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Glufosinate; glyphosate; saflufenacil; tiafenacil; tolpyralate; barnyardgrass; *Echinochloa crus-galli* (L.) P. Beauv.; hairy fleabane; *Erigeron bonariensis* L.; junglerice; *Echinochloa colona* (L.) Link.; almond; *Prunus dulcis* L.; pistachio; *Pistacia vera* L.; prune; *Prunus domestica* L.; walnut; *Juglans regia* L.

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Corresponding author:
Bradley D. Hanson;
Email: bhanson@ucdavis.edu

Evaluation of weed control efficacy and crop safety of the PPO-inhibiting herbicide tiafenacil in California orchard cropping systems

Guelta Laguerre[1], Andres Contreras Jr[2] and Bradley D Hanson[3]

[1]Graduate Student Researcher, Department of Plant Sciences, University of California, Davis, CA, USA; [2]Graduate Student Researcher, Department of Plant Sciences, University of California, Davis, CA, USA and [3]Professor of Cooperative Extension, Department of Plant Sciences, University of California, Davis, CA, USA

Abstract

Tiafenacil is registered in the United States for use in annual crops such as corn and soybean, but not on orchard crops. Field studies were conducted to determine orchard crop safety and efficacy of tiafenacil on important California orchard weeds. To evaluate crop safety, tiafenacil was applied at 74, 148, and 222 g ai ha^{-1} alone and with 38 g ai ha^{-1} of tolpyralate three times per year at the base of almond, pistachio, prune, and walnut trees. The first treatment was applied 2 mo after the trees had been transplanted. In all four tree crop experiments, treatments were applied once in May 2020, then three times again during the winter of 2021 and 2022 at 21-d treatment intervals. There were no visual foliar injury symptoms or treatment-related effects on tree trunk diameter change even at the highest tested rate of tiafenacil applied seven times over three growing seasons. In a separate study of weed control, in most instances, tiafenacil applied at 12 g ai ha^{-1} performed similarly to that of tiafenacil plus glufosinate. Control of glyphosate-resistant hairy fleabane with tiafenacil applied alone at 25 g ai ha^{-1} was 65% by 14 d after treatment. Tiafenacil applied at 50 g ai ha^{-1} to hairy fleabane performed similarly to glufosinate plus glyphosate. In a greenhouse study, tiafenacil applied at 12 g ha^{-1} provided 95% to 100% control of barnyardgrass and junglerice, and there was no significant difference between tiafenacil applied alone or with glufosinate. Saflufenacil applied alone or in a mixture with glufosinate was not as effective as the tiafenacil treatments for grass weed control. Based on experiments conducted over three growing seasons in four tree fruit and tree nut crops, tiafenacil crop safety appeared to be acceptable even at up to 2- or 3-fold the expected use rate.

Introduction

Orchard crops, particularly tree nuts, are an important agricultural crop in California. Almond, walnut, and pistachio have a combined cultivated area of 730,053 ha in California and contributed more than $8.5 billion to the U.S. economy in 2020 (CDFA 2019; USDA-NASS 2021).

Weeds interfere with young tree growth by competing for resources such as light, water, and nutrients that would otherwise be available for trees, and this can have both short-term and long-term effects on orchard productivity (Jarvis-Shean et al. 2018; Zimdahl 2018). In addition, weeds interfere with cultural operations such as irrigation, pruning, harvesting, and application of fertilizers and pesticides (Jarvis-Shean et al. 2018; Osipitan et al. 2020). Almonds and walnuts are mechanically shaken from the tree, then swept into windrows, and picked up from the orchard floor after several days of drying; for those crops, a weed-free orchard floor is necessary for harvest operation efficiency (Gradziel 2017; Micke 1996). One of the main challenges for orchard managers is appropriate and cost-effective weed management. Therefore, research on additional weed management tools or practices in orchards can be beneficial for California orchard production systems.

Many tree nut and vineyard crop weed-control programs rely heavily on a limited number of postemergence herbicides; therefore, the presence of herbicide-resistant biotypes can present serious challenges to these cropping systems (Hanson et al. 2014). In particular, junglerice [*Echinochloa colona* (L.) Link.], barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], and ryegrasses (*Lolium* spp.) are among the most problematic herbicide-resistant grass weeds in California orchards and vineyards (Brunharo and Hanson 2018; Matzrafi et al. 2020; Morran et al. 2018; Tehranchian et al. 2019), whereas hairy fleabane (*Erigeron bonariensis* L.) and horseweed (*Erigeron canadensis* L.), which have developed resistance to several herbicide modes of action, are also problematic in these cropping systems (Moretti et al. 2016, 2021; Shrestha et al. 2008).

