Journal of Integrated Pest Management
RECOMMENDATIONS



# Chemical Control Programs for *Drosophila suzukii* that Comply With International Limitations on Pesticide Residues for Exported Sweet Cherries

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Discussion of research findings necessitates using trade names. This does not constitute product endorsement, nor does it suggest products not listed would not be suitable for use. Some research results included involve use of chemicals which are currently registered for use, or may involve use which would be considered out of label. These results are reported but are not a recommendation for use. Consult the label and use it as the basis of all recommendations.

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J. Integ. Pest Mngmt. 3(2): 2012; DOI: http://dx.doi.org/10.1063/IPM11034

**ABSTRACT.** The recent introduction of *Drosophila suzukii* (Matsumura) into regions of the western United States that produce cherries, *Prunus avium* (L.), has resulted in the need for insecticide-based management programs close to harvest. These treatments have become problematic because of inconsistencies among export markets regarding maximum residue limits (MRLs) that are allowed for different insecticides on imported fruit. As a result, fruit that was treated and harvested in a safe manner according to the U.S. label issued by the Environmental Protection Agency may or may not qualify for export to countries that have MRLs that are lower than those of the United States, or where MRLs have not yet been established. This project addresses this issue by measuring the degradation curves of six insecticides when applied at 7 or 21 d before the initiation of harvest. Based on the results of these tests, we propose a selection of insecticides that can be used for spotted wing drosophila control, with the number of applications and sequence of insecticides used dependent on pest pressure and the number of days required between application and harvest. Three insecticides with favorable characteristics include lambda-cyhalothrin, spinosad and malathion, which allow producers to incorporate the principles of efficacy, fruit susceptibility, and resistance management and still allows for the export of fruit to all major export markets.

**Key Words:** *D. suzukii*, sweet cherry, *Prunus avium*, maximum residue limit, tolerance

Maximum Residue Limits (MRLs) are a measurement of the maximum level of pesticide residues that are allowed on a commodity for human consumption. These levels, often referred to as tolerances, are dictated by government organizations in their efforts to ensure that food products are safe to eat. In the United States, MRLs for all pesticides are established by the U.S. Environmental Protection Agency (USEPA 2011). Initially, laboratory studies are used to determine the no-effect level. This is the level at which no adverse effects to laboratory animals could be detected in a wide range of safety tests. A 100× safety factor is added to the no-effect level to account for potential inaccuracies when converting and scaling up research results from laboratory animals to humans. For most products, an additional 10× safety factor is added to account for potential impacts on infants. As a result, MRLs for treated commodities typically are set at a level at ≈1,000 times lower than the level that would have a negative impact if the person were to be exposed to normally consumed amounts of a food product on a daily basis for their entire life.

All countries have the right to establish their own MRLs, leading to inconsistencies in the amount of residues that are tolerated on food imported from other countries (Table 1; Fig. 1). These differences arise from the use of different datasets and criteria while establishing tolerances, and from different policies regarding default tolerance levels that are used for newer pesticides for which no official tolerance has been established. Thus, a commodity with a legal amount of residue in the country in which it was produced may have an illegal residue in a country to which it is exported. If detected, the shipment will be rejected, and unless an alternative market is found rapidly, may result in a complete economic loss for the exporter.

*Drosophila suzukii* (Matsumura), a direct pest of sweet cherry, *Prunus avium* (L.), recently was introduced into the major production regions of the western United States (Walsh et al. 2011). This new pest has heightened concerns regarding MRLs for countries that import U.S. cherries. Although regions with endemic populations of western cherry fruit fly, *Rhagoletis indifferens* Curran, have customarily applied insecticides during the preharvest period, this pest represents a major programmatic change for regions where *R. indifferens* does not occur. Management programs for *D. suzukii* require one or more insecticide treatments within the last few weeks before harvest to avoid significant economic losses (Bolda et al. 2010). Growers have little choice but to protect their crop from infestation, which can render the fruit unmarketable. The purpose of this project is to address this issue by improving our understanding of the in-field degradation rates of six insecticides that are commonly used for *D. suzukii* so that safe and effective management programs can be developed that still allow for the exportation of fruit.

