OFFICE OF CHEMICAL SAFETY AND POLLUTION PREVENTION

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MEMORANDUM

SUBJECT: Assessment of Usage and Benefits of Malathion (PC # 057701) in Fruit Crops

FROM: Angela Myer, Biologist Monisha Kaul for Angela Myer
Kelly Kulhanek, Biologist Kelly Kulhanek
Biological Analysis Branch

Andrew Lee, Economist Andy C. Lee
Economic Analysis Branch

Rachel Fovargue, Biologist
Science Information and Analysis Branch
Biological and Economic Analysis Division (7503M)

THRU: Monisha Kaul, Chief Monisha Kaul
Biological Analysis Branch

T J Wyatt, Chief, TJ Wyatt
Economic Analysis Branch

Hope Johnson, Chief
Science Information and Analysis Branch
Biological and Economic Analysis Division (7503M)

TO: Carolyn Smith, Chemical Review Manager
Risk Management and Implementation Branch III
Pesticide Re-evaluation Division (7508M)

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SUMMARY

Malathion is a broad-spectrum organophosphate insecticide classified by the Insecticide Resistance Action Committee (IRAC) as a Group 1B Mode of Action insecticide. Malathion is registered on a broad range of fruit crops, including citrus fruit, pear, stone fruit, berries, tropical fruit, and figs.

Malathion has high benefits in the production of cherries and figs. Malathion has a pre-harvest interval (PHI) of only one or three days and is effective against key late-season pests in these crops, including the spotted wing drosophila and the cherry fruit fly in cherries, and dried fruit beetles in figs. In cherries and figs, growers do not have other efficacious tools available for pest control very close to harvest, a critical period for pest control, as other insecticides that are effective for control of common late season berry pests have pre-harvest intervals of 7-14 days. In the absence of malathion, many growers of cherries and figs who rely on malathion to manage late season pest pressures would suffer yield and quality losses.

Malathion provides benefits in cultivated blueberry production that range from high to low, depending on regional climate, harvest timing, and target pest(s). Since only two other chemical classes have similar efficacy to malathion against both SWD and blueberry maggot, malathion provides high benefits where these pests co-occur. Malathion is group 1B insecticide with a very short (1-day) PHI that growers can use as a rotational tool for resistance management. These benefits are moderate-to-high in the southeast because SWD can be detected year-round and frequent rainfall often entails insecticide re-applications to protect ripening fruit. Malathion has moderate benefits in the Northeast and Michigan because SWD is largely a late-season pest so fewer treatments are made for SWD and malathion is not critical for resistance management. In the Pacific Northwest, malathion has low benefits because growers have many alternatives for timing SWD treatments between weekly or bi-weekly harvests, including phosmet (another group 1B insecticide). For the same reason, malathion has low benefits against blueberry maggot. Therefore, malathion has overall moderate benefits in the production of cultivated blueberries across the US. In wild blueberries, malathion has low benefits, because many effective alternatives with a short PHI are available to growers that are likely treating for spotted wing drosophila less often than cultivated berry growers.

Malathion has moderate-to-high benefits as an economical rotational tool for resistance management when used against spotted-wing drosophila in California and Pacific Northwest caneberries. Like blueberries, malathion’s 1-day PHI provides flexibility in application timing, especially for growers who harvest every one to two days. Malathion has high usage, and alternatives from only two other chemical classes are frequently used, including options that are notably more expensive than malathion.

Malathion has moderate-to-high benefits for tropical fruits for control of mealybugs, lace bugs, and scale insects. Broad-spectrum foliar sprays (such as malathion) are typically not

recommended due to negative impacts on natural enemies. However, in cases where target pest populations reach damaging levels and broad-spectrum insecticide usage is warranted, malathion is a frequently used and recommended effective control option. There are few alternatives to malathion for high pressure of these pests. In the absence of malathion, tropical fruit growers would have few alternatives to choose from and may have difficulty managing resistance.

Malathion confers low benefits in the production of other fruit crops, including oranges, pear and strawberry. In oranges, malathion has historically been primarily used to target the Asian citrus psyllid, a key citrus pest that can cause very severe damage and tree death. However, grower surveys have not reported malathion usage targeting Asian citrus psyllid in oranges since 2018, and malathion is not recommended for this use by extension. In pears, malathion is typically used by growers early in the season to control pear psylla. However, growers mainly use kaolin clay, which has extremely high efficacy and is gentle on natural enemies, which provide season-long psylla control and reduce the need for insecticides. In California strawberries, most growers who use malathion target lygus bug in the field after harvest. Lygus bugs are a key pest in strawberries and can cause significant damage to fruit. However, lygus bugs demonstrate resistance to organophosphate insecticides and there are several effective and similarly priced alternatives spanning multiple modes of action that growers use more frequently than malathion for lygus bug control.

