Evaluating mesotrione for weed control in orchards and vineyards

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Introduction:

Since 1946, which marks the debut of 2,4-D, synthetic herbicides have become the most important pest management tool used in US crop production; in 2007, chemical weed control products accounted for 47% of all pesticide active ingredients applied in the US agricultural sector. Despite the widespread adoption and use of herbicides, weeds still persist in agricultural systems. Weeds can escape chemical control for numerous reasons, including: incorrect herbicide active ingredient or rate selection, improper sprayer calibration, clogged nozzles or otherwise malfunctioning equipment, weed size (e.g. too large for control), herbicide applications that are made under less-than-ideal environmental conditions (e.g. too cold, too windy, too wet or too dry), and the evolution and spread of herbicide-tolerant and –resistant weeds.

Currently in CA, there are 20 plant species that are resistant to at least one herbicide or herbicide class. Although the majority of resistances (ALS-inhibitors, ACCase-inhibitors, and thiocarbamates) have developed in rice production systems, the most recently confirmed insensitivities (*Conyza* species, junglerice(ECHCO)) are to glyphosate and have been reported in orchards and vineyards. Recommendations for preventing and managing herbicide resistance advocate rotating chemistries to reduce selection pressure; the registration of new products is necessary to provide/maintain sufficient diversity with respect to mechanism/mode of action. The purpose of these studies was to evaluate mesotrione, which is not currently registered for use in perennial horticultural crops in CA, for crop safety and weed control efficacy in orchards and vineyards.

Materials and methods:

The studies were conducted in a commercial walnut orchard (experimental rootstock and scion; approximately 6 yrs since transplanting) in Wheatland, CA, and in table (Thompson seedless) and wine (Merlot) grapes (seven years since transplanting) at the USDA San Joaquin Valley Agricultural Sciences Center in Parlier, CA. All studies were designed as randomized complete blocks with either three (Parlier) or four (Wheatland) replicates per treatment per crop. Individual experimental units (plots) were 7 feet by 56 feet (392 ft^2, 296 m^2) in Wheatland and 8 feet by 30 feet (240 ft^2, 216 m^2) in Parlier. The studies were comprised of 15 herbicide treatments plus a non-treated check (Table 1). Methylated seed oil (MSO) and ammonium sulfate (AMS) were added to all treatments at rates of 1% v:v and 2 qt per 100 gal (1.9 L per 379 L), respectively, excepting paraquat and mesotrione applied alone and paraquat + saflufenacil (all of which received MSO at 1% v:v, only) and flumioxazin + glufosinate (which received AMS at 2 qt per 100 gal, only [1.9 L per 379 L]).

The studies were initiated on 21 November, 2011 (Wheatland: average wind speed = 2 mph [3.2 km hr^{-1}]; air temperature = 61 F [16 C]; soil temperature = 49 F [9 C]; relative humidity = 58%) and 21 February, 2012 (Parlier: average wind speed = < 1.0 mph [1.6 km hr^{-1}]; air temperature = 68 F [20 C]; soil temperature = 54 F [12 C]; relative humidity = 46%). Sequential treatments were applied on 23 March, 2012 (Wheatland: average wind speed = 2 mph [3.2 km hr^{-1}]; air temperature = 72 F [22 C]; soil temperature = 51 F [11 C]; relative humidity = 38%) and 9 May, 2012 (Parlier: average wind speed = 2 mph [3.2 km hr^{-1}]; air temperature = 81 F [27 C]; soil temperature = 72 F [22 C]; relative humidity = 41%). The treatments in Parlier were applied later in the dormant season in order to avoid/allow for vine pruning operations. All treatments were applied using a CO_2-pressurized backpack sprayer (3 nozzle boom; nozzles = 8002 [flat fan]; nozzle spacing = 20 inches [50 cm]; spray volume = 20 gal A^1 [187 L Ha^1]) in two passes (one on each side of the crop row). Percent (%) weed cover was evaluated and weed density data were collected for each plot multiple times throughout the growing season. Percent weed control for each individual plot was derived by standardizing the percent cover data against the untreated check within the same rep. Because weed numbers and identities were similar for both the wine and table grape studies, these data were combined prior to statistical analysis. The effects of herbicide treatment on percent weed cover, percent weed control, and weed count data were evaluated using mixed models ANOVA; comparisons between treatments means were evaluated using Tukey's adjustment procedure.

