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Short title: Florpyrauxifen-benzyl drift

Grapevine, peach, and plum response to simulated florpyrauxifen-benzyl drift

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Abstract

Off-target movement of rice herbicides is a concern in California, where sensitive crops are often grown nearby. Florpyrauxifen-benzyl and triclopyr are auxin-mimics commonly used in rice systems. To steward florpyrauxifen-benzyl around the time of its initial registration in the state, research was conducted to compare the onset of foliar symptoms from simulated florpyrauxifen-benzyl and triclopyr drift onto grapevine, peach, and plum. The rates were 1/200X, 1/100X, 1/33X, and 1/10X of the 29.4 g ai ha^{-1} florpyrauxifen-benzyl and 1/200X, 1/100X, and 1/33X of the 420.3 g ae ha^{-1} triclopyr rice use rates. Herbicides were applied on one side of one- to two-year-old peach and plum trees and one side of established grapevines in 2020 and 2021. The general symptoms for florpyrauxifen-benzyl and triclopyr were similar and included chlorosis, leaf curling, leaf distortion, leaf malformation, leaf crinkling, necrosis, and twisting on leaves. The symptoms from herbicides were observed on both sides of the grapevine canopy, whereas florpyrauxifen-benzyl symptoms on peach and plum were mostly observed on the treated side of the tree. Florpyrauxifen-benzyl and triclopyr symptoms were observed three days-after-treatment (DAT) for grapevines and seven DAT for peach and plum. In all crops, most symptoms persisted through 42 DAT. Some grape clusters showed deformation and dropping of berries. All treated crops gradually recovered during the season regardless of application rates. Because symptoms were relatively minor in peach and plum, this research suggested that application precautions that reduce off-site drift are likely to minimize the occurrence of significant injury. However, grapevines were more sensitive and showed injury symptoms up to 71% at 14 DAT with a 1/10X florpyrauxifen-benzyl simulated drift rate. Therefore, extra precautions such as using drift-management agents and proper wind speed conditions at the time of florpyrauxifen-benzyl applications may be necessary if there are nearby vineyards.

Nomenclature: Florpyrauxifen-benzyl, benzyl 4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoropyridine-2-carboxylate; triclopyr, 2-(3,5,6-trichloropyridin-2-yl)oxyacetic acid; plum, *Prunus domestica* L. PRNDO; peach, *Prunus persica* (L.) Batsch PRNPS; rice, *Oryza sativa* L. ORYSA; wine grape, *Vitis vinifera* L. VITVI

Introduction

California is a major producer of many specialty fruit commodities in the United States (US), including production of more than 99% of the US' nectarines, plums, prunes, raisins, and table grapes [US Department of Agriculture National Agricultural Statistics Service (USDA-NASS) 2024]. Among those, grapes are the most valued crop in California, with more than $5.5B in farmgate value from 350,000 hectares (ha) of wine, table, and raisin grapes [California Department of Food and Agriculture (CDFA) 2024]. The state is recognized as the fourth largest wine producing region in the world (CDFA 2024; Wine-Institute 2024). Collectively, stone fruits such as peach, nectarine, plum, and prune are grown on 40,000 ha with a value of $750M (CDFA 2024; USDA-NASS 2024). The Sacramento Valley and the Northern San Joaquin Valley are the major California production regions for these fruit crops.

California is also the second largest rice producer in the US, with more than 200,000 ha in production (Galvin et al. 2022), which contributes more than $1B to the economy and 25,000 rice-related jobs in the state (CDFA 2024). The primary rice production area is based in the Sacramento and Northern San Joaquin Valleys and typically is water-seeded and grown in continuously flooded conditions during the growing season [University of California Agricultural and Natural Resources (UCANR) 2023].

Weed competition can dramatically reduce rice yields (Hill et al. 2006) and unmanaged weeds also cause harvest difficulties, host pests and diseases, and increase the weed seedbank (Strand 2013). Alongside cultural management methods such as planting certified weed-free rice seed, high seeding rate, and continuous water management, herbicides are crucial for weed management in rice (Inci and Al-Khatib 2024). Once rice fields are flooded, herbicides are generally applied at the day of seeding or before the two-leaf rice growth stage. Most California rice growers follow up with at least one post-emergent herbicide application during the season, usually around the mid-tillering stage of rice. This herbicide application timing usually occurs in May and June, depending on the planting date, rice variety, and environmental conditions (UCANR 2023).

During May and June, grapevine growth stages range from bloom to veraison (Bettiga 2013). Also currently, many varieties of stone fruits are at a growth stage when the endocarp (pit) hardening process begins, and the fruit size increases (LaRue and Johnson 1989). In the Sacramento Valley, these sensitive fruit crop growth stages coincide with the mid-tillering stage herbicide applications in rice (Bettiga 2013; LaRue and Johnson 1989), which increases the risk of off-target damage to these crops.

