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Tank Mixing Saflufenacil, Glufosinate, and Indaziflam Improved Burndown and Residual Weed Control

Amit J. Jhala, Analiza H. M. Ramirez, and Megh Singh*

Saflufenacil and indaziflam, POST and PRE herbicides, respectively, have been registered recently for weed control in Florida citrus. Glufosinate is under evaluation and may be registered in the future for POST weed control in citrus. Citrus growers often want to have a tank mixture of herbicides that provide broad-spectrum weed control. Saflufenacil is a broadleaf herbicide and needs to be tank mixed with other herbicide(s) to increase weed control spectrum. Information is not available on interaction of saflufenacil, glufosinate, and indaziflam applied in tank mixtures on weed control efficacy. Greenhouse and field experiments were conducted at two locations (Polk and Orange County, FL) to evaluate the efficacy and potential antagonism or synergy of saflufenacil and glufosinate applied in tank mixes, and various three-way mixes with indaziflam. The results suggested that tank mixing saflufenacil with glufosinate had no effect on grass weed control, but had additive effect on broadleaf weed control. Indaziflam tank mixed at the recommended label rate (0.073 kg ha^{-1}) provided better residual weed control compared with the lower rate (0.05 kg ha^{-1}). Tank mixing indaziflam with saflufenacil and glufosinate improved broadleaf and grass weed control, reduced weed density, and biomass compared with tank mixing saflufenacil and glufosinate. Tank mixing indaziflam at 0.073 kg ha^{-1} with saflufenacil and glufosinate provided $\geq$ 88% control of broadleaf and grass weeds at 30 d after treatment (DAT), and it was comparable with tank mixing saflufenacil, glyphosate and pendimethalin. This treatment combination recorded the lowest weed density ($\leq$ 7 plants m^{-2}) and biomass ($<$ 80 g m^{-2}) at 60 DAT. Glyphosate applied alone was less effective than tank mixing with saflufenacil and glufosinate for broadleaf and grass weed control. This indicates additive effect of tank mixture on glyphosate efficacy. It is concluded that saflufenacil can be tank mixed with glufosinate for control of broadleaf and grass weeds; however, addition of indaziflam in tank mixture provided long-term, broad-spectrum weed control in Florida citrus compared with other treatments.

Nomenclature: Glufosinate; glyphosate; indaziflam; pendimethalin; saflufenacil; citrus, *Citrus* spp.

Key words: Herbicides, weed biomass, weed density.

Saflufenacil e indaziflam son herbicidas POST y PRE, respectivamente, que han sido registrados recientemente para el control de malezas en cítricos en Florida. Glufosinate está siendo evaluado y podría ser registrado en el futuro para el control de malezas POST en cítricos. Los productores de cítricos a menudo quieren tener mezclas de herbicidas en tanque que brinden un control de malezas de amplio espectro. Saflufenacil es un herbicida para malezas de hoja ancha, el cual necesita ser mezclado en tanque con otros herbicidas para incrementar el espectro de control de malezas. No hay información disponible acerca de la interacción de saflufenacil, glufosinate e indaziflam al ser aplicados en mezclas en tanque sobre la eficacia en el control de malezas. Se realizaron experimentos de invernadero y de campo en dos localidades (condados Polk y Orange, Florida) para evaluar la eficacia y el potencial de antagonismo o sinergia de saflufenacil y glufosinate aplicados en mezcla en tanque, y de varias mezclas de tres-vías con indaziflam. Los resultados sugirieron que la mezcla en tanque de saflufenacil con glufosinate no tuvo efecto sobre el control de gramíneas, pero tuvo un efecto aditivo sobre el control de malezas de hoja ancha. La mezcla en tanque con indaziflam a la dosis recomendada (0.073 kg ha^{-1}) brindó mejor control residual al compararse con la dosis baja (0.05 kg ha^{-1}). El mezclar en tanque indaziflam con saflufenacil y glufosinate mejoró el control de malezas gramíneas y de hoja ancha, y redujo la densidad y biomasa de malezas en comparación con la mezcla en tanque de saflufenacil y glufosinate. La mezcla en tanque de indaziflam a 0.073 kg ha^{-1} brindó $\geq$88% de control de malezas de hoja ancha y gramíneas a 30 días después del tratamiento (DAT), y fue comparable con la mezcla en tanque de saflufenacil, glyphosate y pendimethalin. Esta combinación registró las densidades de malezas ($\leq$7 plantas m^{-2}) y de biomasa ($<$80 g m^{-2}) más bajas a 60 DAT. Glyphosate aplicado solo fue menos efectivo que la mezcla en tanque con saflufenacil y glufosinate para el control de malezas de hoja ancha y gramíneas. Esto indica un efecto aditivo de la mezcla en tanque sobre la eficacia de glyphosate. Se concluyó que saflufenacil puede ser mezclado en tanque con glufosinate para el control de malezas de hoja ancha y gramíneas. Sin embargo, la adición de indaziflam a la mezcla en tanque brindó el mayor control de amplio espectro y larga duración en cítricos en Florida en comparación con otros tratamientos.

Citrus is an economically important crop in Florida. In 2011, citrus was grown on > 200,000 ha with the production of about 7427,000 tons that contributed to 63% of the total citrus produced in the United States (USDA 2012). Weed control is a major component of citrus grove management. Warm and humid climate in Florida provides a favorable environment for a continuous weed emergence and vigorous vegetative growth. Frequent rainfall or irrigation and nutrient applications further enhance weed pressure in citrus groves.