INTRODUCTION

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Section 3(g) mandates that the Environmental Protection Agency (EPA or the Agency) periodically review the registrations of all pesticides to ensure that they do not pose unreasonable adverse effects to human health and the environment. This periodic review is necessary in order to consider scientific advancements, changes in policy, and changes in use patterns that may alter the conditions underpinning previous registration decisions. In determining whether effects of pesticide use are unreasonable, FIFRA requires that the Agency consider the risks and benefits of any use of the pesticide.

Although significant mitigation on malathion use has been recently enacted based on biological opinions from the US Fish and Wildlife Service and the National Marine Fisheries Service, the Agency has identified ecological risks to non-target species associated with the use of malathion. The Agency is considering various mitigations to reduce such risks which may include reducing the number of malathion applications allowed per year and mandatory spray drift language to product labels. No human health risks were identified.

This memo describes malathion’s use, usage, alternatives, and benefits in fruit crops to inform the final risk and benefit decision. It is one of four documents assessing the use, usage, and benefits, and alternatives of malathion. Other use sites that are also assessed by the Biological and Economic Analysis Division (BEAD) include 1) an overview memo encompassing alfalfa, rice, pine seedlings, and outdoor residential settings, 2) area-wide mosquito adulticides and USDA-Animal and Plant Health Inspection Service (APHIS) uses 3) and vegetables. These complementary memos are available in the malathion docket (EPA-HQ-OPP-2009-0317).

METHODOLOGY

The benefits of malathion are based on various agronomic factors, chemical characteristics of malathion, and alternative control strategies, which influence how a grower chooses to manage pests and to what extent malathion is important to the user. The unit of analysis is an acre of fruit treated with malathion. BEAD assesses benefits at this unit of analysis both because fruit growers make pest control decisions at the acre- or field-level, and because risks to non-target organisms occur in and around treated fields.

BEAD first provides information on the chemical characteristics of malathion in order to understand the physiological constraints on how the pesticide functions. BEAD then evaluates data on malathion usage to identify use patterns, including variations in regional and seasonal usage such as average application rate, frequency of application, and methods of application. BEAD reviews pesticide usage and existing scientific publications to identify the important target pests and the attributes of malathion that make it useful in the pest control system. The way or ways that growers currently use malathion is the baseline scenario. Together, this information establishes where, when, and how vegetable growers use malathion.

Having identified why growers use malathion, BEAD identifies the likely alternative control strategies by reviewing extension recommendations, grower surveys, and considering economic factors. BEAD assesses the magnitude of the benefits by assessing the biological and economic impacts that growers might experience should they need to employ alternative pest control strategies in the absence of malathion. Economic and biological impacts to a grower in the absence of a pesticide can include monetary costs as well as other lost advantages of the pesticide, such as simplicity of use, flexibility, and utility in resistance management and/or integrated pest management programs. Growers may also face costs with respect to crop damage resulting in yield or quality reductions related to diminished pest control. Physical and/or managerial effort may also increase.

A similar approach is followed to assess the impacts of possible mitigations on the use of malathion to reduce risks. BEAD considers how the restrictions (e.g., reduction in the number of applications) would affect the ability of users to control pests or affect the costs of using malathion.

For these analyses, data are sourced from university extension services, United States Department of Agriculture (USDA) (e.g., publicly available crop production, pesticide usage, and cost data as well as information submitted directly to EPA), public and commercially available grower survey data, public comments submitted to the Agency from various stakeholders, the open literature and BEAD's professional knowledge. The most heavily used source of data from grower surveys of pesticide usage are purchased from Kynetec USA Inc, a private research firm, which provides proprietary pesticide usage data on approximately 60 crops collected annually through grower surveys using a statistically valid approach.

CHEMICAL CHARACTERISTICS

Malathion is an organophosphate, classified by the Insecticide Resistance Action Committee (IRAC) as a Group 1B Mode of Action (MOA) insecticide. Most organophosphates act via contact and ingestion by the target pest, disrupting the normal transmission of nerve impulses; specifically, by inhibiting acetylcholinesterase (Chong *et al.*, 2017).