Herbicide drift is due to the physical movement of spray droplets through the air at the time of application or soon thereafter to any site other than the intended target [UC Integrated Pest Management (UCIPM) Herbicide Symptoms 2024]. Under most circumstances, off-target herbicide exposure is at rates from below 1/100X up to 1/33X of the field application rate of the herbicide (Galla et al. 2019). Significant drift events are most frequently associated with relatively high air temperature and wind speed, low relative humidity, small spray droplet size, and relatively short distances to nearby nontarget crops (UCIPM 2016). The concerns about rice herbicide drift to off-target crops in the Sacramento Valley have been increasing among growers, crop consultants, and researchers (UCANR 2023).

Florpyrauxifen-benzyl (CAS: 1390661-72-9) is a synthetic auxin-type (HRAC/WSSA Group IV) herbicide recently registered (EPA Reg No: 62719-743) for use in California rice. Florpyrauxifen-benzyl can provide selective control of grasses, as well as good control of sedges and broadleaf weeds, which is novel among herbicides in this class (Miller and Norsworthy 2018). Triclopyr (CAS: 55335-06-3) is also widely used to control sedges and broadleaf weeds in rice fields. Triclopyr is a pyridyloxy-carboxylate auxin-type herbicide commercially available as in triethylamine salt and butoxyethyl ester formulations. When synthetic-auxin herbicides are applied to susceptible plants, growth abnormalities, leaf epinasty, tissue swelling, stem curling, chloroplast damage, membrane and vascular system damage, wilting, and necrosis are commonly observed, ultimately leading to plant death (Grossmann 2010).

Synthetic auxins are known for their off-target injuries on vegetables, fruit and nut trees, field and forage crops, ornamentals, and vines (Egan et al. 2014; Haring et al. 2022; Inci et al. 2024; Warmund et al. 2022). In regions like the Sacramento Valley with complex cropping systems, it is important to understand the relative sensitivity of crops to simulated drift rates of florpyrauxifen-benzyl particularly considering the economic impact of California grapevine and wine industries. To steward florpyrauxifen-benzyl around the time of its initial registration in the state, this research was conducted to compare the onset of foliar symptoms from simulated florpyrauxifen-benzyl and triclopyr drift rates onto grapevine, peach, and plum. Additionally, florpyrauxifen-benzyl at simulated drift rates was evaluated on stone fruit and grape, and grape yield was determined in response to florpyrauxifen-benzyl. Triclopyr was included in the grape experiments to allow comparison of florpyrauxifen-benzyl to a grower standard herbicide with the same mode of action group.

Materials and Methods

Study Sites

Three simulated non-target drift experiments were conducted in 2020 and 2021 in newly planted peach (lat. 38°32'19.5"N, long. 121°47'41.3"W) and plum (lat. 38°32'19.6"N, long. 121°47'40.8"W) orchards at the UC Davis Plant Sciences Field Facility; and in an established wine grape vineyard (lat. 38°31'31.3"N, long. 121°47'18.7"W) at the UC Davis Department of Viticulture and Enology Tyree Vineyard near Davis, CA, USA. The orchards were established in March 2020 with 'Coralstar' peach on 'Krymsk 86' rootstock and 'French Improved' prune on 'Krymsk 86' rootstock. All peach and plum trees were planted with 6 m intra-row spacing and 4.2 m between rows. The vineyard was established in 1998 with a bi-lateral double-cordon-trained 'Grenache' wine grape planted with 1.8 m intra-row spacing and 3.6 m between rows.

The soil in the orchard location was a Yolo silt loam with NO_3-N: 57 ppm, Olsen-P: 26 ppm, K: 351 ppm, Na: 21 ppm, Ca: 8 meq/100 g, Mg: 10 meq/100 g, CEC: 19 meq/100 g, OM: 2.7%, and pH: 6.7; and in the vineyard the soil was a Yolo silt loam with NO_3-N: 23 ppm, Olsen-P: 12 ppm, K: 288 ppm, Na: 12 ppm, Ca: 11 meq/100 g, Mg: 9 meq/100 g, CEC: 21 meq/100 g, OM: 2.5%, and pH: 7.1 (UC Davis Analytical Lab, Davis, CA, USA). All trees and grapevines followed standard commercial practices to avoid disease and insect infestations (Strand 1999; Buchner 2012; Bettiga 2013). In all experiments, weeds in the inter-rows were mowed, and intra-row strips were treated with a mixture of rimsulfuron at 70 g ai ha^{-1}, indaziflam at 50 g ai ha^{-1}, oxyfluorfen at 560 g ai ha^{-1}, and glufosinate-ammonium at 450 g ai ha^{-1} plus manufacturer recommended surfactants. Irrigation was applied in all crops through a single-line drip irrigation system with emitters spaced every 30 cm.