Crop injury results:

No crop walnut or grape phytotoxicity was noted from any mesotrione treatment in any of these experiments. These treatments, tested in well established trees and vines (>6 yrs) in loam to sandy-loam soils, did not reveal any unexpected sensitivity to mesotrione in walnut or grape. However, moving forward, additional evaluation of crop safety in less established orchards and vineyards or in more coarse soils is recommended before more global inferences of crop safety can be made.

Results from Wheatland, CA:

Weed species present

Burclover (MEDPO)(48 to 59 % of plots), redstem filaree (EROCI) (39 to 59 % of plots), and ryegrass spp. (34 to 78% of plots) were some of the most regularly occurring species across all observation dates (30 January, 21 March, and 17 April, 2012). Although not common early in the season, bindweed (CONAR)(75 to 77% of plots), thistle spp. (64 to 66% of plots), *Conyza* spp. (50 to 61% of plots), and *Polygonum* spp. (41 to 48% of plots) were important components of the late spring and early summer weed communities.

Weed cover

As compared to the untreated check: In general, weed cover (all species combined) increased with increased time after the initial herbicide applications (Table 2). On 21 March, all treatments (except for paraquat and mesotrione, both applied alone) exhibited significantly reduced ($P<0.05$) percent weed cover relative to the untreated check (93 to 98%) (Table 2). On 17 April, only paraquat + penoxsulam/oxyfluorfen, flumioxazin + glufosinate, paraquat + simazine or rimsulfuron + mesotrione, paraquat + mesotrione + oxyfluorfen, and paraquat + mesotrione (6 or 12 oz A^{-1}) applied sequentially statistically reduced ($P<0.05$) mean weed cover (8 to 42%) relative to the control (98%) (Table 2).

As compared to flumioxazin + glufosinate: On 21 March, all herbicide treatments (except paraquat and mesotrione, both applied alone) were statistically similar ($P>0.05$) to the flumioxazin + glufosinate treatment (17%) with respect to percent weed cover. For the last evaluation date (17 April, 2012), paraquat + simazine or rimsulfuron + mesotrione, paraquat + mesotrione + oxyfluorfen, paraquat + mesotrione (6 oz A^{-1}), paraquat + mesotrione (12 oz A^{-1}), paraquat + penoxsulam/oxyfluorfen, and paraquat + indaziflam were statistically similar ($P>0.05$) to flumioxazin + glufosinate (41%) with respect to weed cover; for the same observation date, paraquat + mesotrione (6 or 12 oz A^{-1}) applied sequentially provided significantly reduced ($P<0.05$) percent weed cover (5 to 8%) relative to flumioxazin + glufosinate (41%).

Weed control

As compared to the untreated check: With respect to weed control (all species combined), all of the treatments evaluated (except mesotrione applied alone) were different (P<0.05) from the untreated check (0%) on 19 December, 2011, and 21 March, 2012 (Table 3). Similar results were observed on 17 April, except that the paraquat-only treatment (5%) was now statistically similar (P>0.05) to the untreated check (0%)(Table 3). Despite significant differences between the untreated check and each of the experimental treatments, only a few herbicide programs provided acceptable levels (assuming a minimum of 80%) of global weed control across all evaluation dates (Table3). On 21 March, paraquat + simazine or rimsulfuron + mesotrione, paraquat + mesotrione + oxyfluorfen, paraquat + mesotrione (12 oz A^{-2}) applied sequentially, paraquat + penoxsulam/oxyfluorfen , and flumioxazin + glufosinate provided for 80% weed control or greater; all other tank mixes that included mesotrione + paraquat, with or without an additional partner, averaged between 50% and 79% weed control for the same observation period. On 17 April, only paraquat + penoxsulam/oxyfluorfen and paraquat + mesotrione (6 or 12 oz A^{-1}) applied sequentially provided at least 80% weed control (Table 3).