Malathion was introduced into the market in 1950 and is one of the oldest organophosphates still in use (ATSDR, 2003). Malathion has a broad spectrum of activity against many insects and insect life stages and is a contact insecticide that can provide quick reductions in pest populations in a variety of agricultural and non-agricultural settings.

USE OF MALATHION IN FRUIT CROPS

Malathion is registered for use across a variety of commercially grown fruits: citrus (grapefruits, kumquats, lemons, limes, oranges, tangelos, and tangerines), pome fruit (pears), stone fruits (apricots, cherries, nectarines, peaches), small fruit and berries (blackberries, blueberries, boysenberries, currants, dewberries, gooseberries, grapes, loganberries, raspberries, strawberries), and tropical and subtropical fruits (avocados, figs, guava, mango, papaya, passion fruit, pineapples).

Malathion-containing products registered for use on these sites are formulated as emulsifiable concentrates and can be applied using ground, aerial, chemigation, and handheld equipment. Methods for both ultra-low volume (ULV) and non-ULV applications are allowed on some fruits and maximum application rates vary across these methods. The highest labeled single application rates allowed are on citrus fruits (grapefruit, lemon, limes, oranges, tangelos and tangerines) (7.5 lb a.i./A in California; 4.5 lb a.i./A in other states), avocado (4.7 lb a.i./A) and peaches/nectarines (3 lb a.i./A). The greatest number of applications allowed is 13 per year on guava, mango, papaya, and passion fruit with labeled maximum single application rates for these crops ranging from 0.94-1.25 lb a.i./A. Table 1 lists maximum application allowances for fruit crops surveyed for insecticide usage.

USAGE OF MALATHION IN FRUIT CROPS

The usage values presented in this section are annual averages and are based on the most recent data available from each usage data source. The values presented in this document may differ from those presented in other BEAD documents, such as the Screening Level Usage Analysis (SLUA) or the Summary Use and Usage Matrix (SUUM), because different timeframes are represented in those documents.

Nationally, surveyed fruit growers reported applying almost 200,000 pounds of malathion active ingredient (lbs a.i.) to at least 150,000 total acres treated (TAT) annually from 2017 to 2021 (Kynetec, 2022a, Kynetec, 2022b, USDA NASS, 2022, CDPR 2023). Some small-acreage crops, such as mango, guava, and papaya, are not surveyed at a nationally representative level, and are not included in this estimate; therefore, these national usage values may underestimate total national malathion usage on fruit crops. Malathion usage of all fruit crop sites with nationally representative survey data are summarized in Table 1.

Table 1. National average annual agricultural malathion usage for surveyed fruit crops and current use limits to the number applications allowed per year, 2017-2021.

	Crop	Pounds AI Applied	Total Acres Treated[a]	Percent Crop Treated (PCT)[b]	Single Application Rate (lbs AI/A)	Number of Applications per year	*Max Number of Apps Allowed*
Citrus fruit	Grapefruit	1,000	800	1	1.40	2.1	*3*
	Lemons	<500	<500	<1	2.44	1.0	*3*
	Oranges	53,000	45,000	8	1.18	1.0	*3*
	Tangerines	D	D	D	D	D	*3*
Pome fruit	Pears	15,000	11,000	16	1.39	1.4	*2*
Stone Fruit	Apricots	<500	<500	<1	0.52	1.0	*2*
	Cherries	17,000	13,000	10	1.28	1.1	*4*
	Nectarines	<500	<500	<1	2.97	1.0	*2*
	Peaches	600	<500	1	1.28	1.0	*2*
Small fruit and berries	Blueberries	57,000	53,000[c]	34	1.10	2.0	*3*
	Blackberries	2,300	1,400[c]	18	1.68	1.2	*3 – 4*[d]
	Raspberries	20,000	14,000[c]	60	1.38	1.5	*3 – 4*[d]
	Grapes, Table	900	<500	<1	1.87	1.0	*2*
	Grapes, Wine	1,000	700	<1	1.34	1.0	*2*
	Strawberries	26,000	14,000	16	1.92	2.0	*4*
Tropical & Subtropical fruit	Avocado	<500	<500	<1	2.31	1.0	*2*
	Figs	1,000	800	11	1.72	1.1	*2*

Sources: Kynetec 2022a, Kynetec 2022b; Blueberry, blackberry, raspberry, and tangerine data from USDA NASS, 2023; apricot, nectarine, avocado, and fig data from CDPR 2023

D: information is withheld by USDA-NASS to avoid disclosing data for individual farms

[a] Total Acres Treated is defined as the number of acres treated, accounting for multiple treatments to the same physical acre.