**Determining Insecticide Programs and Timing.** Despite the recent nature of the discovery of *D. suzukii* in North America (Walsh et al. 2011), a number of insecticide efficacy trials have been performed on stone fruits and berry crops (Bolda et al. 2010, Beers et al. 2011, Bruck et al. 2011). Across all of these studies there is a trend indicating good efficacy with three groups of insecticides: organophosphates, synthetic pyrethroids, and spinosyns. In these studies insecticides belonging to other chemical classes, such as neonicotinoids, anthranilic diamides, insect growth regulators, soaps, and oils have had variable or poor results.

Six commonly used insecticides for *D. suzukii* control were chosen to measure residue degradation curves. The insecticides were chosen by researchers and a group of three representatives of the California Cherry Advisory Board based on efficacy data (Bolda et al. 2010, Beers et al. 2011, Bruck et al. 2011) and use patterns by growers in California, Oregon, and Washington. The insecticides included the pyrethroids lambda-cyhalothrin (Warrior II), fenpropathrin (Danitol), and zeta-cypermethrin (Mustang); the spinosyns spinetoram (Delegate) and spinosad (Success); and the organophosphate, malathion (Malathion) (Table 2). These insecticides have preharvest intervals ranging from 3 to 14 d.

**Table 1. Maximum residue limits (MRLs) of major international importers of cherries for six insecticide active ingredients commonly used for control of *D. suzukii***

| Active ingredient | Lower detection level[a] (ppm) | MRL (ppm) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | United States | Canada | Japan | South Korea | Taiwan | European Union | Australia |
| Fenpropathrin | 0.01 | 5.00 | 0.10 | 5.00 | 0.50 | 0.50 | 0.01 | – |
| Spinetoram | 0.05 | 0.20 | 0.20 | 0.01 | 0.10 | – | 0.05 | 0.20 |
| Malathion | 0.01 | 8.00 | 6.00 | 6.00 | 0.50 | 0.50 | 0.02 | 2.00 |
| Zeta-cypermethrin | 0.01 | 1.00 | 0.10 | 2.00 | – | – | 2.00 | 0.01 |
| Spinosad | 0.05 | 0.20 | 0.20 | 0.20 | 0.05 | 0.20 | 1.00 | 1.00 |
| Lambda cyhalothrin | 0.01 | 0.50 | 0.20 | 0.50 | 0.50 | 0.40 | 0.30 | 0.50 |

MRLs are current as of May 2011. Source: Based on the California Cherry Advisory Board's Online Export Manual, May 2011 (http://www.calcherry.com/industry). Since MRLs change frequently, be sure to check for updated and current MRLs prior to shipping fruit to export markets.

[a] Minimum level at which residues can be detected by equipment in commercial laboratories.