Tiafenacil was discovered by FarmHannong Co., Ltd. (Seoul, South Korea) and was co-developed in the United States with ISK Biosciences, Inc. (Painesville, OH); it is a protoporphyrinogen IX oxidase (PPO)–inhibiting herbicide from the pyrimidinedione chemical class. Inhibitors of PPO prevent the production of chlorophyll and heme by binding to the protoporphyrinogen-oxidase enzyme (protox) (Anonymous 2020a, 2020b; Park et al. 2018). This leads to an accumulation of protoporphyrin IX (PPIX), which leaks out of the chloroplast and accumulates in the cytoplasm. In the cytoplasm, PPIX reacts with light and oxygen to create oxygen radicals (singlet oxygen) that cause lipid peroxidation and cell membrane destruction, ultimately leading to plant death (Shaner 2014). Tiafenacil is registered in the United States for preplant use on corn (*Zea mays* L.), cotton (*Gossypium* spp.), soybean [*Glycine max* (L.) Merr.], wheat (*Triticum aestivum* L.), and grape (*Vitis vinifera* L.) at a maximum rate of 75 g ai ha^{-1}, and is a useful tool for managing herbicide resistance (Anonymous 2020b). Tiafenacil provides an alternative for controlling glyphosate-resistant Palmer amaranth (*Amaranthus palmeri* S. Watson) in cotton, suppressing glyphosate-resistant horseweed in corn and soybeans, and controlling common waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] in corn and soybean (USEPA 2020).

Herbicide mixtures are commonly used in agriculture to improve efficacy, increase the spectrum of weed control, and mitigate herbicide resistance (Busi and Beckie 2021; Zhang et al. 2013). Mixing herbicides with different modes of action can be used to address specific weed problems and can be a viable strategy for improving orchard weed control (Moretti et al. 2015). For example, previous research has shown that when a PPO-inhibitor herbicide is mixed with glufosinate, there is enhanced herbicidal activity, compared with these herbicides applied individually (Takano et al. 2020).

Tiafenacil used alone or in mixture with other herbicides has the potential to contribute to broadleaf and grass weed control in orchard cropping systems; however, currently few data are available regarding its safety when used on tree crops or its efficacy on common California orchard weeds. Therefore, the objective of this research was to 1) evaluate weed control efficacy of various rates of tiafenacil alone or mixed with glufosinate and glyphosate on annual weeds relevant to California orchards; and 2) evaluate the crop safety of young fruit and nut trees when tiafenacil is used alone or in a mixture with tolpyralate compared with a currently registered standard.

Materials and Methods

Crop Safety Studies

Seven field experiments were conducted in a mixed-species orchard in Davis, CA (38.538788°N, 121.794460°W) to evaluate the crop safety of applying tiafenacil at the base of young almond (*Prunus dulcis* L.), pistachio (*Pistacia vera* L.), prune (*Prunus domestica* L.), and walnut (*Juglans regia* L.) trees. The soil at this site is mapped as a Yolo silt loam with a 0% to 2% slope (USDA-NRCS 2022). The orchard was planted in March 2020; the almond cultivar was 'Nonpareil' on 'Empyrean 1' rootstock, pistachios were 'Kerman' on 'UCB 1' rootstock, prunes were 'Improved French' on 'Krymsk 86' rootstock, and walnuts were 'Chandler' on clonal 'RX1' rootstock.