As compared to flumioxazin + glufosinate: For the 19 December evaluation date, all of the herbicide treatments (except mesotrione applied alone) were similar (P>0.05) to flumioxazin + glufosinate (99%) with respect to weed control; on 21 March, all treatments (except paraquat applied alone, mesotrione applied alone, and paraquat + saflufenacil) were similar (P>0.05) to flumioxazin + glufosinate (82%) with respect to weed control. For 17 April, the last evaluation date for the study, all of the herbicide treatments (except for paraquat applied alone, mesotrione applied alone, paraquat + mesotrione [3 oz A^{-1}], and paraquat + saflufenacil) provided for levels of weed control that were statistically similar to that of flumioxazin + glufosinate (58%).

Weed Density

Weed cover and weed control were not directly related (positively or negatively) to either total weed density (Table 4) or individual species density (data not shown) expressed on a per m^2 basis, for any evaluation date. Because of significant variability in the weed count data, total weed densities did not differ significantly (P>0.05) among any of the treatments.

Results from Parlier, CA:

Weed species present

Redstem filaree (74 to 91% of plots), spotted spurge (EPHMA)(77 to 100% of plots), *Conyza* spp. (47 to 74% of plots), and grasses (*Poa* spp., hare barley [HORLE]) (22 to 57% of plots) were the most commonly occurring species in the studies on 10 April and 10 May, 2012. Although some yellow nutsedge (CYPES), common lambsquarters (CHEAL), prickly lettuce (LACSE), and prostrate knotweed (POLAV) were observed in the experimental plots on 20 June, 2012, spotted spurge (98 % of plots) and *Conyza* spp.) (74% of plots) dominated the early summertime weed communities.

Weed cover

As compared to the untreated check: In general, weed cover (all species combined) increased with increased time after the initial herbicide applications (Table 5). On 10 April and 10 May, all treatments, except for paraquat and mesotrione applied alone, exhibited significantly reduced (P<0.05) percent weed cover, relative to the untreated check (41 to 57%) (Table 5). As of 20 June, only paraquat + indaziflam, paraquat + penoxsulam/oxyfluorfen, flumioxazin + glufosinate, paraquat + simazine or rimsulfuron + mesotrione, and paraquat + mesotrione (6 or 12 oz A^{-1}) applied sequentially provided for statistically reduced (P<0.05) mean weed cover (14 to 56%) as compared to the control (98%) (Table 5).

As compared to flumioxazin + glufosinate: None of the herbicide treatments differed significantly (P>0.05) from flumioxazin + glufosinate (12 to 18%), with respect to percent weed cover, on either 10 April or 10 May, 2012. On 20 June, percent weed cover was significantly lower in the paraquat + simazine + mesotrione, and the sequential paraquat + mesotrione (6 or 12 oz A^{-1}) treatments (14 to 18%), relative to flumioxazin + glufosinate (48%).

Weed control

As compared to the untreated check: With respect to weed control (all species combined), all of the treatments evaluated (excepting the paraquat-only treatment on 20 June) were different (P<0.05) from the untreated check (0%) (Table 6). Despite statistically significant differences between the control and the experimental treatments, only a few herbicide protocols provided acceptable levels (assuming a minimum of 80%) of global weed control across observation dates (Table 6). On 10 April and 10 May, paraquat + simazine + mesotrione and paraquat + penoxsulam/oxyfluorfen were the best treatments for providing residual weed control (87% to 96%); tank mixes that included mesotrione + paraquat (with or without an additional partner) averaged between 68% and 87% weed control for the same observation periods. On 20 June, only paraquat + simazine + mesotrione and paraquat + mesotrione (6 or 12 oz A^{-1}) applied sequentially provided greater than 80% weed control (Table 6).