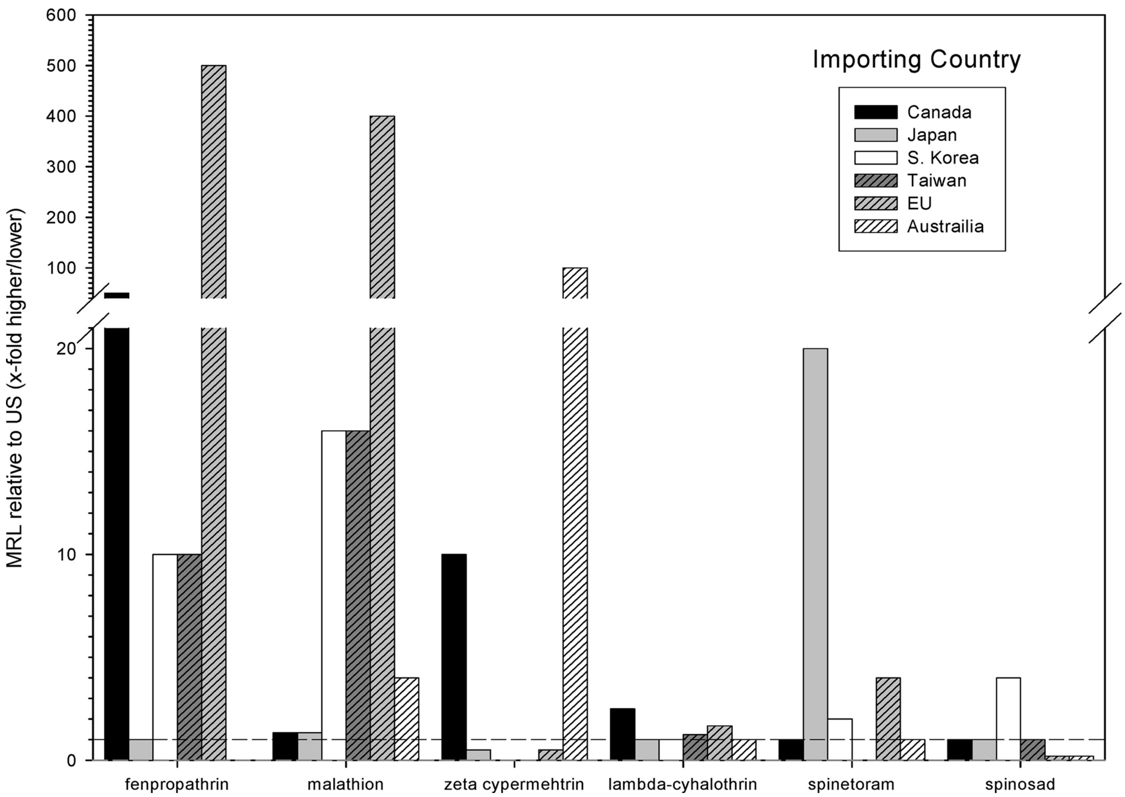


**Fig. 1.** Discrepancy between U.S. MRLs and those for other countries for six insecticides (the x-fold increase from the U.S. MRL). The horizontal line at 1-fold indicates the MRLs are the same; higher numbers indicate that MRL is lower than the one for the U.S.; and numbers $<1$ indicate the MRL for a given country/insecticide is higher than that for the U.S.

**Table 2. Names, manufacturers, use rates, and preharvest intervals for insecticides that were tested for residues**

| Active ingredient | Product and formulation | Manufacturer | Rate form. product[a] | | Preharvest interval[b] (days) |
|---|---|---|---|---|---|
| | | | Per ha | Per acre | |
| Fenpropathrin | Danitol 2.4 EC | Valent U.S.A Corp., Walnut Creek, CA | 1,559 ml | 21.3 fl oz | 3 |
| Spinetoram | Delegate 25 WG | Dow AgroSciences LLC, Indianapolis, IN | 490 g | 7 oz | 7 |
| Malathion | Malathion 8 Aq | Loveland Products Inc., Greeley, CO | 1,754 ml | 1.5 pt | 3 |
| Zeta-cypermethrin | Mustang 1.5 EW | FMC Corp., Philadelphia, PA | 301 g | 4.3 oz | 14 |
| Spinosad | Success 2 SC | Dow AgroSciences LLC, Indianapolis, IN | 584 ml | 8 fl oz | 7 |
| Lambda-cyhalothrin | Warrior II 2 CS | Syngenta Crop Prot. Inc., Greensboro, NC | 187 ml | 2.56 fl oz | 14 |

[a] With the exception of Malathion, application rates were defined as the highest rate allowable per the pesticide label. Due to the risk of phytotoxicity, the Malathion rate was lowered to a level that is generally considered to be effective on *D. suzukii*, but that minimizes the risk of damaging the leaves and fruit.

[b] Based on current labels in the United States as of May 2011.