Several methods are available for weed control in citrus; however, chemical control is the most effective method adopted by citrus growers. Many PRE and POST herbicides have been registered for weed control in Florida citrus (Futch and Singh 2011). Some herbicides are in the process of

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* First author: Assistant Professor, Department of Agronomy and Horticulture, University of Nebraska-Lincoln, NE 68583-0915; second and third authors: Postdoctoral Research Associate and Professor, Citrus Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida, 700 Experiment Station Road, Lake Alfred, FL 33850-2299. Corresponding author's E-mail: amit.jhala@unl.edu

registration or have recently been registered in citrus. For example, saflufenacil, a POST herbicide was registered for broadleaf weed control in 2010. Indaziflam, a PRE herbicide was registered in 2011 for broad-spectrum weed control. Glufosinate, a POST herbicide is currently being evaluated and it is expected that it will be registered in the near future. There is no information available on tank mixes of these new herbicides and impact they may have on weed population; therefore, it is important to know if they have additive, synergistic or antagonistic effects.

Saflufenacil, a uracil-based herbicide, is a potent inhibitor of protoporphyrinogen oxidase (PPO) (Grossman et al. 2010). It is primarily a contact herbicide, translocated mainly in the xylem with limited mobility in the phloem (Liebl et al. 2008). The recommended label rate of saflufenacil for citrus is 0.05 kg ai ha^{-1} in a single application with a maximum cumulative annual amount of 0.15 kg ha^{-1}. It can be applied as a single application or sequentially up to three times per year (Anonymous 2010a). Few studies reported that addition of adjuvants greatly improved efficacy of saflufenacil to control broadleaf weeds (Knezevic et al. 2009; 2010). However, if saflufenacil is to be applied POST in annual crops, addition of adjuvants may cause injury. Soltani et al. (2009) reported that addition of an adjuvant to saflufenacil applied POST caused 99% injury to corn (*Zea mays* L.) at three-leaf stage and reduced yield up to 59% compared to saflufenacil applied without adjuvant. Saflufenacil can be effective for control of glyphosate-resistant broadleaf weeds. For example, Owen et al. (2011) reported 94% control of glyphosate-resistant horseweed (*Conyza canadensis* L.) with saflufenacil before planting cotton (*Gossypium hirsutum* L.).

Indaziflam is an alkylazine, soil-applied herbicide for broad-spectrum weed control. The recommended label rate of indaziflam in Florida citrus ranges from 0.073 to 0.11 kg ai ha^{-1} in a single application with a maximum cumulative annual amount of 0.15 kg ha^{-1} (Anonymous 2011). Indaziflam provided three to five months of residual weed control in citrus depending on weather conditions and weed pressure (Singh et al. 2011b). Brosnan et al. (2012) reported 89 to 100% control of smooth crabgrass (*Digitaria ischaemum* Schreb.) with indaziflam applied at 35, 52.5 or 70 g ha^{-1}. Citrus producers have limited options for POST herbicides. Glufosinate is a nonselective, foliar applied herbicide for control of annual and perennial grasses and broadleaf weeds. Glufosinate inhibits the activity of glutamine synthetase, an enzyme involved in the synthesis of the amino acid glutamine. Glufosinate is not yet registered for weed control in citrus; however, it has been registered in several annual and perennial crops. The recommended label rate of glufosinate in tree, vine, and berry crops is in the range of 0.65 to 1.0 kg ai ha^{-1} depending on weed size at the time of application; however, it is being evaluated with higher rates for weed control in citrus.

Over-reliance on a single herbicide or herbicide with the same mode of action could result in loss of effectiveness for weed control because of selection pressure (Powles 2008). Glyphosate has been used extensively for POST weed control in Florida citrus for many years. The occurrence of weed shifts and evolution of glyphosate resistant biotypes in several parts of the United States and many other countries led to an increased need for alternative herbicide programs including tank mix of herbicides with different mode of action (Beckie 2006). Currently, 21 weed species have evolved resistance to glyphosate worldwide (Heap 2011); however, there is no confirmed report of glyphosate-resistant weed in Florida citrus. Therefore, a pro-active management practice is required that reduces the selection pressure.

Tank mixing herbicides is one of the methods to reduce herbicide rates while increasing weed control spectrum (Green and Owen 2011). In addition, it is also effective for controlling herbicide resistant weeds (Beckie 2006). Saflufenacil and glufosinate are POST herbicides, with varying weed control spectrum and do not provide residual weed control. Herbicide(s) with limited weed control spectrum are more effective if tank mixed with herbicides that may improve the efficacy of partner herbicide(s). Therefore, to achieve residual weed control, herbicides with short windows of action (e.g. saflufenacil, glufosinate) should be tank mixed with those with residual activity (e.g. indaziflam). It is expected that when saflufenacil is tank mixed with glufosinate and indaziflam, the combination will provide control of existing grass and broadleaf weeds as well as residual weed control in citrus.

To develop herbicide programs for weed control involving new herbicides such as saflufenacil, indaziflam, and glufosinate in citrus, it is necessary to understand interactions among these herbicides. Therefore, the objectives of this study were (1) to evaluate the efficacy of saflufenacil or glufosinate applied alone or in tank mixes at various rates and combinations for weed control in established citrus groves and (2) to evaluate weed control with indaziflam tank mixed with saflufenacil and glufosinate for broad-spectrum weed control in Florida citrus.