As compared to flumioxazin + glufosinate: In general, none of the herbicide treatments differed significantly (P>0.05) from flumioxazin + glufosinate (66-81%), with respect to percent weed control, on either 10 April or 10 May. On 20 June, percent weed control was significantly (P<0.05) lower in the plots that received paraquat or mesotrione applied alone, and paraquat + saflufenacil relative to the flumioxazin + glufosinate treatment (48%).

Spotted spurge density

As compared to the untreated check: With respect to spotted spurge, the most numerous (on a per plot basis) and commonly occurring (across all plots) weed species identified in the study, only paraquat + indaziflam, paraquat + penoxsulam/oxyfluorfen, paraquat + flumioxazin + glufosinate, and paraquat + simazine or rimsulfuron + mesotrione prevented weed germination/emergence up to 4 months after the initial herbicide application (Table 7). As compared to the untreated check (94 to 139 plants m^{-2}), these treatments (<1 to 51 plants m^{-2}) reduced (P<0.05) spotted spurge weed densities between 46 and 99% (Table 7). None of the remaining treatments, including the majority of the mesotrione-based programs, differed significantly (P>0.05) from the control plots for the same observation periods (Table 7). Spotted spurge control achieved on 20 June using sequential applications of paraquat + mesotrione (6 and 12 oz A^{-1}) (14 plants m^{-2}) was likely due to the burndown effect of the paraquat (Table 7). According to these results, mesotrione did not significantly control spotted spurge.

As compared to flumioxazin + glufosinate: On 10 April, spotted spurge densities in the paraquat + simazine + mesotrione, paraquat + rimsulfuron + mesotrione, paraquat + penoxsulam/oxyfluorfen, and paraquat + indaziflam treatments (3 to 19 plants m^{-2}) were statistically similar (P>0.05) to those in the flumioxazin + glufosinate program (2 plants m^{-2}). For both 10 May and 20 June, only paraquat + indaziflam (1 to 5 plants m^{-2}) controlled spotted spurge as well as flumioxazin + glufosinate (<1 to 4 plants m^{-2}); paraquat + mesotrione (12 oz A^{-1}) applied sequentially was statistically similar (P>0.05) to flumioxazin + glufosinate, with respect to spotted spurge density, on 20 June, only. All other treatments had spurge population densities that were statistically greater (P<0.05) than the flumioxazin + glufosinate standard at this time.

***Conyza* spp (hairy fleabane and horseweed) density**

As compared to the untreated check: Unlike spotted spurge, mesotrione-based treatments provided statistically significant (P<0.05) control of *Conyza* spp. (0 to 4 plants m^{-2}), relative to the untreated check (20 to 38 plants m^{-2}), for each survey date (Table 8). Conversely, *Conyza* spp. weed densities in the paraquat (alone), paraquat + indaziflam, paraquat + penoxsulam/oxyfluorfen, paraquat + saflufenacil, and flumioxazin + glufosinate treatments (2 to 21 plants m^{-2}) did not differ significantly from the control on 10 April, 10 May, and 20 June (Table 8). Under the conditions of this study (which was characterized by a late initial herbicide application and a relatively dry winter), the use of mesotrione significantly improved (P<0.05) hairy fleabane and horseweed control for up to 4 months after the treatments were initiated.

As compared to flumioxazin + glufosinate: Most of the herbicide programs containing mesotrione (except paraquat + mesotrione [6 oz A] applied sequentially and paraquat + saflufenacil + mesotrione) (<1 plant m^{-2}) differed significantly (P<0.05) from the flumioxazin + glufosinate treatment (7 plants m^{-2}) with respect to *Conyza* densities. On both 10 May and 20 June, paraquat + simazine or rimsulfuron + mesotrione and sequential applications of paraquat + mesotrione (6 or 12 oz A^{-1}) had fewer numbers of *Conyzas* present (0 to 1 plant m^{-2}) relative to the flumioxazin + glufosinate treatment (10 plants m^{-2}).