The orchard used a single-line drip irrigation system, and all crops were maintained with pruning, mowing, and maintenance pesticides as needed throughout the year. Herbicide treatments included two rates of tiafenacil applied alone (74 and 148 g ai ha^{-1}, DCC-38256, 70WDG; ISK Biosciences, Concord, OH) and in mixture with tolpyralate (74 + 38 g ai ha^{-1}, Tolpyralate 400SC; ISK Biosciences), and saflufenacil alone (49 and 98 g ai ha^{-1}, Saflufenacil CS; BASF Corporation, Research Triangle Park, NC). The almond experiment also included a higher rate of tiafenacil (222 g ai ha^{-1}), an additional mixture of tiafenacil plus tolpyralate (148 + 38 g), and an additional rate of saflufenacil (147 g/ha). Ammonium sulfate (BroncMax; Wilbur-Ellis, Aurora, CO) and methylated seed oil (Contingent; Helena Chemical Co, Collierville, TN) were included at 10 ml L^{-1} in all treatments. Each tree crop was considered a separate experiment and had individual plots of 3 m by 6 m centered on a single tree set up in a randomized complete block design with four replicates. Herbicide treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} at 241 pKa through three TeeJet XR11002 flat-fan nozzles (Spraying Systems Company, Wheaton, IL) in two passes. In 2020, the young trees received one herbicide application 2 mo after transplanting; subsequently the plots were retreated with three herbicide applications at 21-d intervals in spring 2021 and spring 2022. The 21-d retreatment interval follows the shortest interval allowed for use of similar herbicides registered for use on these crops and was included as a worst-case scenario for potential crop injury. Data collection consisted of visual assessments of crop injury using a 0 to 100 scale at monthly intervals starting 1 mo after the first application in May 2020. Trunk diameter 46 cm above the soil surface was measured before the first tiafenacil application in May 2020, and then in each subsequent year between January and March while the trees were dormant.

Field Herbicide Efficacy Studies

One experiment was conducted on April 12, 2022, at the Wolfskill Experimental Orchard in Winters, CA (38.5053790°N, 121.9807380°W) in a 5-yr-old mixed species orchard with 'Lapins' cherry and 'Howard' walnut trees. Twelve herbicide treatments including tiafenacil alone (9 and 12 g ai ha^{-1}) or in multiple mixtures with glufosinate (180, 270, 361, 451, 541, 229, 482, 602, and 722 g ai ha^{-1}, Rely 280 SL; BASF Corporation) were applied in a small-plot research study to evaluate potential additive and synergistic interactions on weed control efficacy. Weeds in this location were 8 to 10 cm tall at application. The plots were 3 m by 6 m centered on a single tree and were set up in a randomized complete block design with four replicates.

The second field weed-control experiment was conducted in a fallow field at the University of California–Davis Plant Science Field Facility in Davis, CA (38.5387579°N, 121.7819151°W) in spring 2022 with tiafenacil alone (25 and 50 g ai ha^{-1}) or mixed with glufosinate (1,037 g ai ha^{-1}) or glyphosate (984 g ai ha^{-1}, Roundup PowerMax; Bayer Crop Science, St. Louis, MO). The plots were 2 m by 5 m and arranged in a randomized complete block design with four replicates. Weeds present were common winter annual weeds for the region and ranged from 8 to 13 cm tall at application. Treatment efficacy was visually assessed at 7, 14, and 28 d after treatment (DAT) using a 0 to 100 scale. The aboveground plant tissues were harvested in 1-m^{-2} quadrat for each plot and dried to a constant weight in a convection oven at 50 C, then dry biomass data were collected.

Greenhouse Herbicide Efficacy Studies

Two experiments were initiated on May 24 and October 1, 2022, respectively, in a greenhouse (38.5430721°N, 121.7640843°W) at the University of California–Davis to evaluate the efficacy of tiafenacil alone or mixed with glufosinate on barnyardgrass and