Materials and Methods

Greenhouse Experiments. Research was conducted under greenhouse conditions at the Citrus Research and Education Center, University of Florida, Lake Alfred, FL in 2011. Seeds of barnyardgrass [*Echinochloa crus-galli* (L.) Beauv], yellow foxtail [*Setaria pumila* (Poir.) Roem. & Schult], and common beggar's-tick (*Bidens alba* 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 separate plastic pots (15 cm diam and 15 cm ht) at the depth of 1 to 2 cm in commercial potting mix (Sun Gro Horticulture Distribution Inc., Bellevue, WA). The soil was tamped lightly to ensure adequate seed-to-soil contact and watered until saturated. Seedlings of Brazil pusley (*Richardia brasiliensis* Moq.), dogfennel [*Eupatorium capillifolium* (Lam.) Small], and purple nutsedge (*Cyperus rotundus* L.) were collected from a citrus grove near Winter Garden, FL, and four seedlings were immediately transplanted per pot (15 cm diam and 15 cm ht) containing commercial potting mix. All the pots were surface watered daily or as needed throughout the experiment to maintain adequate soil moisture for plant growth. The greenhouse was maintained at day/night temperature of 25/16 C ($\pm$ 0.5 C), 70% ($\pm$ 5%) relative humidity, and normal photoperiod. Two weeks after seeding or transplanting, plants were thinned to three plants per pot.

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The fertilizer solution [Tractite 20-20-20, Helena Chemical Company, Collierville, TN] was applied with water after 15 d of planting for better plant growth.

The experiment was conducted in a randomized complete block design with four replications. Each pot with three plants represented a single replication of a treatment. The herbicide treatments included saflufenacil (herbicide Treevix™, BASF, 26 Davis Drive, Research Triangle Park, NC) applied alone at 0.037, 0.05 and 0.075 kg ha^{-1}; glufosinate (herbicide Rely® 280, Bayer CropScience, Research Triangle Park, NC) applied alone at 1.0, 1.33, and 1.66 kg ha^{-1}; saflufenacil at 0.037 or 0.05 kg ha^{-1} tank mixed with glufosinate at 1.0 or 1.33 kg ha^{-1}; saflufenacil (0.037 kg ha^{-1}) and glufosinate (1 kg ha^{-1}) tank mixed with indaziflam (herbicide Alion™, Bayer CropScience) at 0.05 or 0.073 kg ha^{-1}; saflufenacil at 0.05 kg ha^{-1} tank mixed with pendimethalin (herbicide Prowl H_2O™ BASF Corporation) at 2.5 kg ai ha^{-1} and glyphosate (herbicide Roundup WeatherMax, Monsanto Company, St Louis, MO) at 2.24 kg ae ha^{-1}; and glyphosate applied alone at 2.52 kg ha^{-1} (Table 1). Citrus growers usually apply soil applied herbicide in tank mix with burndown herbicides; therefore, in this study, indaziflam was not applied alone and compared in combination with saflufenacil and glufosinate. Glyphosate is applied alone and also in tank mixes by many citrus growers; therefore, for better comparison we included those treatments in this study. An untreated control was included for comparison. To improve 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 glufosinate treatments were mixed with nonionic surfactant (Induce, Helena) at 0.25% v/v. Herbicide treatments were applied when weeds were 5 to 7 cm tall or 6- to 8-true-leaf stage. 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.

Weed control was visually evaluated at 7, 14, and 21 d after treatment (DAT) on a scale of 0 to 100%, where 0% being no control and 100% being complete control of weeds at the time of observation compared with the nontreated control. The above ground biomass of all weed species was harvested at 21 DAT, dried in an oven at 70 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 was a Florida Candler fine sand (hyperthermic, uncoated, Typic Quartzipsamment) with a pH 6.5, 91.7% sand, 4.5% silt, 4.0% clay, and 0.5% organic matter. The soil at the Orange County, FL, site had a pH of 6.3, 91.0% sand, 4.8% silt, 3.8% clay, and 0.4% organic matter. The experiments were conducted in a randomized complete block design with four replications. A total of eight tree rows were selected for the study at each site and each treatment was assigned randomly within two rows (replication). The herbicide treatments were the same as explained in the greenhouse study (Table 2). At both the sites, the plot size was 2 m by 10 m, arranged between the tree rows

Table 1. Effects of herbicide treatments on broadleaf and grass weed control and biomass at 21 d after treatment (DAT) in a greenhouse study.