Treatment timing for the trials was established based on work by Lee et al. (2011) that determined that cherries become susceptible to attack approximately 3–4 weeks before harvest when fruit of the earliest variety starts changing from green to yellow. Cherries become increasingly susceptible from this period of time through full maturation of the fruit. Harvest of all varieties in an orchard may extend up to 3 or 4 weeks, thus the period when fruit must be protected in most orchards is approximately 8 weeks.

## Materials and Methods

Degradation rates of six insecticides used for spotted wing drosophila (Table 2) were measured in two field trials during the spring of 2011. The first trial was located in a mature 'Brooks' cherry orchard in the Edison region of Kern County, CA. The second trial was conducted in a mature 'Champagne Coral' cherry orchard near Arvin, CA. Each of the two trials had five plots. Plot 1 of each trial was sprayed with a tank mix of Delegate and Success on 15 April 2011 (21 d before harvest); plot 2 was sprayed with a tank mix of Danitol, Mustang, and Warrior on 15 April 2011; plot 3 was sprayed with Malathion on 15 April 2011; plot 4 was sprayed with a tank mix of Delegate and Success on 26 April 2011 (7 d before harvest); and plot 5 was sprayed with a tank mix of Danitol and Mustang on 26 April 2011. Plot size in the Brooks trial was three rows wide by 12 trees long, containing at least 12 'Brooks' trees. Plot size in the Coral trial was one row wide by 12 trees long, containing at least six 'Champagne Coral' trees. Both orchards contained pollinizer trees that were not sampled and plots were organized such that plots treated with the same product on different dates were not adjacent to each other to ensure that there was no cross-contamination.

Spray applications were made to simulate commercial practices by using a Pul-Blast (Rear's Mfg. Co., Eugene, OR) air blast sprayer that was calibrated 1 d before the trial to deliver 935 liters/ha (100 gpa) at a ground speed of 4 km/hour (2.5 miles/h). This water volume provided slight runoff of the spray solution on leaves and fruit in the lower 2.5 m of the tree where samples were collected.

For treatments made 21 days before harvest, residue samples were collected 1 hour before treatment and then 0, 3, 7, 14, and 21 days after treatment (DAT). Samples for the 0 DAT measurement were collected after residues had dried, within 2 hours after plots were sprayed. For treatments made 7 days before harvest, residue samples were collected 1 hour before treatment and then 0, 1, 2, 3, and 7 DAT. Each sample consisted of ≈300 g of cherries that were picked at random from the lower 2.5 m of trees in each plot. The total surface area and number of fruit in each sample changed on each sampling date as the fruit matured. At the time of application on 15 April 2011 (≈21 days before harvest) Brooks fruit weighed 3.77 ± 0.22 g and had a diameter of 19.0 ± 1.4 mm, whereas Coral fruit weighed 1.87 ± 0.20 g and had a diameter of 14.0 ± 1.4 mm. On 26 April 2011 (≈7 days before harvest) Brooks fruit weighed 7.16 ± 0.26 g and had a diameter of 25.0 ± 1.9 mm whereas Coral fruit weighed 3.27 ± 0.22 g and had a diameter of 17.6 ± 1.1 mm.

Fruit samples were sent via overnight shipping to PrimusLabs (Santa Maria, CA) in insulated shipping containers with ice-packs for residue analysis. Samples all were processed the day of arrival at PrimusLabs according to standard residue testing protocols outlined in the U.S. Food and Drug Administration Pesticide Analytical Manual, vol. 1 (2009). Residue levels for spinosad and spinetoram were determined through extraction by liquid-liquid partitioning with methylene chloride followed by reversed-phase high-performance liquid chromatography with ultraviolet detection to a lower detection limit of 0.05 ppm (Li-Tain et al. 1997). Additional insecticides were extracted according to FDA LIB 4178 (Luke et al. 1999) and quantified to a level of 0.01 using electrolytic conductivity detectors and gas chromatograph mass spectrometers for zeta-cypermethrin and lambda-cyhalothrin, flame photometric and pulsed-flame photometric detectors for malathion, or thermionic specific detector and gas chromatograph-mass spectrometers for fenpropathrin.