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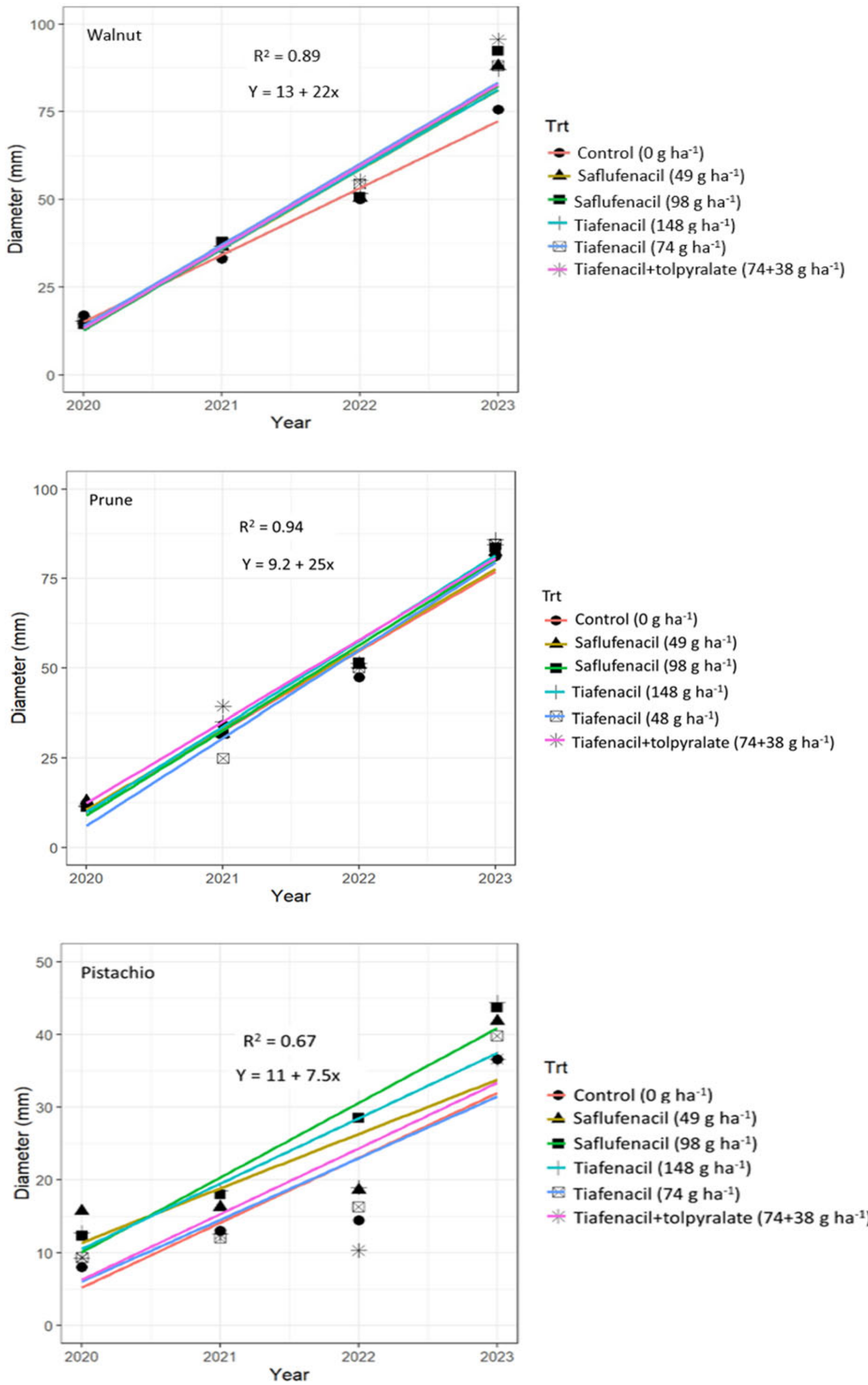

Figure 1. Increase in young walnut, prune, and pistachio trunk diameter over time with or without tiafenacil applied around the base of the tree seven times over 3 yr.

junglerice. Seeds were collected in January 2022, from an orchard site in Davis, CA. Junglerice and barnyardgrass seeds were chemically scarified for 30 min in concentrated (90%–99%) sulfuric acid followed by rinsing in deionized water (Buhler and Hoffman 1999). Seeds were treated with a 0.2 g L^{-1} Captan solution (Captan 50 WP; UPL NA Inc., King of Prussia, PA) and germinated at room temperature on moist blotter paper in petri dishes. Germinated seeds were sown into 10- by 10-cm pots at approximately 2 mm below the soil surface of commercial potting media (Sun Gro Horticulture Canada Ltd, Vancouver, BC, Canada). The experimental design was a randomized complete block with six treatments, including a nontreated control with four replicates of each treatment. Treatments included tiafenacil (12 g ai ha^{-1}) alone or plus glufosinate (180 g ai ha^{-1}), saflufenacil (49 g ai ha^{-1}) alone or plus glufosinate (180 g ai ha^{-1}), and glufosinate (180 g ai ha^{-1}) alone. Herbicide treatments were applied using a moving-nozzle cabinet sprayer (Technical Machinery Inc., Sacramento, CA) calibrated to deliver 140 L ha^{-1} at 241 kPa using a TeeJet 8002E flat-fan nozzle (Spraying Systems Co.). Plants were 8 cm tall at the 3-leaf stage at treatment. The nozzle was

