g	0 g	61 cd	62 cd	65 cd
Saflufenacil + sethoxydim	0.037 + 0.245	74 d	73 fg	75 e	73 cd	75 cd	72 cd	53 g	56 e	51 ef	53 f	50 f	53 f
Saflufenacil + sethoxydim	0.05 + 0.315	82 cd	86 bc	79 cde	83 b	82 bc	83 b	59 ef	59 cde	62 cd	58 de	57 e	63 de
Saflufenacil + sethoxydim + pendimethalin	0.037 + 0.245 + 2	83 c	84 cd	82 cd	83 b	80 bc	78 bcd	62 de	64 bc	63 cd	59 de	61 de	60 e
Saflufenacil + sethoxydim + pendimethalin	0.05 + 0.315 + 2.5	85 bc	83 cde	84 bc	84 b	80 bc	80 bc	64 cd	63 cd	63 cd	63 cd	62 cd	64 d
Saflufenacil + sethoxydim + pendimethalin	0.05 + 0.315 + 3.0	85 bc	83 cd	83 cd	83 b	85 ab	83 b	67 c	69 ab	68 bc	64 c	66 bc	68 bc
Saflufenacil + sethoxydim + glyphosate	0.05 + 0.315 + 2.24	98 a	96 a	95 a	92 a	92 a	92 a	76 a	73 a	80 a	80 a	80 a	82 a
Saflufenacil + glyphosate + pendimethalin	0.05 + 2.24 + 3.0	91 b	91 b	89 b	77 bc	78 bc	79 bc	73 b	71 a	71 b	73 b	70 b	71 b
Glyphosate	2.52	79 cd	76 efg	78 de	78 bc	79 bc	80 bc	65 cd	64 bc	65 bc	62 cd	64 cd	63 de

[a] The data were arcsine square-root transformed for homogenous variance before analysis; however, data presented are the means of actual values for comparison, based on interpretation from the transformed data.

[b] Means within columns with no common letter or letters are significantly different according to Fisher's Protected LSD test, where $P \leq 0.05$.

glyphosate tank mixes with saflufenacil and sethoxydim at 60 DAT (data not shown).

Broadleaf and grass weed density was influenced by various herbicide treatments at 60 DAT at the Orange County, FL, site (Table 5). The highest broadleaf and grass weed density was in the range of 15 to 28 plants m^{-2} in the nontreated control, which was comparable to saflufenacil applied alone for grass weed density and to sethoxydim applied alone for broadleaf weed density. The lowest broadleaf ($\leq$ 8 plants m^{-2}) and grass weed density ($\leq$ 5 plants m^{-2}) and the least biomass ($<$ 100 g m^{-2}) were observed with glyphosate tank mixed with saflufenacil and sethoxydim, which was comparable to glyphosate tank mixed with saflufenacil and pendimethalin for broadleaf weed density ($\leq$ 9 plants m^{-2}) and biomass ($<$ 105 g m^{-2})(Table 5). The efficacy of sethoxydim on numerous grass species is very susceptible to antagonism when applied in tank mixes with some broadleaf herbicides, such as the sodium salt of bentazon (Rhodes and Coble 1984). However, in this study, tank mixing saflufenacil with sethoxydim did not provide any antagonistic effect on grass weeds in the greenhouse or field studies. Similarly, Corkern et al. (1999) reported no reduction in control of barnyardgrass or broadleaf signalgrass [*Urochloa platyphylla* (Nash) R.D. Webster] when sethoxydim was tank mixed with atrazine or 2,4-D.

Citrus growers often want to have a tank mixture of herbicides that may provide acceptable broad-spectrum weed control in a single application, which can reduce labor and fuel costs (Singh et al. 2011a). Results of this study indicate that the effectiveness of sethoxydim for control of grass weeds and of saflufenacil for broadleaf weeds will make feasible the use of these herbicides applied POST in tank mixes for broad-spectrum weed control in Florida citrus. Because there were no antagonistic effects, tank mixing saflufenacil and sethoxydim will provide control of existing broadleaf and grass weeds in a single application. In addition, pendimethalin as a tank-mix partner improved residual weed control later in the season; however, glyphosate tank mixed with saflufenacil and sethoxydim provided the greatest broad-spectrum weed control.