## Results

Analysis of samples taken before application showed that no detectable residues were present for insecticides measured before the initiation of the experiment. Environmental conditions were recorded at the California Irrigation Management Information System, Department of Water Resources, CA weather station in Arvin, located <10 km from both experimental orchards. Average daily high temperatures for each of the 3 weeks of the study ranged from 23.2 to 27.1°C (73.8–80.7°F); average daily lows for each week ranged from 4.8 to 13.2°C (47.0–55.7°F). Weekly averages for solar radiation ranged from 612 to 690 langleys per day. Average maximum daily relative humidity for each week of the study ranged from 72.6 to 85.9%, whereas average minimum daily relative humidity each week ranged from 23.5 to 41.4%. No precipitation occurred during the study period. This weather was very typical for regions where cherries are produced in California.

Applications of the spinosyns Delegate and Success resulted in relatively low residue levels that degraded quickly (Fig. 2a–b). When applied 21 days before harvest, residue levels for both insecticides ranged from 0.06 to 0.19 ppm at zero and three DAT, respectively, and were at or below the limit of detection of 0.05 ppm thereafter. The 21 DAT sample was omitted because of the minimal to nondetectable residue levels during the previous two samples. When applications of Delegate and Success were made 7 days before harvest, similar results were found with residue levels ranging from nondetectable to 0.09 ppm through three DAT, followed by levels below the minimum detection level for both products at both sites.

Residue levels for pyrethroids (Fig. 2c–e) were more variable among products than they were for the two spinosyns; residue levels remained higher for a longer period of time for pyrethroids than they did for spinosyns. Applications of fenpropathrin produced the highest residue levels and had the slowest degradation. When applied 21 or 7 days before harvest, fenpropathrin residue levels at three DAT (the U.S. preharvest interval) ranged from 0.89 to 2.93 ppm. These numbers are well within the United States and Japanese MRLs for fenpropathrin (five ppm), but exceed tolerances for Canada, Korea, Taiwan, and the European Union (0.01–0.5 ppm) (Table 1). Residue levels on both cultivars remained above the MRLs for the latter countries even at 21 DAT.

Applications of lambda-cyhalothrin at 21 days before harvest resulted in residue levels ranging from 0.10 to 0.31 ppm from the time of application through seven DAT (Fig. 2c). At 14 DAT (the U.S. preharvest interval), residue levels ranged from 0.08 to 0.11 ppm. These levels were approximately one-half to one-fifth lower than the MRLs for all major export markets (0.20–0.50 ppm) (Table 1).

Applications of zeta-cypermethrin at 21 days before harvest resulted in residue levels ranging from 0.08 to 0.23 ppm at zero through seven DAT (Fig. 2d). At the preharvest interval of 14 day residue levels ranged from 0.09 to 0.11 ppm. This is within the United States, Japan, and European Union MRLs (1.0–2.0 ppm), but is about equivalent to the Canada MRL of 0.1 ppm and above the Australian MRL of 0.01 ppm (Table 1). Korea and Taiwan do not have MRLs established for zeta-cypermethrin, thus any residue would cause fruit to be rejected. By 21 DAT residue levels ranged from 0.02 to 0.05 ppm, which would have qualified fruit for export to Canada, Japan, and the European Union (0.1–2.0 ppm), but would still result in the rejection of fruit in Australia, Korea, and Taiwan (0.00–0.01 ppm).

Applications of the organophosphate Malathion at 21 and 7 days before harvest at the 1,754 ml/ha (1.5 pt/acre) rate (which is lower than the maximum label rate because of risk of phytotoxicity) resulted in residue levels that ranged from nondetectable to 0.12 ppm through two DAT and from nondetectable to 0.06 ppm at the preharvest interval of three DAT (Fig. 2f). These levels were below the MRLs for all countries (0.50–8.0 ppm) except the European Union (0.02 ppm); the extremely low MRL for the European Union meant that some of the residues found would be unacceptable (Table 1). By seven DAT residue levels for Malathion ranged from nondetectable to 0.02 ppm.