Herbicide Applications

Florpyrauxifen-benzyl (Loyant® CA, 25 g ai L^{-1}, Corteva Agriscience, Indianapolis, IN, USA) treatments were applied on 9 June 2020 in the peach and plum orchards. Florpyrauxifen-benzyl and triclopyr (Grandstand™ CA, 359 g ae L^{-1}, Corteva Agriscience, Indianapolis, IN, USA) treatments were applied on 11 June 2020 in the vineyard experiment. In all experiments, florpyrauxifen-benzyl was applied to simulate drift rates of 1/200X (0.5% drift), 1/100X (1% drift), 1/33X (3% drift), and 1/10X (10% drift) of the rice use rate of 29.4 g ai ha^{-1}; the vineyard experiment included triclopyr at three drift rates of 1/200X, 1/100X, and 1/33X of the rice use rate of 420.3 g ae ha^{-1} (Galla et al. 2019). Nontreated control (NTC) plots were also included for comparison in each experiment. The florpyrauxifen-benzyl spray mixtures included methylated seed oil (SUPER SPREAD® MSO, Wilbur-Ellis, Fresno, CA, USA) at 584 ml ha^{-1} and triclopyr spray mixtures included crop oil concentrate (MOR-ACT® COC, Wilbur-Ellis, Fresno, CA, USA) at 1% v v^{-1}.

All herbicide treatments were applied to one side of the tree or vine canopy as one pass (top to bottom for trees and side to side for cordon-trained vines) with a handheld, carbon dioxide-propelled backpack sprayer calibrated to deliver 187 L ha^{-1} at 206 kPa pressure through XR8004-VS nozzle tips (TeeJet® Technologies, Camarillo, CA, USA). The sprayer boom had two nozzles spaced 50 cm apart and spray was delivered based on a three-second pass per tree or vine. Plots were sprayed early in the morning when the weather conditions were not windy to avoid drift to nearby trees or vines. Environmental conditions at the time of the orchard and vineyard applications were 16 C air temperature (temp), 58% relative humidity (RH), and 0.4 m s^{-1} wind speed on June 9, 2020, and 15 C air temp, 60% RH, and 0.5 m s^{-1} wind speed on June 11, 2020, respectively. No in-season auxin-type herbicides were used to avoid potential confusion with florpyrauxifen-benzyl and triclopyr symptoms and injury.

Studies were repeated on 31 May 2021 with a different set of trees or vines in the same field (one-year exposure study, where $n = 8$). In addition, the trees that were treated with florpyrauxifen-benzyl and the vines that were treated with florpyrauxifen-benzyl and triclopyr in 2020 were also retreated in 2021 to evaluate cumulative effects from two-year exposure (two-year exposure study, where $n = 4$) (Bhatti et al. 1995). The two-year exposure experiment was not repeated on the trees initially treated in the second year of the study. All the two-year exposure study methodology was similar to the one-year exposure study described above. Environmental conditions during second-year applications were 18 C air temp, 50% RH, and 0.6 m s^{-1} wind speed. Because the two tree crops were newly planted for this experiment, the grapevine was the only crop with fruit present at the time of herbicide application; berry diameters were 5 to 10 mm, both on June 11, 2020, and May 31, 2021.

Data Collection and Experimental Design

Experiments were arranged in a randomized complete block design with four replicates, where an individual tree or vine was an experimental unit. One- and two-year studies were arranged as separate experiments with a nonadjacent layout in orchards and vineyards. A nontreated tree or three consecutive vines between treated plots was included in the 2020 orchard experiments and in both years in the vineyard as a buffer.

Trees and vines were observed for visual injury symptoms at 6, 12, 24, 48, and 72 hours after herbicide treatment as well as 7, 14, 21, 28, 35, 42, and 90 DAT. Symptomology descriptions of the treated foliage were made according to UC IPM Herbicide Symptoms guidelines (UCIPM Herbicide Symptoms 2024). Injury was rated on a scale where 0 = no injury and 100 = death (Al-Khatib et al. 1992; Bhatti et al. 1995; Sciumbato et al. 2004) according to the following scale:

- 0% = Normal size growth; green pigmentation of all leaves; identical appearance to NTC.
- 1–4% = Normal-sized leaves; less than 5% of the leaves have only one discernible chlorotic spot; overall canopy has faint but indistinct symptoms.
- 5–9% = Slight reduction in leaf size; 2 to 5 diffuse chlorotic spots visible on 5 to 10% of the leaves; up to 5% of leaf curling and crinkling at only young leaves.
- 10–29% = Reduction in leaf size up to 5%; growth restriction and chlorosis at interveinal tissue; symptoms moderate to severe on 10 to 30% of the leaves; less than 30% of the leaf surface chlorotic; 5 to 10% of necrosis, leaf curling, and crinkling; adjacent chlorotic areas merge and result in necrosis at the interveinal areas; up to 5% shoot curling.
- 30–49% = Reduction in leaf size from 5 to 10%; shoot tip growth restricted; symptoms severe on 30 to 50% of the leaves; up to 50% of the leaves with chlorosis; from 10 to 25% necrosis; from 5 to 10% moderate to severe curling at shoots and stems.
- 50–69% = Reduction in leaf size from 10 to 25%; growth significantly restricted; symptoms very severe on 50 to 70% of the leaves; up to 70% of leaf surface chlorotic; from 25 to 50% necrosis, leaf curling, and crinkling; up to 10% stunting and irregular growth at the overall canopy; interveinal tissue-restricted; noticeable stem discoloring with dark red-brown spots up to 15% of the young branches.
- 70–89% = Growth severely restricted; symptoms very severe on 70 to 90% of the leaves; up to 90% of leaf surface chlorotic; necrosis becomes the primary indicator of plant injury; distinguishable leaf loss; from 10 to 50% stunting at the overall canopy; severe leaf distortion and malformation; obvious stem discoloring with dark red-brown-black spots up to 50% of the branches; terminal bud malformation and death.

- 90–99% = Almost no development of leaf and interveinal tissues; symptoms extremely severe on all the leaves; epinasty is extreme throughout the leaves, chlorosis and necrosis widespread; more than 50% of stunting; extremely damaged appearance.
- 100% = Plant dead.

Herbicide symptoms on treated grapevines, peach, and plum trees were compared with NTC plants at each observation. Photos were taken from the treated side of the canopy throughout the growing season to ensure consistency in evaluations. Furthermore, trunk diameters from peach and plum trees were measured using a digital caliper with ± 25 µm accuracy at approximately 25 cm above the ground before the spring growth started in April (spring-data) and at the end of the summer (fall-data) approximately 140 DAT (Martín-Palomo et al. 2019). Tree growth was expressed through trunk diameter growth as a percent increase based on the following formula (Equation 1):

$$Y = \left[\left(\frac{X_f}{X_s}\right) - 1\right] \times 100$$

where Y is the percent increase of trunk diameter, X_f = trunk diameter at the fall, X_s = trunk diameter at the spring. The relative change in herbicide treated trees' trunk diameter was compared to NTC trees' trunk diameter change.

Grapes were hand harvested when berries in NTC plots reached ~20°Brix (1% soluble solids), a common practice for the Northern San Joaquin and Sacramento Valleys grapevine industry (Bettiga 2013). Grape clusters were harvested from all treated vines as well as NTC and weighed for total fruit yield and sugar content from a fruit subsample determined with a handheld refractometer (Haring et al. 2022).

Statistical Analysis

Visible injury ratings and trunk diameter data were subjected to analysis of variance (ANOVA) using 'agricolae' (Mendiburu 2024), 'emmeans' (Searle et al. 1980), and 'dplyr' (Wickham et al. 2023) packages in RStudio Version 2024.04.2+764 (R Core Team 2024), and Tukey's honestly significant difference (HSD) test were used at α = 0.05 to separate means using 'multcomp' package (Bretz et al. 2010), when applicable. Treatment by exposure interactions were analyzed and presented separately due to the different sample numbers (one-year exposure study n = 8 and two-year exposure study n = 4). The herbicide and fractional drift rates were considered fixed factors, while year, block and replication were considered random factors. We used Type II

Wald *F* tests with the Kenward-Roger degrees-of-freedom method and Type III with Satterthwaite's method, when the confidence level at 0.95, and the significance level at α = 0.05 for both ANOVA types. Grape yield and °Brix were analyzed with analysis of covariance at α = 0.05 (Kniss and Streibig 2018). Visual illustration was generated using ‘ggplot2’ package version 3.5.1 in RStudio, when needed (Wickham et al. 2024).

Results and Discussion

Because there were no significant interactions between year and treatment (data not shown), the visual symptom data for 2020 and 2021 were combined for presentation (Table 1, 2, 3). Generally, florpyrauxifen-benzyl and triclopyr symptoms were apparent on all treated vines (Figure 1, 2) and florpyrauxifen-benzyl symptoms were apparent on all treated trees (Figure 3, 4) with symptoms increasing as herbicide rate increased (Table 1, 2, 3). However, the florpyrauxifen-benzyl symptoms were more severe on grapevine than peach and plum, and the most apparent symptoms were observed in the 1/10X florpyrauxifen-benzyl rate. Furthermore, the time to develop florpyrauxifen-benzyl symptoms at all rates was shorter with grapevine than with peach and plum. All crops had slightly more injury after two years of exposure which may suggest cumulative injury.