Glyphosate applied alone was not as effective as when it was tank mixed with saflufenacil and sethoxydim or pendimethalin, suggesting the additive effect of tank mixtures on glyphosate efficacy. Knezevic et al. (2009b) also reported additive effects of tank mixing saflufenacil with glyphosate, suggesting that the addition of saflufenacil could be useful for control of problem broadleaf weeds in cropping systems based on glyphosate-resistant crops, including control of glyphosate-resistant broadleaf weeds (Owen et al. 2011; Waggoner et al. 2011). There are no published reports of glyphosate-resistant weeds in Florida citrus, to our knowledge; however, it has been observed that the efficacy of glyphosate has been reduced for control of several common weeds in Florida citrus (Singh et al. 2011b). Tank mixtures of herbicides are an important aspect of glyphosate stewardship programs (Duke and Powles 2008); therefore, applying herbicides with a different mode of action, such as saflufenacil, with glyphosate will reduce the selection pressure and occurrence of glyphosate-resistant weeds in citrus. Overall, results suggested that saflufenacil

Table 5. Effects of herbicide treatments on weed density and biomass at 60 d after treatment in a field experiment conducted in Orange County, FL.

Herbicide	Rate	Weed density[a,b]						Biomass[a,b]	
		Brazil pusley	Benghal dayflower	Cutleaf evening-primrose	Barnyardgrass	Goosegrass	Johnsongrass	Broadleaf weeds	Grass weeds
	kg ae or ai ha^{-1}	No. m^{-2}						g m^{-2}	
Nontreated control	—	28 a	20 a	19 a	16 a	15 a	17 a	375 a	358 a
Saflufenacil	0.037	18 c	10 b	15 b	15 a	13 a	16 a	282 b	357 a
Saflufenacil	0.05	13 ef	7 d	11 c	15 a	15 a	17 a	188 c	344 a
Sethoxydim	0.245	27 a	19 a	18 a	12 b	11 b	13 b	384 a	259 b
Sethoxydim	0.315	28 a	20 a	19 a	13 b	9 cd	11 b	372 a	204 c
Saflufenacil + sethoxydim	0.037 + 0.245	16 cd	12 bc	11 c	12 b	10 bc	12 b	280 b	265 b
Saflufenacil + sethoxydim	0.05 + 0.315	15 de	8 cd	14 bc	12 b	10 bc	12 b	208 c	198 c
Saflufenacil + sethoxydim + pendimethalin	0.037 + 0.245 + 2.0	13 ef	7 d	11 c	7 c	8 de	9 c	186 d	177 d
Saflufenacil + sethoxydim + pendimethalin	0.05 + 0.315 + 2.5	12 f	7 d	9 d	7 c	6 f	9 c	184 d	185 d
Saflufenacil + sethoxydim + pendimethalin	0.05 + 0.315 + 3.0	12 f	6 d	12 c	7 c	7 ef	8 c	170 e	183 d
Saflufenacil + sethoxydim + glyphosate	0.05 + 0.315 + 2.24	7 g	2 e	8 d	5 d	3 g	5 d	96 f	94 f
Saflufenacil + glyphosate + pendimethalin	0.05 + 2.24 + 3.0	8 g	3 e	9 d	8 c	6 f	8 c	95 f	104 e
Glyphosate	2.52	17 cd	8 cd	14 bc	12 b	10 bc	12 b	214 c	209 c

[a] The data were arcsine square-root transformed for homogenous variance before analysis; however, data presented are the means of actual values for comparison, based on interpretation from the transformed data.

[b] Means within columns with no common letter or letters are significantly different according to Fisher's Protected LSD test, where $P \leq 0.05$.

will fit well into herbicide weed-control programs, when applied as a tank mix with graminicide (sethoxydim) and glyphosate; however, more research is required to understand interaction of saflufenacil with other herbicides commonly used in Florida citrus, including paraquat, carfentrazone, indaziflam, diuron, bromacil, rimsulfuron, among others.

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