Summary:

In general, all herbicide treatments evaluated in these studies were able to significantly improve total species weed control, relative to the untreated check, although only a few (paraquat + simazine or rimsulfuron or oxyfluorfen + mesotrione, paraquat + penoxsulam/oxyfluorfen, flumioxazin + glufosinate) were able to provide approximately 80% or greater weed control three to four months after initial herbicide applications were made across both sites. Paraquat + mesotrione, without the inclusion of an additional tank mix partner, provided between 50 and 79% weed control. Sequential applications of paraquat + mesotrione (6 or 12 oz A^{-1}) provided for 85 to 95% weed control between four and five months following the initiation of the studies. Observed weed control in the grape study was likely affected by the differential activity of the evaluated herbicides against individual weed species, particularly spotted spurge and *Conyza* spp. While mesotrione was relatively ineffective at reducing spotted spurge densities, it was statistically better than the flumioxazin + glufosinate standard for controlling horseweed and fleabane.

Table 1. Herbicide treatments included in each of three mesotrione trials in perennial crops in CA in 2012. One study was conducted in walnuts in Wheatland, CA, and two studies were conducted in grapes (table and wine) in Parlier, CA.

Treatment active ingredients (a.i.)	Formulation concentrations (a.i./unit)	Rate
Untreated check	NA	NA
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
mesotrione	4 lb gal^{-1} (0.47 kg L^{-1})	6 oz A^{-1} (0.4 L Ha^{-1})
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
mesotrione	4 lb gal^{-1} (0.47 kg L^{-1})	3 oz A^{-1} (0.2 L Ha^{-1})
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
mesotrione	4 lb gal^{-1} (0.47 kg L^{-1})	6 oz A^{-1} (0.4 L Ha^{-1})
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
mesotrione	4 lb gal^{-1} (0.47 kg L^{-1})	12 oz A^{-1} (0.8 L Ha^{-1})
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
mesotrione	4 lb gal^{-1} (0.47 kg L^{-1})	6 oz A^{-1} (0.4 L Ha^{-1})
simazine	4 lb gal^{-1} (0.47 kg L^{-1})	2 qt A^{-1} (5.6 L Ha^{-1})
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
mesotrione	4 lb gal^{-1} (0.47 kg L^{-1})	6 oz A^{-1} (0.4 L Ha^{-1})
rimsulfuron	25%	4 oz A^{-1} (280 g Ha^{-1})
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
mesotrione	4 lb gal^{-1} (0.47 kg L^{-1})	6 oz A^{-1} (0.4 L Ha^{-1})
oxyfluorfen	2 lb gal^{-1} ((0.23 kg L^{-1})	5 pt A^{-1} (7.0 L Ha^{-1})
paraquat (2X)	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
mesotrione (2X)	4 lb gal^{-1} (0.47 kg L^{-1})	6 oz A^{-1} (0.4 L Ha^{-1})
paraquat (2X)	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
mesotrione (2X)	4 lb gal^{-1} (0.47 kg L^{-1})	12 oz A^{-1} (0.8 L Ha^{-1})
flumioxazin	51%	10 oz A^{-1} (700 g Ha^{-1})
glufosinate	2.34 lb gal^{-1} (0.29 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
saflufenacil	70%	1 oz A^{-1} (70 g Ha^{-1})
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 3 pt A^{-1} (4.2 L Ha^{-1})
saflufenacil	70%	1 oz A^{-1} (70 g Ha^{-1})
mesotrione	4 lb gal^{-1} (0.47 kg L^{-1})	6 oz A^{-1} (0.4 L Ha^{-1})
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
penoxsulam/oxyfluorfen	4.013 lb gal^{-1} (0.48 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
paraquat	2 lb gal^{-1} (0.23 kg L^{-1})	3 pt A^{-1} (4.2 L Ha^{-1})
indaziflam	1.67 lb gal^{-1} (0.20 kg L^{-1})	6.5 oz A^{-1} (0.5 L Ha^{-1})

Table 2. Mean percent (%) weed cover (all species) in Walnut (Wheatland, CA) in response to herbicide treatments. Initial treatments were applied on 21 November, 2011; sequential applications were made on 23 March, 2012. Values followed by a star (*) within a column are statistically different from the untreated check.