Florpyrauxifen-benzyl injury symptoms were observed 3 DAT for grapevine and gradually peaked by 42 DAT. Grapevine symptoms were noticeable on both the treated and nontreated side of the vines and the developing leaves and shoots showed more symptoms than fully developed leaves and shoots. The injury symptoms on both sides of the canopy might be due to the cordon training that kept the vine canopy relatively narrower than the tree crops, which allowed more spray solution to reach the nontreated side of the plant. Grapevine symptoms included chlorosis, chlorotic spot, epinasty, leaf curling, leaf narrowing, leaf crinkling, necrosis, necrotic spots, shoot curling, and twisting (Figure 1). Initial chlorosis symptoms turned to necrosis within seven to 14 DAT and eventually to necrotic spots and holes in the leaf. Chlorosis and epinasty, especially in the interveinal areas, and necrosis were characteristic at the 1/33X and 1/10X rates. The 1/10X florpyrauxifen-benzyl drift caused the most severe symptoms on the grapevine, including deformation of grape clusters and individual berries—such as irregular color, shape, and size of berries—compared to NTC. Some of the damaged berries dropped later in the season and looked abnormal or misshapen due to the abortion of individual berries giving the clusters a physically damaged appearance at 1/10X florpyrauxifen-benzyl rate. Two-year treated grapevine showed more abnormal clusters and reduced foliage growth with necrosis throughout the 2021 season. However, even at this high simulated drift rate, these vines gradually recovered by 90 DAT due to a lack of symptoms on the new leaves, except at 1/10X florpyrauxifen-benzyl rate treated vines, which injury symptoms remained throughout the season (data not shown). Triclopyr injury symptoms were observed at 7 DAT for grapevines and gradually peaked at 42 DAT. In general, grapevine injury symptoms from triclopyr were similar to florpyrauxifen-benzyl injury symptoms at the same rates (Figure 2).

Grapevine visible injury ratings tended to be highest at 1/10X rate of florpyrauxifen-benzyl throughout the observation period (Table 1). Other florpyrauxifen-benzyl treatments caused similar injury levels to one another, except 1/33X rate at 42 DAT. Similar to 1/33X florpyrauxifen-benzyl rating at 42 DAT, triclopyr also caused injury of 35% at a 1/33X drift rate. Our results indicated lower levels of visible injury to grapevines from triclopyr at 1/100X and 1/33X rates compared with previous research (Haring et al. 2022; Roberto et al. 2021). This variation could be the result of the application timing, adjuvant selection, environmental conditions at the time of application, and the maturity of vines.

Grapevines treated with 1/33X and 1/10X florpyrauxifen-benzyl and 1/33X triclopyr rates two years in a row had up to approximately 50% yield reduction (Table 4) compared to the NTC which was 22.1 kg vine^{-1} in the one-year exposure study and 19.3 kg vine^{-1} in the two-year exposure study. However, the grape yield from plots treated with 1/200X and 1/100X drift rates of both florpyrauxifen-benzyl and triclopyr was not different than the NTC. Furthermore, grape sugar content tended to increase as florpyrauxifen-benzyl and triclopyr fractional drift rates increased (Table 4) but was only different from the NTC in florpyrauxifen-benzyl at the 1/10X rate in the one-year exposure study, florpyrauxifen-benzyl at the 1/33X and 1/10X rates, and triclopyr at the 1/33X rates in the two-year exposure study. The highest florpyrauxifen-benzyl rate increased °Brix up to ~20% compared to NTC vines that were ~20°Brix at harvest. The higher sugar content with greater herbicide rates were similar with previous research (Haring et al. 2022).

Florpyrauxifen-benzyl symptoms were observed at 7 DAT for peach, and generally peaked at 14 DAT (Table 2). The injury was apparent on the treated side of the peach canopy particularly on developing leaves and terminal buds and initially appeared as chlorosis and leaf curling and included stunting at the 1/10X rate (Figure 3). At approximately 14 DAT, leaf curling became more severe and young shoots also showed curling symptoms. Shoot curling, stunting, and twisting were more apparent at 1/33X and 1/10X rates than at the lower rates. Peach visible injury ratings were up to 50% at 14 DAT with 1/10X florpyrauxifen-benzyl drift rate in the one-year exposure study (Table 2). In the two-year exposure study, florpyrauxifen-benzyl at 1/10X resulted in 61% injury at 28 DAT. However, injury symptoms dissipated through 42 DAT and peach trees appeared normal at the end of the growing season except for trees treated with the 1/10X florpyrauxifen-benzyl rate. Peach trees treated with the1/10X florpyrauxifen-benzyl rate were stunted throughout the growing season and had noticeable symptoms in the following spring.