Herbicide	Rate [1]	Control[a,b] Barnyard grass	Yellow foxtail	Beggar's-tick	Brazil pusley	Dogfennel	Purple nutsedge	Biomass[a,b] Barnyard grass	Yellow foxtail	Beggar's-tick	Brazil pusley	Dogfennel	Purple nutsedge
	kg ae or ai ha^{-1}	%						g pot^{-1}					
Nontreated control	—	0 d	0 e	0 g	0 g	0 g	0 f	16 a	17 a	18 a	18 a	20 a	19 a
Saflufenacil	0.037	0 d	0 e	60 f	63 f	59 f	0 f	16 a	17 a	14 b	14 b	15 b	17 b
Saflufenacil	0.05	1 d	9 d	73 de	75 d	73 de	4 e	17 a	16 ab	9 cd	9 d	9 d	18 ab
Saflufenacil	0.075	10 c	10 d	75 d	75 d	75 d	6 e	15 a	16 ab	8 de	8 d	8 de	20 a
Glufosinate	1	71 b	69 c	62 f	69 ef	62 f	56 d	8 bc	9 d	10 c	9 d	9 de	14 c
Glufosinate	1.33	87 a	87 a	75 d	86 b	76 d	79 b	3 fg	4 g	8 d	8 d	9 de	11 d
Glufosinate	1.66	86 a	87 a	78 c	87 b	83 c	80 b	2 g	3 g	6 f	5 e	6 f	11 d
Saflufenacil + glufosinate	0.037 + 1.0	72 b	70 c	83 c	80 c	83 c	80 b	5 ef	7 ef	7 ef	8 d	7 e	7 e
Saflufenacil + glufosinate	0.05 +1.0	87 a	87 a	96 a	98 a	96 a	88 a	3 fg	3 g	3 g	2 f	3 g	3 f
Saflufenacil + glufosinate	0.05 +1.33	87 a	88 a	97 a	99 a	97 a	87 a	2 g	2 g	3 g	2 f	3 g	3 f
Saflufenacil + glufosinate + indaziflam	0.037 + 1.0 + 0.05	72 b	71 c	93 b	98 a	97 a	85 ab	8 bc	7 ef	6 f	3 f	4 g	3 f
Saflufenacil + glufosinate + indaziflam	0.037+ 1.0 + 0.073	72 b	70 c	93 b	98 a	96 a	85 ab	6 b	7 ef	6 f	3 f	3 g	2 f
Saflufenacil + glyphosate + pendimethalin	0.05 + 2.24 + 2.5	86 a	80 b	93 b	98 a	91 b	79 b	2 g	2 g	3 g	2 f	4 g	10 d
Glyphosate	2.52	71 b	70 c	69 e	73 de	69 e	69 c	9 b	11 c	10 c	12 c	12 c	11 d

[a] Weed control data were arc-sine square-root transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison.

[b] Means (n = 8) within columns with no common letter(s) are significantly different according to Fisher's protected LSD test where $P \leq 0.05$.

Table 2. Efficacy of herbicide treatments for weed control at 15 and 30 d after treatment (DAT) in a field experiment conducted in Polk County, FL.

		15 DAT[a,b]						30 DAT[a,b]					
Herbicide	Rate [1]	Brazil pusley	Puncture vine	Eclipta	Bermuda grass	Guinea grass	Signal grass	Brazil pusley	Puncture vine	Eclipta	Bermuda grass	Guinea grass	Signal grass
	kg ae or ai ha^{-}	%											
Nontreated control	—	0 h	0 g	0 g	0 g	0 f	0 g	0 j	0 j	0 h	0 g	0 g	0 f
Saflufenacil	0.037	71 f	68 f	70 f	2 fg	9 e	0 g	64 gh	63 h	64 f	0 g	0 g	0 f
Saflufenacil	0.05	74 ef	74 de	75 de	5 ef	5 f	5 f	68 f	68 f	72 e	0 g	0 g	0 f
Saflufenacil	0.075	78 de	78 d	79 d	7 e	11 e	7 f	70 f	71 e	73 e	0 g	0 g	0 f
Glufosinate	1	64 g	68 f	68 f	71 d	70 d	71 e	59 i	58 i	59 g	68 e	67 e	66 d
Glufosinate	1.33	72 f	71 ef	71 ef	71 d	72 d	71 e	66 g	67 fg	66 f	67 e	64 fe	65 de
Glufosinate	1.66	79 d	83 c	80 d	77 cd	79 cd	71 cde	70 f	73 e	70 e	71 d	71 d	73 c
Saflufenacil + glufosinate	0.037 + 1.0	85 c	85 c	85 c	76 d	78 cd	78 cde	74 e	78 d	76 d	73 d	73 d	72 c
Saflufenacil + glufosinate	0.05 +1.0	97 a	97 ab	95 b	77 cd	77 cd	75 de	80 d	79 d	80 c	76 c	78 c	81 b
Saflufenacil + glufosinate	0.05 +1.33	95 a	96 b	95 b	79 cd	79 cd	80 cd	83 c	83 c	82 c	76 c	77 c	79 b
Saflufenacil + glufosinate + indaziflam	0.037 + 1.0 + 0.05	97 a	98 a	98 a	85 bc	84 bc	84 bc	85 b	84 b	85 b	82 b	81 b	79 b
Saflufenacil + glufosinate + indaziflam	0.037 + 1.0 + 0.073	97 a	98 a	97 ab	89 b	88 b	88 b	88 a	89 a	89 a	88 a	89 a	88 a
Saflufenacil + glyphosate + pendimethalin	0.05 + 2.24 + 2.5	97 a	97 a	98 a	96 a	96 a	98 a	89 a	89 a	89 a	90 a	91 a	90 a
Glyphosate	2.52	72 f	71 ef	71 ef	75 d	73 d	73 de	63 h	66 g	64 f	63 f	61 f	62 e

[a] Data were arc-sine square-root transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison based on interpretation from the transformed data.

[b] Means (n = 4) within columns with no common letter(s) are significantly different according to Fisher's protected LSD test where $P \leq 0.05$.

(middles). Herbicides were applied on July 7, 2011 and July 18, 2011 at the Polk County and Orange County sites, respectively, using a tractor mounted computerized boom sprayer fitted with 8002 nozzles (TeeJet, Spraying Systems Co.) calibrated to deliver 188 L ha^{-1} at 279 kPa. Citrus trees were 5- and 7-yr old 'Valencia' sweet orange at the Polk County and Orange County sites, respectively.