	% Weed cover	
Treatment	3/21/2012	4/17/2012
untreated check	93	98
paraquat	69	94
mesotrione 6 oz/A	95	99
paraquat + ***mesotrione 3 oz/A***	47 *	84
paraquat + ***mesotrione 6 oz/A***	35 *	75
paraquat + ***mesotrione 12 oz/A***	22 *	68
paraquat + simazine + ***mesotrione 6 oz/A***	19 *	42 *
paraquat + rimsulfuron + ***mesotrione 6 oz/A***	10 *	31 *
paraquat + oxyfluorfen + ***mesotrione 6 oz/A***	18 *	42 *
paraquat + ***mesotrione 6 oz /A*** (2X)	26 *	8 *
paraquat + ***mesotrione 12 oz /A*** (2X)	18 *	5 *
flumioxazin + glufosinate	17 *	41 *
paraquat + saflufenacil	48 *	79
paraquat + saflufenacil + ***mesotrione 6 oz/A***	29 *	72
paraquat + penoxsulam/oxyfluorfen	8 *	20 *
paraquat + indaziflam	24 *	59 *

Table 3. Mean percent (%) weed control (all species) in Walnut (Wheatland, CA) in response to herbicide treatments. Initial treatments were applied on 21 November, 2011; sequential applications were made on 23 March, 2012. Values followed by a star (*) within a column are statistically different from the untreated check.

	% Weed control		
Treatment	12/19/2011	3/21/2012	4/17/2012
untreated check	0	0	0
paraquat	93 *	26 *	5
mesotrione 6 oz/A	10	2	1
paraquat + ***mesotrione 3 oz/A***	91 *	50 *	14 *
paraquat + ***mesotrione 6 oz/A***	91 *	62 *	24 *
paraquat + ***mesotrione 12 oz/A***	95 *	76 *	30 *
paraquat + simazine + ***mesotrione 6 oz/A***	94 *	79 *	57 *
paraquat + rimsulfuron + ***mesotrione 6 oz/A***	92 *	89 *	69 *
paraquat + oxyfluorfen + ***mesotrione 6 oz/A***	96 *	80 *	58 *
paraquat + ***mesotrione 6 oz /A*** (2X)	93 *	72 *	92 *
paraquat + ***mesotrione 12 oz /A*** (2X)	97 *	81 *	95 *
flumioxazin + glufosinate	99 *	82 *	58 *
paraquat + saflufenacil	96 *	49 *	18 *
paraquat + saflufenacil + ***mesotrione 6 oz/A***	96 *	68 *	27 *
paraquat + penoxsulam/oxyfluorfen	98 *	91 *	80 *
paraquat + indaziflam	96 *	74 *	40 *

Table 4. Mean number of weeds per m^2 cover (all species) in Walnut (Wheatland, CA) in response to herbicide treatments. Initial treatments were applied on 21 November, 2011; sequential applications were made on 23 March, 2012. Values followed by a star (*) within a column are statistically different from the untreated check. The relatively high weed densities observed in the paraquat + mesotrione (3 oz/A) and the paraquat + saflufenacil treatments on 21 March and 17 April can be attributed almost exclusively to a large number of *Conyza* spp. that occurred in one or more replicate plots in each treatment.