Injury symptoms were detectable by 7 DAT in plum, and generally peaked at 14 DAT (Table 3). Plum injury symptoms were only distinguishable on the treated side of the tree and symptoms were more apparent on developing leaves and branches. In general, injury symptoms from florpyrauxifen-benzyl on plum were less than on grapevine and peach (Figure 4). Florpyrauxifen-benzyl injury symptoms on plum included chlorosis, leaf curling, necrosis, and stem curling. In addition, minor epinasty symptoms on the tips of developing branches were observed in the following growing season at 1/10X florpyrauxifen-benzyl rate. Visible injury ratings on plum were less than 6% at all rates for all observations in both one- and two-year exposure studies (Table 3). The results showed that plums rapidly recovered from visible injury, even at the highest rate compared to grapevine and peach. Plum trees appeared normal throughout most of the growing season and was the least sensitive crop to florpyrauxifen-benzyl in this study.

Tree trunk diameter changed over year showed no significant interactions between herbicide treatment, exposure for peach or plum trees. In both crops, the relative trunk diameter growth was not statistically different ($P > 0.05$) compared to the NTC trees (data not shown). This indicates that, despite foliar symptoms, trunk diameter was not affected by simulated florpyrauxifen-benzyl drift.

Overall, grapevine was more sensitive to florpyrauxifen-benzyl than peach or plum. The results regarding visible injury recovery suggest that peach and plum can recover from florpyrauxifen-benzyl drift exposure with limited long-lasting injury. Grapevine foliage can recover from a single exposure of the typical drift rates of florpyrauxifen-benzyl and triclopyr. However, florpyrauxifen-benzyl and triclopyr drift at 1/33X and greater rates may result in significant yield reduction despite of foliage recovery from the initial injury symptoms. This simulated drift research was conducted using constant spray volume and variable rates which is different than actual drift scenarios in which both concentration and volume change as herbicides move off-target. Other researchers have suggested droplet concentration can dramatically affect crop injury (Banks and Schroeder 2002); however, understanding the relative sensitivity of the three fruit crops species grown in proximity to California rice fields is highly relevant to stewardship of florpyrauxifen-benzyl in the Sacramento Valley.

Practical Implications

The differences between grapevine, peach, and plum responses to simulated florpyrauxifen-benzyl rates are not surprising because the absorption, translocation, and metabolism of herbicides can vary among plant species (Al-Khatib et al. 1992). In addition, severe symptoms on developing leaves is common since young leaves are metabolically more active and absorb more herbicide than fully developed leaves (Al-Khatib et al. 1992). Realistic herbicide drift rates under field conditions generally range from below 1/100X up to 1/33X of field use rates (Al-Khatib and Peterson 1999); the 1/10X florpyrauxifen rate in this study was added to simulate a worst-case scenario, considering consecutive drift events in a short interval of time, an accidental herbicide application, or herbicide-contaminated tank, events that are much less common than typical drift situations.

Due to its selective grass activity and good control of broadleaves and sedges, florpyrauxifen-benzyl is expected to be widely used in rice fields (Inci 2024). California growers are familiar with management programs for triclopyr, another auxin-type herbicide that has been registered for use in rice for many years. This research suggests that peach and plum trees can be visibly injured by florpyrauxifen-benzyl drift but can recover; however, grapevines are more sensitive and can incur significant damage if exposure rates are sufficient. Because grapevines are more sensitive to florpyrauxifen-benzyl than the tree crops tested, extra precautions should be considered if there are nearby vineyards. Currently, spray drift advisories for florpyrauxifen-benzyl applications only allow ground applications whereas triclopyr is allowed aerially applied (Corteva Agriscience 2024). Likewise, allowable wind speed at the time of application for florpyrauxifen-benzyl is also more restrictive than triclopyr ground applications, which helps to reduce the risk of significant levels of drift from florpyrauxifen-benzyl applications.

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Competing Interests. The authors declare none.

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Table 1. Grapevine injury following simulated drift rates of florpyrauxifen-benzyl and triclopyr in 2020 and 2021.

Herbicide	Rate[b]	One-year exposure[a]						Two-year exposure					
		14 DAT[c]		28 DAT		42 DAT		14 DAT		28 DAT		42 DAT	
		Visible injury (%)											
FPB	1/200x	11	b[d]	10	b	17	b	9	c	9	c	9	b
FPB	1/100x	15	b	12	b	22	b	12	c	12	bc	20	b
FPB	1/33x	17	b	15	b	32	ab	37	b	37	bc	55	a
FPB	1/10x	49	a	46	a	66	a	71	a	66	a	66	a
TRC	1/200x	6	b	9	b	12	b	8	c	13	bc	19	b
TRC	1/100x	7	b	14	b	29	b	8	c	16	bc	22	b
TRC	1/33x	8	b	22	b	35	ab	8	c	34	b	49	a

[a] One-year exposure: Vines were treated in 2020 and the study was repeated on different vines in 2021, where sample size n = 8. Two-year exposure: The vines which were treated in 2020 were retreated in 2021, where sample size n = 4.