Control of weeds was visually evaluated at 15, 30, 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. Weed density is the number of weeds in a specific area and it gives information about weed control efficacy of herbicide treatments when recorded after certain period of time of herbicide application. The weed densities and biomass were assessed during the growing season within 0.5-m^2 quadrats (2 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 72 h at 60 C, and the biomass was recorded.

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

Results and Discussion

Greenhouse Experiments. Treatment by experiment interaction among greenhouse studies was nonsignificant; therefore, data of both the experiments were pooled and the combined data are presented. Saflufenacil applied alone at any rate was not effective ($\leq$ 10% control) for control of barnyardgrass and yellow foxtail (Table 1). This was caused by the fact that saflufenacil is a broadleaf herbicide and has very limited grass activity (Anonymous 2010a). Glufosinate applied alone at 1 kg ha^{-1} provided $\leq$ 71% control of barnyardgrass and yellow foxtail compared to $\geq$ 86% control when applied alone at $\geq$ 1.33 kg ha^{-1} (Table 1). Tank mixing saflufenacil with glufosinate did not improve or reduce control of barnyardgrass or yellow foxtail compared with glufosinate applied alone. Indaziflam tank mixed with glufosinate and saflufenacil did not improve control of barnyardgrass and yellow foxtail at 21 DAT in greenhouse study. This was because indaziflam is a soil-applied herbicide and provides most effective weed control when applied before weed seedling emergence (Anonymous 2011). In this study, indaziflam was applied POST in tank mixes when barnyardgrass and yellow foxtail were 5 to 7 cm tall; therefore, it was expected that indaziflam applied POST as a tank mix partner at any rate would not improve weed control. Glyphosate applied alone provided $\leq$ 71% control of grass weeds; however, glyphosate tank mixed with saflufenacil and pendimethalin was as effective as saflufenacil tank mixed with glufosinate at higher rates for control of barnyardgrass. Affeldt and Rice (2008) reported that a tank mix of pendimethalin and glyphosate provided 95% control of witchgrass (*Panicum capillare* L.) and yellow foxtail compared to glyphosate applied alone at 45 DAT in glyphosate-resistant alfalfa (*Medicago sativa* L.).

Saflufenacil applied alone at a recommended rate of 0.05 kg ha^{-1} or higher rate (0.075 kg ha^{-1}) resulted in $\leq$ 75% control of common beggar's-tick, Brazil pusley, and dogfennel compared to $\leq$ 63% control with saflufenacil applied at 0.037 kg ha^{-1} (Table 1). Preliminary experiments conducted in California confirmed that saflufenacil is a strong performer on several winter annual broadleaf weeds, including glyphosate resistant horseweed and hairy fleabane [*Conyza bonariensis* (L.) Cronq.] in perennial crops (B. Hanson, personal communication). Glufosinate applied alone at 1.66 kg ha^{-1} provided 78 and 83% control of common beggar's-tick, and dogfennel, respectively, compared to $\leq$ 76% control at lower rates; however, control of Brazil pusley was $\geq$ 86% with glufosinate applied alone at $\geq$ 1.33 kg ha^{-1}. Tank mixing saflufenacil and glufosinate resulted in better control of broadleaf weeds and it was higher than application of these herbicides alone. For example, saflufenacil at 0.05 kg ha^{-1} plus glufosinate at 1.0 or 1.33 kg ha^{-1} provided the highest control (> 95%) of common beggar's-tick, Brazil pusley and dogfennel. Glyphosate applied alone was not much effective and provided < 75% control of broadleaf and grass weeds; however, tank mixing glyphosate with saflufenacil and pendimethalin improved weed control. Tank mixing saflufenacil and glufosinate provided $\geq$ 80% control of purple nutsedge (Table 1).

Similar results were reflected in weed biomass. Saflufenacil applied alone at any rate resulted in the highest grass weed biomass and it was comparable with the nontreated control. The lowest biomass ($\leq$ 3 g) was observed for barnyardgrass and yellow foxtail when glufosinate was usually applied at $\geq$ 1.33 kg ha^{-1} and it was comparable with saflufenacil tank mixed with glyphosate and pendimethalin (Table 1). Saflufenacil tank mixed with glufosinate reduced broadleaf weed biomass. For example, the lowest biomass was reported for common beggar's-tick (3 g), Brazil pusley ($\leq$ 3 g), and dogfennel ($\leq$ 4 g) with these treatments and it was usually comparable with saflufenacil tank mixed with glyphosate and pendimethalin (Table 1). Saflufenacil or glufosinate applied alone resulted in higher biomass ($\geq$ 11 g) of purple nutsedge compared to their tank mixes ($\leq$ 7 g). Similar results were observed in a study for weed control in citrus with tank mixing saflufenacil, sethoxydim and glyphosate (Jhala et al. 2013).

Overall, it was determined that saflufenacil or glufosinate applied alone were not as effective as applied in tank mixes for broadleaf weed control. Glyphosate applied alone also provided < 75% control of broadleaf and grass weeds, but tank mixing glyphosate with saflufenacil was usually comparable with certain treatments of mixing saflufenacil with glufosinate.

Field Experiments. Weed species at Polk County and Orange County sites were different; therefore weed control, weed density, and weed biomass data were presented separately for each site.