## Conclusions

The ability to produce fruit that is suitable for export depends on a combination of interacting factors, including the interval between

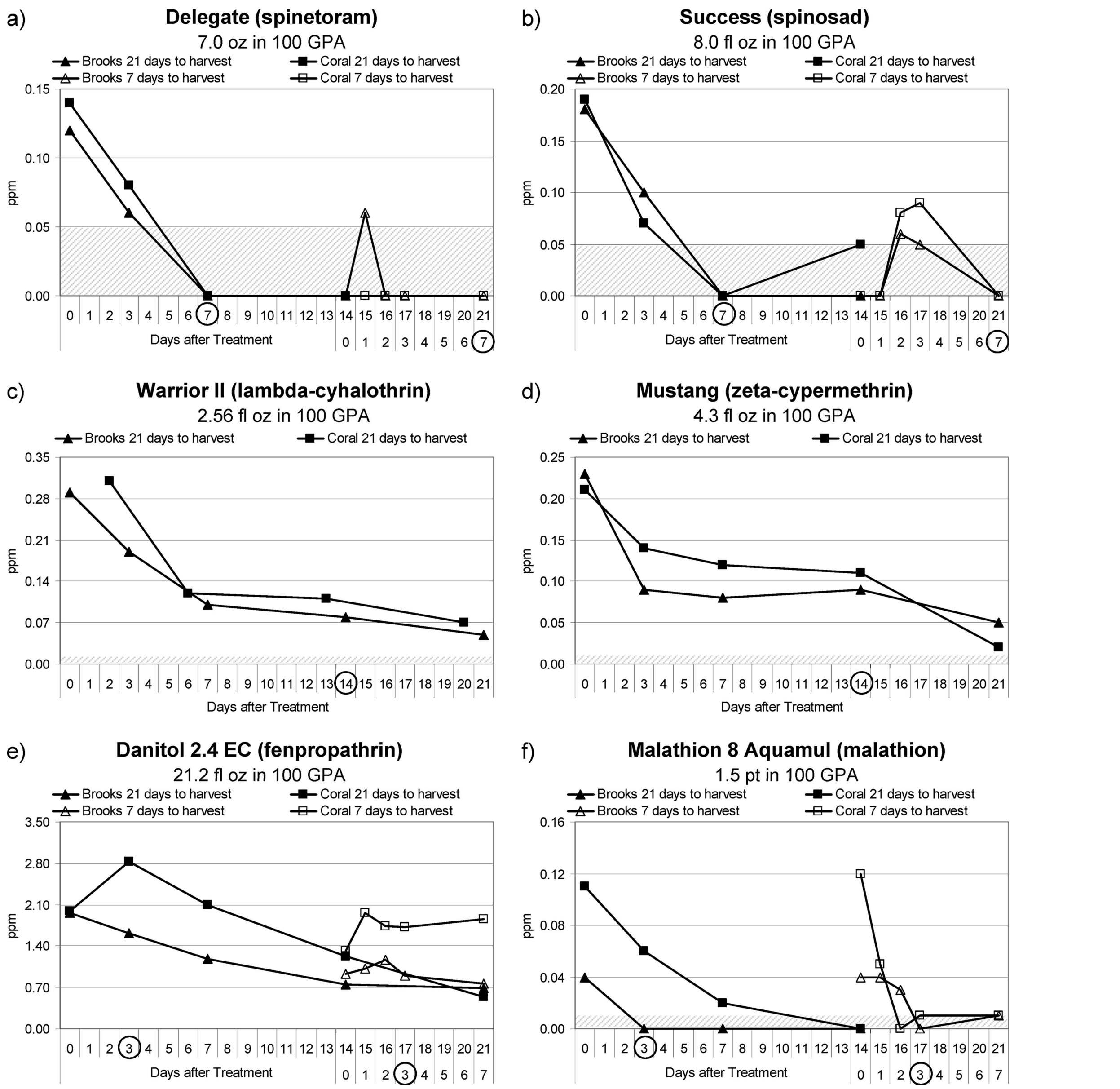


**Fig. 2.** Residue levels of a) Delegate, b) Success, c) Warrior II, d) Mustang, e) Danitol, and f) Malathion following applications at 21 and/or 7 days before the initiation of harvest. The shaded areas indicate the minimum detection level. Non-detectable residue levels are reported as zero. Circled dates indicate the label preharvest interval for sweet cherries in California during 2011.

application and harvest, the inherent persistence of the material(s), and the discrepancy between the U.S. MRL and that of the importing country (Fig. 1). Two factors which argue in favor of a material (outside of its efficacy against spotted wing drosophila) are a short persistence (e.g., the spinosyns) or export MRLs that are similar to the MRLs in the United States. When considering the latter factor, it becomes clear that the extreme differences from the U.S. MRL (e.g., fenpropathrin, with a 500-fold lower MRL in the European Union) likely will be problematic, regardless of how early in the season the material is applied, or how short the persistence. Conversely, if the U.S. MRL is similar to that of other countries (e.g., lambda-cyhalothrin), then the use pattern specified in the U.S. label likely will not cause illegal residues in other countries. The short persistence of the spinosyns, coupled with generally similar MRLs across countries (with the possible exception of spinetoram in Japan) makes these candidates for use near harvest.

Another factor growers and packers may weigh in their choice of insecticides is the value of the export market to their operation versus the value of the protection provided by the insecticide. Although certain residue levels may limit the ability to export fruit, there is a substantial domestic market that is still eligible. The benefit provided by the insecticide is that of keeping fruit free from infestation by *D. suzukii* so that it can be exported; fruit with infestations are unacceptable for exported (a food contamination issue), and in the case of Australia and New Zealand, a quarantine issue.