	Plants/1m^2	Plants/1m^2	Plants/1m^2
Treatment	1/30/2012	3/21/2012	4/17/2012
untreated check	28	97	34
paraquat	5	133	63
mesotrione 6 oz/A	26	51	20
paraquat + ***mesotrione 3 oz/A***	4	144	125
paraquat + ***mesotrione 6 oz/A***	3	52	46
paraquat + ***mesotrione 12 oz/A***	2	46	33
paraquat + simazine + ***mesotrione 6 oz/A***	2	22	18
paraquat + rimsulfuron + ***mesotrione 6 oz/A***	1	26	22
paraquat + oxyfluorfen + ***mesotrione 6 oz/A***	1	42	30
paraquat + ***mesotrione 6 oz /A*** (2X)	3	82	8
paraquat + ***mesotrione 12 oz /A*** (2X)	2	35	5
flumioxazin + glufosinate	2	33	16
paraquat + saflufenacil	2	339	267
paraquat + saflufenacil + ***mesotrione 6 oz/A***	4	81	40
paraquat + penoxsulam/oxyfluorfen	0	32	15
paraquat + indaziflam	1	64	29

Table 5. Mean percent (%) weed cover (all species) in table and wine grapes (Parlier, CA) in response to herbicide treatments. Initial treatments were applied on 21 February 2012; sequential applications were made on 9 May, 2012. Values followed by a star (*) within a column are statistically different from the untreated check.

	% Weed cover		
Treatment	4/10/2012	5/10/2012	6/20/2012
untreated check	40.8	57.0	98.0
paraquat	17.5 *	32.8	95.0
mesotrione 6 oz/A	27.8	36.0	72.0
paraquat + ***mesotrione 3 oz/A***	8.8 *	13.8 *	74.0
paraquat + ***mesotrione 6 oz/A***	10.0 *	13.8 *	74.0
paraquat + ***mesotrione 12 oz/A***	6.7 *	11.8 *	65.0
paraquat + simazine + ***mesotrione 6 oz/A***	1.5 *	1.4 *	18.0 *
paraquat + rimsulfuron + ***mesotrione 6 oz/A***	10.2 *	6.6 *	40.0 *
paraquat + oxyfluorfen + ***mesotrione 6 oz/A***	8.2 *	13.8 *	64.0
paraquat + ***mesotrione 6 oz /A*** (2X)	11.8 *	16.8 *	14.4 *
paraquat + ***mesotrione 12 oz /A*** (2X)	8.7 *	13.0 *	14.6 *
flumioxazin + glufosinate	9.4 *	10.7 *	48.3 *
paraquat + saflufenacil	13.2 *	18.2 *	78.0
paraquat + saflufenacil + ***mesotrione 6 oz/A***	13.3 *	15.8 *	69.0
paraquat + penoxsulam/oxyfluorfen	5.2 *	5.0 *	55.0 *
paraquat + indaziflam	11.7 *	17.8 *	56.0 *

Table 6. Mean percent (%) weed control (all species) in table and wine grapes (Parlier, CA) in response to herbicide treatments. Initial treatments were applied on 21 February 2012; sequential applications were made on 9 May, 2012. Values followed by a star (*) within a column are statistically different from the untreated check.

	% Weed control		
Treatment	4/10/2012	5/10/2012	6/20/2012
untreated check	0.0	0.0	0.0
paraquat	56.0 *	42.0 *	4.0
mesotrione 6 oz/A	37.0 *	42.0 *	27.0 *
paraquat + ***mesotrione 3 oz/A***	78.0 *	73.0 *	25.0 *
paraquat + ***mesotrione 6 oz/A***	74.0 *	74.0 *	25.0 *
paraquat + ***mesotrione 12 oz/A***	84.0 *	79.0 *	34.0 *
paraquat + simazine + ***mesotrione 6 oz/A***	96.0 *	98.0 *	82.0 *
paraquat + rimsulfuron + ***mesotrione 6 oz/A***	76.0 *	87.0 *	59.0 *
paraquat + oxyfluorfen + ***mesotrione 6 oz/A***	80.0 *	76.0 *	35.0 *
paraquat + ***mesotrione 6 oz /A*** (2X)	71.0 *	68.0 *	86.0 *
paraquat + ***mesotrione 12 oz /A*** (2X)	78.0 *	74.0 *	85.0 *
flumioxazin + glufosinate	66.0 *	81.0 *	48.0 *
paraquat + saflufenacil	65.0 *	65.0 *	21.0 *
paraquat + saflufenacil + ***mesotrione 6 oz/A***	63.0 *	68.0 *	30.0 *
paraquat + penoxsulam/oxyfluorfen	87.0 *	90.0 *	44.0 *
paraquat + indaziflam	69.0 *	69.0 *	43.0 *