[b] Florpyrauxifen-benzyl rate is expressed as a fraction of the rice use rate, 29.4 g ai ha^{-1}. Triclopyr rate is expressed as a fraction of the rice use rate, 420.3 g ae ha^{-1}.

[c] DAT = days after treatment; FPB = florpyrauxifen-benzyl; TRC = triclopyr.

[d] Means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using Tukey's honestly significant difference test.

Table 2. Peach injury following simulated drift rates of florpyrauxifen-benzyl in 2020 and 2021.

	One-year exposure[a]			Two-year exposure		
Rate[b]	14 DAT[c]	28 DAT	42 DAT	14 DAT	28 DAT	42 DAT
	Visible injury (%)					
1/200x	5 b[d]	4 b	1 b	3 b	3 c	3 b
1/100x	9 b	7 b	3 b	7 b	4 bc	4 b
1/33x	10 b	14 b	12 b	10 b	20 b	4 b
1/10x	50 a	37 a	31 a	42 a	61 a	51 a

[a] One-year exposure: Trees were treated in 2020 and the study was repeated on different trees in 2021, where sample size $n = 8$. Two-year exposure: The trees which were treated in 2020 were retreated in 2021, where sample size $n = 4$.

[b] Florpyrauxifen-benzyl rate is expressed as a fraction of the rice use rate, 29.4 g ai ha^{-1}.

[c] DAT = days after treatment.

[d] Means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using Tukey's honestly significant difference test.

Table 3. Plum injury following simulated drift rates of florpyrauxifen-benzyl in 2020 and 2021.

	One-year exposure[a]			Two-year exposure		
Rate[b]	14 DAT[c]	28 DAT	42 DAT	14 DAT	28 DAT	42 DAT
	Visible injury (%)					
1/200x	2 a[d]	0 b	0 a	1 b	0 b	0 a
1/100x	2 a	0 b	0 a	2 ab	0 b	0 a
1/33x	4 a	0 b	0 a	4 ab	1 ab	0 a
1/10x	4 a	3 a	1 a	5 a	3 a	1 a

[a] One-year exposure: Trees were treated in 2020 and the study was repeated on different trees in 2021, where sample size $n = 8$. Two-year exposure: The trees which were treated in 2020 were retreated in 2021, where sample size $n = 4$.

[b] Florpyrauxifen-benzyl rate is expressed as a fraction of the rice use rate, 29.4 g ai ha^{-1}.

[c] DAT = days after treatment.

[d] Means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using Tukey's honestly significant difference test.

Table 4. Grape yield and sugar concentration response to florpyrauxifen-benzyl and triclopyr simulated drift rates.

		One-year exposure[a]				Two-year exposure			
Herbicide	Rate[b]	Yield		Brix[c]		Yield		Brix	
		kg vine^{-1}		°Bx		kg vine^{-1}		°Bx	
FPB[d]	1/200x	22	a[e]	20.7	ab	15.7	ab	20.8	bc
FPB	1/100x	13.8	ab	20.8	ab	12.2	ab	22.4	abc
FPB	1/33x	12.3	b	23.9	ab	11.8	b	24.7	ab
FPB	1/10x	11.2	b	24.9	a	11.3	b	25.4	a
TRC	1/200x	21.8	a	20.6	b	17	ab	20.7	bc
TRC	1/100x	14	ab	20.8	ab	12.4	ab	21.5	abc
TRC	1/33x	12.1	b	22.7	ab	11.9	b	24.2	ab
NTC	–	22.1	a	20.3	b	19.3	a	19.9	c

[a] One-year exposure: Vines were treated in 2020 and the study was repeated on different vines in 2021, where sample size n = 8. Two-year exposure: The vines which were treated in 2020 were retreated in 2021, where sample size n = 4.

[b] Florpyrauxifen-benzyl rate is expressed as a fraction of the rice use rate, 29.4 g ai ha^{-1}. Triclopyr rate is expressed as a fraction of the rice use rate, 420.3 g ae ha^{-1}.

[c] One degree Brix is 1 g of sucrose in 100 g of solution (1°Brix = 1% sugar).

[d] FPB = florpyrauxifen-benzyl; TRC = triclopyr; NTC, nontreated control.

[e] Means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using Tukey’s honestly significant difference test.