A longer-term perspective of the problem includes resistance management. The probability of resistance development (at some unknown, future date) has tended to be a lower priority for producers, especially faced with the exigencies of growing the current season's crop. Coupled with this is the uncertainty about whether resistance will develop, or the speed at which it will occur. Resistance has occurred in some insecticide–pest systems at alarming speed, and yet in other cases, prolonged use has resulted in little or no increase in resistance. With some older classes of insecticides, the strategy may be that the material will be withdrawn from the market before it becomes unusable because of resistance. *D. suzukii* could be considered a high risk for resistance development because of its short generation time; conversely, it also could be classed as a low risk for resistance because (in northern regions) the majority of the seasonal phenology occurs after fruit crops are harvested or outside of the treated area. Selection pressure is likely to be very low during that period, diluting any resistant genes that build up during the preharvest period. In mild-winter climates, the life cycle postcherry harvest may be spent in a variety of other crops, where cherry growers are unlikely to have control over the pesticide selection pressure. Establishment in alternate hosts should also delay resistance if any fitness costs are associated with the resistance.

Another factor arguing in favor of the use of multiple active ingredients is the potential for buildup of residues from repeated applications. Rotating to a different active ingredient for each application within a given season should minimize this possibility. This may make a more compelling argument for resistance management with producers than the more nebulous threat of reduced efficacy at some point in the future.

Current management programs for *D. suzukii* are based on three general types of treatments. These are long-residual products with preharvest intervals of ≥14 days, midrange products with a 7–10 day preharvest interval, and products for use close to harvest (1–3 day preharvest interval). Long-residual products are those that would be applied when fruit becomes susceptible to attack by *D. suzukii* at the initiation of color change from green to yellow. Of the products tested, the pyrethroids Danitol, Mustang, and Warrior II all had relatively persistent residues. Of these, Warrior II has the best overall profile as a long-residual product whose application resulted in residue levels in this study that were below the MRLs of all major export markets for cherries. These data also suggest that growers who export fruit should avoid the use of Danitol; Mustang use should be avoided on fruit that is for export to Canada, Korea, and Taiwan.