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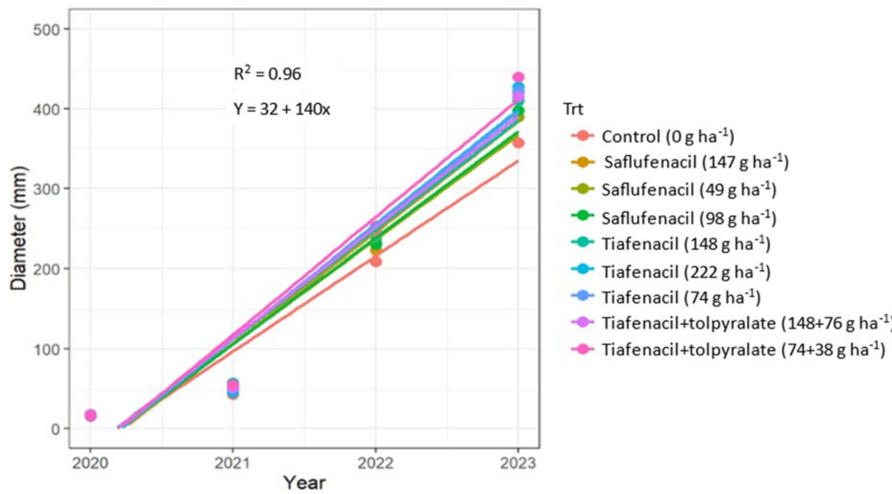

Figure 2. Increase in young almond trunk diameter over time with or without tiafenacil applied around the base of the tree seven times over 3 yr.

adjusted to 30 cm above the canopy during the application. Plants remained in the greenhouse with a day/night temperature of approximately 30 C with no additional lighting, and were irrigated as needed. Treatment efficacy was visually assessed at 7 and 14 DAT using a 0 to 100 scale. The experiments were terminated 14 DAT, and the aboveground plant biomass was cut at the surface of the soil, placed in separate paper bags, and dried to a constant weight in a convection oven at 40 C.

Data Analysis

Weed control data were analyzed using a one-way ANOVA with R software (version 4.1.2; R Development Core Team 2021), with means comparisons using Fisher's protected least significant difference (LSD) test with $\alpha = 0.05$, where appropriate. The aboveground biomass data were analyzed using a linear model with the *lmer* function in the LME4 package. The EMMEANS package and the *cld* function with LSD test ($\alpha = 0.05$) were used to separate treatment means when appropriate for the dry biomass (Kniss and Streibig 2020; Lenth 2019). Trunk diameter data were analyzed using a simple linear model to characterize the growth of the orchard crops over 3 yr for the different tiafenacil and mixture treatments using the linear equation $Y = A + BX$, where Y is the predicted value, A is the y-intercept; B is the slope of the line, and X is the time in years. All graphs were created using R Studio (R Development Core Team 2021).

Results and Discussion

Crop Safety

No foliar injury was observed from any treatments at any rating interval on the young trees (data not shown). Although no fruit yield measurements were taken because the trees were too young for meaningful yield data, visual fruit quality appeared normal on all treated trees. Trunk diameter change has been widely used as a measure of orchard crop growth (Hernandez-Santana et al. 2017; Martin-Palomo et al. 2019; Moriana et al. 2003). From 2020 to 2022, average trunk diameter increased substantially for all crops (Figures 1 and 2). The rate of trunk diameter increase of all four fruit tree species was not affected by the herbicide treatments (Tables 1 and 2).

Some growers use the highest labeled rates and complex mixtures in their efforts to manage difficult weeds, particularly in winter, but these practices are costly and can occasionally lead to crop safety problems (Brunharo et al. 2020). Tiafenacil was tested at rates up to 148 g ai ha^{-1} in young prune, walnut, and pistachio trees, and up to 222 g ai ha^{-1} in young almond trees (Figure 2). Because the highest tested rates were double or triple the likely maximum use rate (75 g ai ha^{-1}) in these crops, these data suggest that tiafenacil would likely have acceptable crop safety in commercial production of these orchard crops.