Table 7. Mean number of spotted spurge per m^2 in table and wine grapes (Parlier, CA) in response to herbicide treatments. Initial treatments were applied on 21 February 2012; sequential applications were made on 9 May, 2012. Values followed by a star (*) within a column are statistically different from the untreated check.

	Spurge/1m^2	Spurge/1m^2	Spurge/1m^2
Treatment	4/10/2012	5/10/2012	6/20/2012
untreated check	138.7	87.4	94.0
paraquat	172.8	92.0	100.0
mesotrione 6 oz/A	183.3	89.0	100.0
paraquat + ***mesotrione 3 oz/A***	189.5	91.0	98.0
paraquat + ***mesotrione 6 oz/A***	161.7	92.0	95.0
paraquat + ***mesotrione 12 oz/A***	166.0	82.0	85.0
paraquat + simazine + ***mesotrione 6 oz/A***	2.5 *	4.4 *	17.8
paraquat + rimsulfuron + ***mesotrione 6 oz/A***	19.2 *	19.4 *	51.4
paraquat + oxyfluorfen + ***mesotrione 6 oz/A***	142.3	84.0	93.0
paraquat + ***mesotrione 6 oz /A*** (2X)	163.8	99.0	16.4 *
paraquat + ***mesotrione 12 oz /A*** (2X)	174.7	88.4	11.6 *
flumioxazin + glufosinate	2.2 *	0.3 *	4.3 *
paraquat + saflufenacil	179.2	99.0	100.0
paraquat + saflufenacil + ***mesotrione 6 oz/A***	200.0	96.0	100.0
paraquat + penoxsulam/oxyfluorfen	35.0 *	16.8 *	61.6
paraquat + indaziflam	3.5 *	1.4 *	5.4 *

Table 8. Mean number of *Conyza* spp. (hairy fleabane and horseweed) per m^2 in table and wine grapes (Parlier, CA) in response to herbicide treatments. Initial treatments were applied on 21 February 2012; sequential applications were made on 9 May, 2012. Values followed by a star (*) within a column are statistically different from the untreated check.

	Conyza/1m^2	Conyza/1m^2	Conyza/1m^2
Treatment	4/10/2012	5/10/2012	6/20/2012
untreated check	20.0	34.2	38.4
paraquat	11.0	13.0	17.0
mesotrione 6 oz/A	0.3 *	1.2 *	2.4 *
paraquat + ***mesotrione 3 oz/A***	0.5 *	3.4	3.0 *
paraquat + ***mesotrione 6 oz/A***	0.5 *	2.0 *	2.4 *
paraquat + ***mesotrione 12 oz/A***	0.7 *	1.4 *	1.0 *
paraquat + simazine + ***mesotrione 6 oz/A***	0.0 *	0.0 *	0.4 *
paraquat + rimsulfuron + ***mesotrione 6 oz/A***	0.2 *	0.0 *	0.2 *
paraquat + oxyfluorfen + ***mesotrione 6 oz/A***	0.2 *	1.2 *	1.6 *
paraquat + ***mesotrione 6 oz /A*** (2X)	1.5 *	0.8 *	0.4 *
paraquat + ***mesotrione 12 oz /A*** (2X)	0.2 *	0.6 *	0.0 *
flumioxazin + glufosinate	6.8	9.7	10.3
paraquat + saflufenacil	2.0	3.4	4.4
paraquat + saflufenacil + ***mesotrione 6 oz/A***	1.2 *	2.2	2.0 *
paraquat + penoxsulam/oxyfluorfen	1.2 *	3.4	3.8 *
paraquat + indaziflam	11.3	10.0	21.2