Of the middle-range products for use 7–10 days before harvest, Delegate and Success both produced residue levels below the lower detection limit of 0.05 ppm at the preharvest interval of 7 days. This suggests that either insecticide is equally valuable for use. However, of these two products, Success has a better MRL profile of 0.05–1.00 ppm for major export markets, whereas MRLs for Delegate include a default MRL in Canada of 0.01 ppm. Taiwan has not yet established MRLs for Delegate, thus any detection would disqualify fruit.

Malathion and Danitol are the only two insecticides in this study that have preharvest intervals of 3 days or less. At a use rate of 1.75 liters/ha (1.5 pt/acre) residue levels for Malathion were low enough to allow for the export of fruit to all major export markets with the exception of the European Union, which has an exceptionally low MRL for this product. Growers planning on shipping fruit to the European Union should probably avoid Malathion because residue levels, even at seven DAT with a below-maximum labeled rate, were still close to the European Union MRL of 0.02 ppm.

Data from this project can be used to outline potential spray programs that should be effective for *D. suzukii* and still allow for the export of fruit. For example, areas requiring three insecticide applications could consider using Warrior II at the initiation of straw, followed by an application of Success 7–14 days before harvest, and followed by an application of Malathion 3–7 days before harvest. This should allow fruit to be shipped to all major export markets with the possible exception of the European Union (depending on how quickly Malathion residues degrade). In areas where only two applications are needed because of reduced pest presence, Warrior II at the initiation of color change from green to yellow could be followed by either Success or Malathion around 7 days before harvest (with the same potential concern for Malathion in the European Union).

When organized in the manner described above, growers should be able to successfully treat for *D. suzukii* in a manner that is effective, that uses multiple modes of action as part of a resistance management program, and that allows fruit to qualify for export. However, because of the complexity of treatment programs for *D. suzukii* and the potential for residue-based export restrictions of fruit, growers should develop plans for management well before harvest. Plans should be made only after consulting with representatives of the packing house and should include multiple options for control programs depending on where the fruit will be shipped and current MRLs at their potential destinations. They should also be flexible enough to account for one or more treatments based on in-field monitoring programs and new information that is developed over time regarding the relationship between pesticide residues and control. For example, the currently proposed program is based on the assumption that treatments, to be effective, are needed approximately every 7 days. However, studies on the relationship between residue levels and residual control of products may have the potential to allow for modifications in the intervals between treatments.

Growers also should be conservative while estimating how data from this project relate to their individual orchards. Residue levels are dependent on many factors such as equipment type, application type, water volume, drive speed, rate used, tree size, canopy density, exposure to sunlight, or precipitation. For that reason researchers that define degradation curves and preharvest intervals for pesticides usually conduct at least eight trials in locations representative of a cross-section of production regions throughout the United States. In the case of this project, despite the fact that this project was conducted under typical commercial field conditions, it is important to remember that this project only represents two orchards in Kern County, CA during the 2011 harvest season, and results are expected to vary among locations throughout the western United States.

## Acknowledgments

We thank Rich Handel, Greg Costa, and Steve Southwick for assistance in project design, and John Pulford, Rick Deckard, Kirschenman Enterprises, Lance Leffler, Ron Leffler, Jose Ramos, Andiamo Ranch, LLC, Stephanie Rill, Minerva Gonzalez, and Rick Ramirez for assistance in project implementation. Funding for this project was provided through a joint agreement by the California Cherry Advisory Board, the Oregon Sweet Cherry Commission, the Washington Tree Fruit Research Commission, and the Okanagan Kootenay Cherry Growers Association of British Colombia.

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*Received 19 December 2011; accepted 11 May 2012.*