Weed Control

In the fallow field study, control of hairy fleabane with tiafenacil alone (25 or 50 g ai ha^{-1}) ranged from 53% to 58% at 7 DAT (Table 3). Control of hairy fleabane with tiafenacil alone (25 g ai ha^{-1}) at 14 DAT ranged from 65% to 70%. Control of hairy fleabane was numerically improved when glyphosate was mixed with tiafenacil at all rates. Tiafenacil in mixture with glufosinate and glyphosate (25 g ha^{-1} + 984 g ai ha^{-1} + 1,037 g ae ha^{-1}) provided 68% control of hairy fleabane. All mixture treatments with tiafenacil at 50 g ai ha^{-1} resulted in similar control of hairy fleabane. Glyphosate (1,037 g ae ha^{-1}) applied alone provided only 10% control of hairy fleabane, but glyphosate (1,037 g ae ha^{-1}) in mixture with glufosinate (50 + 984 g ai ha^{-1}) provided 80% control of hairy fleabane. Tiafenacil alone or in mixture improved control of hairy fleabane compared to glyphosate applied alone. In this study, control of hairy fleabane with tiafenacil alone did not exceed 60% by 28 DAT at the growth stage we tested (15–18 cm tall). Weed dry biomass from treated plots ranged from 31 to 83 mg per plant. All treatments reduced weed dry biomass relative to the nontreated plots at 28 DAT.

In the mixed-species orchard study conducted in April 2022, all treatments provided 83% to 90% control of hairy fleabane at 7 DAT, except for tiafenacil at 9 g ai ha^{-1}, which controlled hairy fleabane by only 67% (Table 4). However, all treatments resulted in 100% control of hairy fleabane by 14 DAT. Control of hairy fleabane likely was better in this study because weeds were treated at an earlier growth stage (8–10 cm tall) compared with the previous study. Treated plots tended to have lower biomass than the nontreated control; however, there were no statistical differences in biomass in this experiment.

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Table 1. Regression parameters for trunk diameter increase in almond after seven tiafenacil and other herbicide applications made during 2020–2023.[a–c]

Treatment	Rate	A	B	SE
	g ai ha^{-1}	mm		
Control	0	156	120	22.04
Tiafenacil	74	184	130	10.3
Tiafenacil	148	180	130	25.4
Tiafenacil	222	184	140	11.6
Tiafenacil + tolpyralate	74 + 38	191	140	11.4
Tiafenacil + tolpyralate	148 + 38	183	150	26.4
Saflufenacil	49	171	140	26.4
Saflufenacil	98	172	140	25.1
Saflufenacil	147	176	140	24.2

[a]Almond trees received one herbicide application in May 2020, three applications in February-April 2021, and three applications in February–April 2022 on a 21-d retreatment interval.
[b]Regression parameters: $Y = A + BX$, where Y is the expected values of the tree trunk diameter (in millimeters), A is the y-intercept, B is the slope, and X is the time in years.
[c]SE indicates standard error.

Table 2. Regression parameters for trunk diameter increase in California orchard crops after seven applications of tiafenacil and other herbicides during 2020–2023.[a–c]

		Pistachio			Walnut			Prune		
Treatment	Rate	A	B	SE	A	B	SE	A	B	SE
	g ai ha^{-1}	mm			mm			mm		
Control	0	17	8.9	1.8	46	22	2.6	43	22	1.9
Tiafenacil	74	19	8	1.7	51	24	2.3	43	25	2.3
Tiafenacil	148	19	9.6	1.8	50	26	2.3	46	24	2.8
Tiafenacil + tolpyralate	74 + 38	19	10	1.9	52	26	2.6	48	24	3.3
Saflufenacil	49	15	9	1.8	49	28	2.6	46	24	3.3
Saflufenacil	98	17	10	1.0	50	24	2.5	45	24	2.9

[a]Pistachio, prune, and walnut trees received one herbicide application in May 2020, three applications between February and April 2021, and three applications between February and April 2022 on a 21-d interval.
[b]Regression parameters: $Y = A + BX$, where Y is the expected value of the tree trunk diameter (in millimeters), A is the y-intercept, B is the slope, and X is the time in years.
[c]SE indicates standard error.

Table 3. Glyphosate-resistant hairy fleabane control at 7, 14, and 28 d after treatments and total weed biomass from a trial conducted in a fallow field near Davis, CA in April 2022.[a,d]

								Dry biomass	
Treatment[b,c]	Rate	7 DAT		14 DAT		28 DAT		28 DAT	
	g ai ha^{-1}	%						g m^{-2}	
Untreated	–	–		–		–		146	a
Tiafenacil	25	53	bc	65	bc	48	ab	72	bc
Tiafenacil	50	58	ab	70	ab	50	ab	31	c
Tiafenacil + glyphosate	25 + 1,037	45	c	58	c	45	b	50	bc
Tiafenacil + glufosinate	25 + 984	60	ab	78	a	55	ab	55	bc
Tiafenacil + glyphosate	50 + 1,037	53	bc	70	ab	53	ab	56	bc
Tiafenacil + glufosinate	50 + 984	63	ab	75	ab	55	ab	43	bc
Tiafenacil + glyphosate + glufosinate	25 + 1,037 + 984	68	ab	78	a	58	ab	53	bc
Tiafenacil + glyphosate + glufosinate	50 + 1,037 + 984	60	ab	78	a	58	ab	38	c
Glufosinate	984	60	ab	75	ab	55	ab	73	bc
Glyphosate	1,037	10	d	10	d	10	c	83	b
Glyphosate + glufosinate	1,037 + 984	58	ab	80	a	60	a	57	bc
P-value	N/A	<0.0001		<0.0001		<0.0001		0.001	