Polk County Experiment. Primary grass weeds present at the Polk County site were bermudagrass [*Cynodon dactylon* (L.) Pers.], guineagrass (*Panicum* maximum Jacq.), and broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash]. Saflufenacil applied alone regardless of application rates resulted in poor control ($\leq$ 11%) of grass weeds compared with other herbicide treatments at 15 and 30 DAT (Table 2). Glufosinate applied alone at 1 kg ha^{-1} resulted in similar control of grass weeds (70 to 79%) compared to higher rates (1.33 or 1.66 kg ha^{-1}) at 15 DAT; however, at 30 DAT control of grass weeds was 71 to 73% with glufosinate applied at 1.66 kg ha^{-1} compared with 66 to 68% control at 1 kg ha^{-1}.

Tank mixing saflufenacil with glufosinate did not affect grass weed control, but addition of indaziflam provided additive effect. For example, indaziflam at 0.073 kg ha^{-1} tank mixed with glufosinate and saflufenacil resulted in 89, 88, and 90% control of bermudagrass, guineagrass, and broadleaf signalgrass, respectively; however, the highest control ($\geq$ 96%) of grass weeds was achieved with the tank mix of glyphosate and pendimethalin at 15 DAT (Table 2). Singh et al. (2011b) reported that tank mixing saflufenacil and glyphosate provided similar control of grass weeds compared to tank mixing saflufenacil, glyphosate, and pendimethalin at 30 DAT. Tank mixing indaziflam at 0.073 kg ha^{-1}, glufosinate and saflufenacil was comparable with tank mixing saflufenacil, glyphosate and pendimethalin for grass weed control at 30 DAT (Table 2). This treatment combination resulted in the lowest grass weed density ($\leq$ 6 plants m^{-2}) and biomass (< 40 g m^{-2}) at 60 DAT compared to other treatments (Table 3). In a similar study, indaziflam tank mixed with glyphosate provided excellent initial burn down of emerged weeds in addition to extended residual weed control in California orchards and vineyards (Jhala and Hanson 2011).

Primary broadleaf weeds present at the Polk County site were Brazil pusley, puncture vine (*Tribulus terrestris* L.), and eclipta (*Eclipta prostrata* L.). Compared to the nontreated control, all herbicide treatments provided $\geq$ 68% and $\geq$ 58% control of broadleaf weeds at 15 and 30 DAT, respectively (Table 3). Saflufenacil applied alone at the lowest rate (0.037 kg ha^{-1}) showed $\leq$ 71% control of broadleaf weeds compared with the recommended rate ($\geq$ 74%) at 15 DAT (Table 2). In a dose response study, 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%.

Glufosinate applied alone at the lowest rate (1 kg ha^{-1}) resulted in < 70% and < 60% control of broadleaf weeds at 15 and 30 DAT, respectively, compared with the higher rate (1.66 kg ha^{-1}) that resulted in $\geq$ 79% and $\geq$ 70% control at 15 and 30 DAT, respectively (Table 2). Beyers et al. (2002) reported > 85% control of velvetleaf (*Abutilon theophrasti* Medic.), common waterhemp (*Amaranthus rudis* Sauer), and common ragweed (*Ambrosia artemisiifolia* L.) with glufosinate applied alone at 0.4 kg ha^{-1} at 30 DAT in glufosinate resistant soybean. Saflufenacil at the recommended rate (0.05 kg ha^{-1}) tank mixed with glufosinate at 1 or 1.33 kg ha^{-1} resulted in $\geq$ 95% control of broadleaf weeds at 15 DAT and it was comparable with tank mixing saflufenacil, glufosinate or glyphosate, and indaziflam or pendimethalin.

At 30 DAT, indaziflam at 0.073 kg ha^{-1} tank mixed with saflufenacil and glufosinate provided $\geq$ 88% control of broadleaf weeds and it was comparable with tank mixing

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

Herbicide	Rate	Weed density[a,b]						Biomass[a,b]	
		Brazil pusley	Puncture vine	Eclipta	Bermuda grass	Guinea grass	Signal grass	Broadleaf weeds	Grass weeds
	kg ae or ai ha^{-1}	No m^{-2}						g m^{-2}	
Nontreated control	—	21 a	17 a	19 a	25 a	20 a	16 bc	340 a	351 a
Saflufenacil	0.037	13 b	12 b	15 b	24 a	19 a	16 bc	161 f	342 a
Saflufenacil	0.05	9 de	9 def	8 de	23 a	19 a	15 bc	136 gh	252 a
Saflufenacil	0.075	7 gf	7 f	7 e	22 a	17 abc	15 bc	153 fg	342 a
Glufosinate	1	13 b	13 b	14 bc	18 b	18 ab	18 ab	233 b	275 b
Glufosinate	1.33	10 c	10 cd	10 d	16 bc	15 cd	15 c	223 bc	268 b
Glufosinate	1.66	9 cd	9 de	9 d	14 c	13 d	13 cd	207 cd	259 b
Saflufenacil + glufosinate	0.037 +1.0	9 cde	8 def	7 e	17 b	18 ab	20 a	187 de	227 c
Saflufenacil + glufosinate	0.05 +1.0	8 ef	8 ef	7 e	17 b	18 ab	18 ab	172 ef	189 d
Saflufenacil + glufosinate	0.05 +1.33	6 gh	5 g	5 f	15 bc	16 bcd	14 c	129 h	158 e
Saflufenacil + gIndaziflam	0.037 + 1.0 + 0.05	6 gh	4 gh	4 f	9 d	8 ef	8 e	87 i	80 g
Saflufenacil + glufosinate + indaziflam	0.037 + 1.0 + 0.073	2 j	0 i	0 h	2 e	5 g	6 f	24 j	38 h
Saflufenacil + glyphosate + pendimethalin	0.05 + 2.24 + 2.5	4 i	3 h	3 g	8 d	7 f	8 ef	72 i	81 g
Glyphosate	2.52	12 b	12 bc	12 c	11 d	11 e	11 d	204 cd	209 cd

[a] Data were arc-sine square-root transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison.