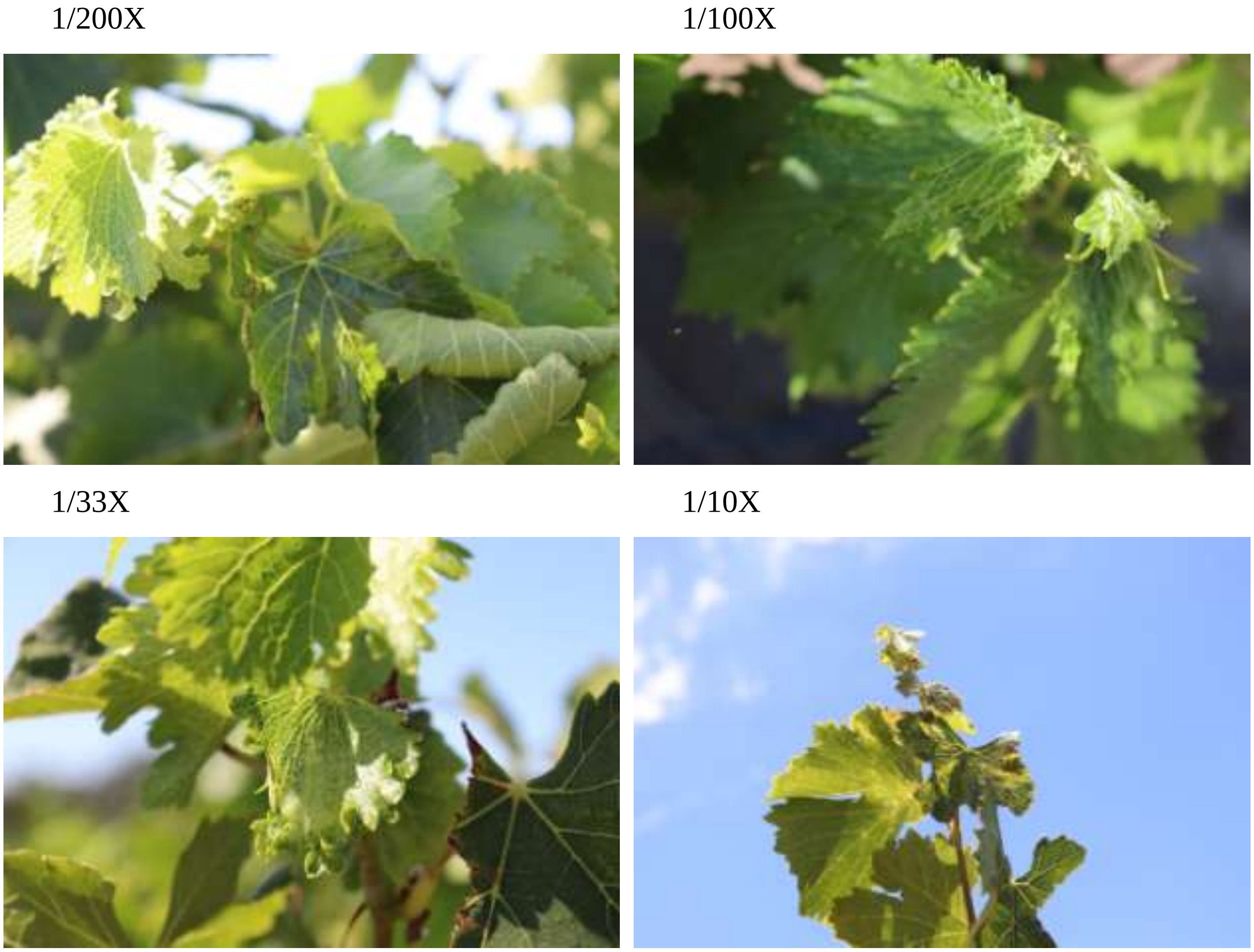

Figure 1. Chlorosis, epinasty, leaf crinkling, necrosis, and shoot curling symptoms on grapevine 28 days after treatment with florpyrauxifen-benzyl at 1/200X, 1/100X, 1/33X, and 1/10X simulated drift rates. Florpyrauxifen-benzyl rice use rate is 29.4 g ai ha^{-1}. Photos were taken on 28 June 2021, in the two-year exposure study.


1/200X

1/100X

1/33X

Figure 2. Chlorosis, epinasty, leaf crinkling, leaf narrowing and twisting symptoms 28 days after treatment with triclopyr at 1/200X, 1/100X, and 1/33X simulated drift rates. Triclopyr rice use rate is 420.3 g ae ha^{-1}. Photos were taken on 28 June 2021, in the two-year exposure study.

1/200X

1/100X

1/33X

1/10X

Figure 3. Chlorosis, epinasty, and necrosis symptoms on peach 28 days after treatment with florpyrauxifen-benzyl at 1/200X, 1/100X, 1/33X, and 1/10X simulated drift rates. Florpyrauxifen-benzyl rice use rate is 29.4 g ai ha^{-1}. Photos were taken on 28 June 2021, in the two-year exposure study.

1/200X

1/100X

1/33X

1/10X

Figure 4. Chlorosis, epinasty, and stem curling symptoms on plum 28 days after treatment with florpyrauxifen-benzyl at 1/200X, 1/100X, 1/33X, and 1/10X simulated drift rates. Florpyrauxifen-benzyl rice use rate is 29.4 g ai ha^{-1}. Photos were taken on 28 June 2021, in the two-year exposure study.