[a]Abbreviations: AMS, ammonium sulfate; DAT, days after treatment; MSO, methylated seed oil; N/A, not applicable.
[b]All herbicide treatments included MSO and AMS at 10 ml L^{-1}.
[c]Glyphosate rate is expressed as grams of acid equivalent per hectare (g ae ha^{-1}).
[d]Means followed by the same letter are not significantly different ($\alpha = 0.05$).

Greenhouse Herbicide Efficacy

Tiafenacil at 12 g ai ha^{-1} provided 95% control of junglerice and 100% control of barnyardgrass in the summer experiment (Table 5). Tiafenacil in mixture with glufosinate at 180 g ai ha^{-1} provided similar control of junglerice as did tiafenacil alone. Saflufenacil at 49 g ai ha^{-1} did not adequately control junglerice or

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Table 4. Visual control and dry biomass of Italian ryegrass and glyphosate-resistant hairy fleabane at 7 and 14 d after treatment in a mixed-species orchard in Winters, CA, in April 2022.[a,b]

Treatment[c]	Rate	Hairy fleabane 7 DAT		Hairy fleabane 14 DAT	Italian ryegrass 7 DAT	Italian ryegrass 14 DAT	Filaree 7 DAT		Filaree 14 DAT		Dry biomass 28 DAT
	g ai ha^{-1}	%									g m^{-2}
Untreated	–	–		–	–	–	–		–		96
Tiafenacil	9	67	b[c]	100	53	50	50	c	50	b	47
Tiafenacil	12	87	a	100	60	53	63	b	63	a	61
Tiafenacil + glufosinate	9 + 180	90	a	100	70	57	67	ab	70	a	57
Tiafenacil + glufosinate	9 + 270	90	a	100	73	57	70	ab	67	a	76
Tiafenacil + glufosinate	9 + 361	90	a	100	70	50	68	ab	63	a	64
Tiafenacil + glufosinate	9 + 451	90	a	100	70	57	63	b	67	a	75
Tiafenacil + glufosinate	9 + 541	90	a	100	73	57	63	b	63	a	49
Tiafenacil + glufosinate	12 + 229	83	a	100	73	53	67	ab	67	a	61
Tiafenacil + glufosinate	12 + 361	90	a	100	77	60	67	ab	67	a	74
Tiafenacil + glufosinate	12 + 482	90	a	100	80	60	77	a	73	a	57
Tiafenacil + glufosinate	12 + 602	90	a	100	80	61	73	ab	73	a	42
Tiafenacil + glufosinate	12 + 722	90	a	100	70	60	63	b	65	a	62
P-value	N/A	0.048		0.471	0.243	0.352	0.012		0.030		0.309

[a]Abbreviations: AMS, ammonium sulfate; DAT, days after treatment; MSO, methylated seed oil; N/A, not applicable.
[b]Means followed by the same letter are not significantly different (α = 0.05).
[c]All herbicide treatments included AMS and MSO at 10 ml L^{-1}.

Table 5. Visual control and total biomass of junglerice and barnyardgrass at 14 d after treatment from two greenhouse experiments conducted in June and October 2022 to evaluate the efficacy of tiafenacil alone or mixed with glufosinate.[a–c]

Treatment[c]	Rate	Summer 2022 Junglerice		Summer 2022 Barnyardgrass		Summer 2022 Junglerice		Summer 2022 Barnyardgrass		Fall 2022 Junglerice		Fall 2022 Barnyardgrass		Fall 2022 Junglerice		Fall 2022 Barnyardgrass	
	g ai ha^{-1}	%				mg plant^{-1}				%				mg plant^{-1}			
Untreated	–	–		–		7,040	b	9,008	a	–		–		2,210	a	2,680	a
Tiafenacil	12	95	ab	100	a	73	a	448	b	98	a	98	a	73	c	98	b
Glufosinate	180	95	ab	93	bc	413	a	458	b	93	a	85	a	63	c	118	b
Saflufenacil	49	10	c	10	d	1,410	a	485	b	0	b	0	b	1,540	b	2,060	a
Tiafenacil +glufosinate	12 + 180	97	a	100	a	60	a	325	b	98	a	95	a	108	c	85	b
Saflufenacil +glufosinate	49 + 180	93	b	98	ab	180	a	515	b	85	a	75	a	88	c	70	b
P-value	N/A	0.0004		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	