[b] Means (n = 4) within columns with no common letter(s) are significantly different according to Fisher's protected LSD test where $P \leq 0.05$.

saflufenacil, glyphosate, and pendimethalin (Table 2). Similarly, Singh et al. (2011b) reported the greatest control of Brazil pusley, Common beggar's-tick, and cutleaf evening-primrose (*Oenothera laciniata* Hill) with tank mixing saflufenacil, glyphosate and pendimethalin compared with saflufenacil or glyphosate applied alone in Florida citrus at 60 DAT. Later in the season, indaziflam at 0.073 kg ha^{-1} tank mixed with saflufenacil and glufosinate reduced density ≤ 2 plants m^{-2} and biomass < 25 g m^{-2} compared to other treatments (Table 3). This is because indaziflam has a longer half-life in soil (> 150 d) that may have provided longer residual weed control (Jhala and Singh 2012). Waggoner et al. (2011) reported that a tank mix of saflufenacil with glyphosate reduced density of glyphosate resistant horseweed to as low as ≤ 3 plants m^{-1}.

Several studies reported that glufosinate applied in a combination with soil-applied herbicide resulted in excellent burn down and residual weed control. Jones et al. (2001) reported that atrazine plus glufosinate enhanced Palmer amaranth (*Amaranthus palmeri* S. Watson) control compared to glufosinate alone. Lanie et al. (1994) showed that pitted morningglory (*Ipomoea lacunosa* L.) control with glufosinate was 63%, but when glufosinate was tank mixed with metribuzin or imazaquin, control was 100%.

Orange County Experiment. Major broadleaf weeds present at the Orange County site were Brazil pusley, dayflower (*Commelina benghalensis* L.), and cutleaf evening-primrose. Major grass weeds were southern sandbur (*Cenchrus echinatus* L.), johnsongrass (*Sorghum halepense* L.), and natalgrass [*Rhynchelytrum repens* (Willd.) Hubb]. All herbicide treatments were effective for control of broadleaf and grass weeds compared with the nontreated control at 15 and 30 DAT, except saflufenacil applied alone for grass weed control (Table 4). Similar to the Polk County site, tank mixing indaziflam at 0.073 kg ha^{-1}, glufosinate and saflufenacil was the best treatment for control of broadleaf and grass weeds at 30 DAT (Table 4). This treatment combination resulted in the lowest grass weed density (≤ 6 plants m^{-2}) and biomass (72 g m^{-2}) as well as broadleaf weed density (≤ 7 plants m^{-2}) and biomass (52 g m^{-2}) at 60 DAT (Table 5). Brosnan et al. (2011) reported 93 to 100% control of annual bluegrass with application of indaziflam at 30 to 60 g ai ha^{-1} at 28 weeks after treatment in bermudagrass turf. Similar to this study, Hanson and Jhala (2010) reported that tank mixing indaziflam with glufosinate provided $> 90\%$ control of common chickweed (*Stellaria media* L.) and field bindweed (*Convolvulus arvensis* L.) at 21 DAT in established orchards in California.

This is the first report of weed control efficacy of tank mixing saflufenacil, glufosinate, and indaziflam in citrus. Application of herbicides as a tank mixture is a popular method adopted by citrus growers because it provides broad-spectrum weed control in a single application that reduces labor and fuel costs (Singh et al. 2011a). Results of this study indicate that the weed control spectrum of saflufenacil can be expanded by tank mixing with glufosinate in Florida citrus. There was no antagonistic effect; therefore, tank mixing saflufenacil and glufosinate will provide control of existing broadleaf and grass weeds in a single application. In addition, indaziflam as a tank mix partner provided residual weed control later in the season. Thus, the excellent soil residual activity of indaziflam may provide citrus growers with an option for controlling secondary flushes of weeds germinating in fall and early spring.

In this study, glyphosate applied alone was not as effective as when tank mixed with saflufenacil and pendimethalin suggesting the additive effect of tank mixture on glyphosate efficacy. There is no report of glyphosate-resistant weeds in Florida citrus; however, because of continuous use for several years, efficacy of glyphosate has been reduced for control of

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Table 4. Efficacy of herbicide treatments for weed control at 15 and 30 d after treatment (DAT) in a field experiment conducted in Orange County, FL.

		15 DAT[a,b]						30 DAT[a,b]					
Herbicide	Rate	Brazil pusley	Day flower	Evening-primrose	Southern sandbur	Johnson grass	Natal grass	Brazil pusley	Day flower	Evening primrose	Southern sandbur	Johnson grass	Natal grass
	kg ae or ai ha^{-1}	%											
Nontreated control	—	0 i	0 g	0 h	0 g	0 g	0 h	0 k	0 k	0 j	0 h	0 i	0 g
Saflufenacil	0.037	72 g	70 f	72 g	2 fg	9 f	0 h	66 h	65 i	65 gh	0 h	0 i	0 g
Saflufenacil	0.05	76 ef	75 e	77 ef	5 ef	4 g	3 g	70 f	70 g	74 e	0 h	0 i	0 g
Saflufenacil	0.075	79 de	80 d	80 de	7 e	12 f	8 f	71 f	72 f	74 e	0 h	0 i	0 g
Glufosinate	1	66 h	70 f	70 g	73 d	72 e	72 e	60 j	59 j	60 i	69 f	69 f	68 e
Glufosinate	1.33	74 fg	73 ef	73 fg	73 d	74 de	72 e	68 g	68 h	67 g	68 f	65 g	66 e
Glufosinate	1.66	81 d	85 c	81 d	79 cd	81 cd	78 de	71 f	74 e	71 f	72 e	72 e	74 d
Saflufenacil + glufosinate	0.037 + 1.0	86 c	86 c	86 c	78 d	80 cd	80 cd	75 e	79 d	78 d	74 e	74 e	74 d
Saflufenacil + glufosinate	0.05 + 1.0	98 ab	98 ab	98 ab	78 d	78 cde	76 de	81 d	80 d	82 c	78 d	79 d	82 b
Saflufenacil + glufosinate	0.05 + 1.33	97 b	97 b	97 b	80 cd	80 cd	81 cd	84 c	84 c	83 c	77 d	78 d	80 c
Saflufenacil + glufosinate + indaziflam	0.037 + 1.0 + 0.05	99 a	99 a	99 a	86 bc	85 bc	84 c	86 b	86 b	86 b	83 c	82 c	81 bc
Saflufenacil + glufosinate + indaziflam	0.037 + 1.0 + 0.073	99 a	99 a	99 a	90 b	90 b	90 b	90 a	90 a	90 a	89 b	90 b	90 a
Saflufenacil + glyphosate + pendimethalin	0.05 + 2.24 + 2.5	99 a	99 a	99 a	97 a	97 a	99 a	90 a	90 a	90 a	91 a	92 a	91 a
Glyphosate	2.52	73 g	69 f	70 g	77 d	71 de	71 e	64 i	65 i	65 gh	61 g	61 h	62 f

[a] Data were arc-sine square-root transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison based on interpretation from the transformed data.

[b] Means (n = 4) within columns with no common letter(s) are significantly different according to Fisher's protected LSD test where $P \leq 0.05$.

several common weeds in Florida citrus (Singh et al. 2011c). Tank mixtures of herbicides is an important aspect of glyphosate stewardship program (Duke and Powles 2008); therefore, applying herbicides with a different mode of action such as saflufenacil, indaziflam or glufosinate (upon registration) will reduce the selection pressure and occurrence of glyphosate-resistant weeds in citrus. Overall results suggest that saflufenacil can fit in herbicide weed control programs if applied in tank mixes with suitable partner(s) such as glufosinate and indaziflam; however, more research is required to understand interaction of saflufenacil or indaziflam with other herbicides commonly used in Florida citrus including paraquat, carfentrazone, diuron, bromacil, rimsulfuron etc.

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

		Weed density at 60 DAT[a,b]						Biomass[a,b]	
Herbicide	Rate	Brazil pusley	Day flower	Evening-primrose	Southern sandbur	Johnson grass	Natal grass	Broadleaf weeds	Grass weeds
	kg ae or ai ha^{-1}	No m^{-2}						g m^{-2}	
Nontreated control	—	26 a	23 a	21 a	26 a	18 a	14 b	381 a	400 a
Saflufenacil	0.037	19 b	18 b	17 b	25 a	17 a	13 bc	202 g	389 ab
Saflufenacil	0.05	14 e	14 d	9 fg	24 a	17 a	13 bc	177 hi	395 a
Saflufenacil	0.075	13 e	12 f	7 i	24 a	16 a	12 bc	184 h	388 ab
Glufosinate	1.0	19 b	18 b	15 c	19 b	16 a	16 a	299 b	345 bc
Glufosinate	1.33	16 cd	15 cd	11 e	17 bc	13 cd	13 bc	264 c	251 ef
Glufosinate	1.66	15 de	14 d	11 ef	15 c	11 d	10 c	249 d	305 cd
Saflufenacil + glufosinate	0.037 + 1.0	14 ef	13 de	8 gh	19 b	16 a	16 a	230 e	271 de
Saflufenacil + glufosinate	0.05 + 1.0	13 f	12 ef	7 hi	19 b	16 a	16 a	214 f	236 ef
Saflufenacil + glufosinate	0.05 + 1.33	12 g	10 g	6 j	17 bc	14 bc	11 bc	170 i	206 fg
Saflufenacil + glufosinate + indaziflam	0.037 + 1.0 + 0.05	11 h	8 h	4 k	10 d	6 e	5 e	78 k	160 gh
Saflufenacil + glufosinate + iIndaziflam	0.037 + 1.0 + 0.073	7 i	6 i	0 m	6 e	2 g	0 f	54 l	72 i
Saflufenacil + glyphosate + pendimethalin	0.05 + 2.24 + 2.5	10 h	8 h	3 l	9 d	5 f	4 e	76 k	116 hi
Glyphosate	2.52	12 c	16 c	12 d	10 d	8 e	7 d	234 e	243 ef

[a] Data were arc-sine square-root transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison based on interpretation from the transformed data.

[b] Means (n = 4) within columns with no common letter(s) are significantly different according to Fisher's protected LSD test where $P \leq 0.05$.

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