[a]Abbreviation: N/A, not applicable.
[b]All herbicide treatments included ammonium sulfate and methylated seed oil at 10 ml L^{-1}.
[c]Means followed by the same letter are not significantly different (α = 0.05).

barnyardgrass. Tiafenacil plus glufosinate provided better control of junglerice (97%) than saflufenacil plus glufosinate, which provided 93% control of junglerice. Jhala et al. (2013) similarly found that saflufenacil did not affect grass weed control in citrus orchards. All treatments resulted in significantly less grass weed dry biomass than the nontreated control. Barnyardgrass biomass ranged from 325 to 9,008 mg, with the numerically lowest dry biomass from the mixture of tiafenacil and glufosinate. Tiafenacil applied at 12 g ai ha^{-1} provided 98% control of junglerice and barnyardgrass in the fall greenhouse experiment, and this was similar to glufosinate alone and the mixture of tiafenacil plus glufosinate.

Overall, tiafenacil alone performed in a manner that was similar to glufosinate for junglerice and barnyardgrass control in this greenhouse experiment. These results agree with previous reports that demonstrated the efficacy of glufosinate in controlling barnyardgrass (Lanclos et al. 2002). Saflufenacil applied alone or mixed with glufosinate was not as effective as tiafenacil applied alone or in mixture with glufosinate for grass weed control. Most postemergence PPO-inhibiting herbicides registered for use on tree crops hav1e activity on broadleaf weeds only; however, these results indicate that tiafenacil has good activity on broadleaf weeds and some activity on grass weeds that are relevant to California orchard crops.

After seven applications over three growing seasons, tiafenacil applied at up to 148 g ai ha^{-1} to young prune, walnut, and pistachio, and up to 222 g ai ha^{-1} to young almond did not result in visible crop injury nor did it negatively affect tree growth. At the proposed use rate of 75 g ai ha^{-1} tiafenacil would be sufficient for effective control of some key weeds while having adequate safety on young tree crops. These results demonstrate that tiafenacil can contribute to grass weed control, which is unique among postemergence PPO-inhibiting herbicides currently registered for use on orchard crops; however, it would likely need to be mixed with another herbicide for more broad-spectrum annual grass control. In the mixture experiments, increasing the rate of glufosinate in combination with tiafenacil did not dramatically increase weed control; thus, with timely applications, relatively lower glufosinate rates plus tiafenacil may be sufficient. Glyphosate alone suppressed hairy fleabane, but control was substantially increased when a mixture of glyphosate with tiafenacil or glufosinate was used. Tiafenacil appears to have adequate crop safety and unique weed control contributions for registration consideration on some California orchard crops and could contribute to resistance management efforts in these crops.

Practical Implications

Weed management is an ongoing challenge in orchard production systems in California. Concerns about competition in young orchards and weed interreference with harvest operations and other horticultural practices in older orchards lead to the need for highly effective weed management practices. In most orchards, both preemergence and postemergence herbicides are commonly used; however, registered broad-spectrum postemergence herbicide options are somewhat limited for these specialty crops. Resistance to key postemergence herbicides, particularly glyphosate, as well as consumer concerns about glyphosate, paraquat, and glufosinate, underline the need for additional broad-spectrum herbicides for these specialty crops. This research was conducted to evaluate the efficacy of a PPO-inhibiting herbicide with postemergence activity on key broadleaf weeds and grasses and to determine whether crop safety on key tree nut and fruit crops is adequate to pursue registration for use of tiafenacil on fruit tree crops. Field and greenhouse results suggest that tiafenacil could be useful for controlling several important weeds in California orchards, including glyphosate-resistant hairy fleabane. Importantly, no crop injury was observed in plots treated seven times over a 3-yr period with tiafenacil rates at 2- to 3-fold the expected use rate on orchard crops. If registered, tiafenacil could provide a useful postemergence weed control option for California orchard crop producers.

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