[b] Percent Crop Treated is defined as Base Acres Treated, the number of acres treated at least once, divided by the number of crop acres grown.

[c] Total acres treated is not reported by USDA NASS; this value is calculated by dividing reported pounds of AI applied by the average single application rate.

[d] 24(c) Special Local Needs registrations in Washington and Oregon state allow 4 applications of malathion on caneberries in these states

Among surveyed fruit crops, a few stood out as nationally reporting a substantial percentage of crop acres treated with malathion. As shown in Table 1, in terms of percent crop treated (PCT), berry crops reported high usage: blueberries (34 PCT), blackberries (18 PCT), raspberries (60 PCT), and strawberries (16 PCT). Cherries, pears and figs also reported at least 10 PCT of their national acreage as treated with malathion.

When considering total acres of a crop treated with malathion, oranges also stand out as having notable usage. An average of 45,000 TAT was reported annually from 2017 to 2021 (Table 1). In contrast, malathion has not been highly used in recent years on non-orange citrus fruits, noncherry stone fruits, or grapes terms of PCT or TAT.

Between 2017-2021, average single application rates varied by crop, with the highest rates observed on lemons, nectarines, and avocado. The number of applications of malathion made within a year to a malathion-treated field also varied by crop. One application of malathion was reported on average each year to half of surveyed fruit crops (crops in Table 1). Malathion was applied, on average, the greatest number of times per year to grapefruit, blueberries and strawberries (Kynetec, 2022).

Additional usage data such as regional patterns or timing of applications is provided, when relevant, at the beginning of each crop-specific assessment sections below.

DETERMINATION OF ASSESSMENT SCOPE

BEAD first assessed available usage data to evaluate the role of malathion in commercial fruit crop production. Usage data presented above suggests that malathion may be important in the production of blueberries, blackberries, raspberries, strawberries, cherries, figs, and oranges. A comment from USDA OPMP (2023) suggests that malathion is important in the production of berries (including blueberries, caneberries, strawberries, cherries, and other berries), figs, and other tropical fruits. BEAD, therefore, assesses the benefits of malathion in blueberries, caneberries, strawberries, cherries, figs, other tropical fruits, oranges, and pears. Crops are presented beginning with berries and then in order of higher to lower benefits.

Because of minimal reported usage of malathion in other fruit crops, and because of comments from USDA OPMP (2023) do not suggest that malathion is important in the production of other fruit crops, BEAD concludes that either growers have access to efficacious alternatives to malathion in other fruit crops, or that target pests which malathion is effective against are not economically damaging. For this reason, BEAD concludes that malathion has low benefits in other fruit crops.

BENEFITS OF MALATHION IN FRUIT CROPS

The generic lifecycle of a fruit in commercial production starts with the crop being planted or transplanted, which can be followed by several years without fruit production. In fruiting years, development begins with a vegetative growth cycle when the stem and leaves grow, then a reproductive growth phase that includes bud formation, bloom, petal fall, fruit formation, fruit ripening, and harvest. Insecticide applications to target pests can occur at any stage of this generic crop production cycle and can also be used in pre-harvest cleanup sprays in machine-harvested berries to eliminate arthropod pests which might contaminate harvested fruit (DeFrancesco *et al.,* 2018). The importance of insecticide application timing throughout the growing season of fruit crops varies by crop type, major target pests, and local pesticide resistance patterns within a given geographic area.

Blueberries

Over 150,000 acres of blueberries are grown annually across the U.S. with the highest acreage in Maine (25% of national acres grown), Georgia (15%), Michigan (12%), Washington (10%), Oregon (8%), New Jersey (6%), Florida (6%), California (5%), North Carolina (5%) (USDA NASS 2022). Unique among blueberry producing states, Maine blueberries are predominantly wild-grown types (a low-input production system) and are therefore not surveyed for pesticide usage by NASS chemical use surveys. BEAD assesses this wild grown production system separately from the other states which produce cultivated blueberries. Malathion usage was reported in all of the surveyed states in recent years (survey years: 2017, 2019, 2021) with state-level PCT estimates within individual survey years ranging from 12% to 85% (USDA NASS 2023). Across all surveys within the five-year period, North Carolina reported the highest average annual PCT (61) followed by Georgia (46 PCT) (USDA NASS 2023). Kynetec USA Inc. did not survey blueberry growers during this time period.

According to USDA-OPMP (2023), malathion is of critical importance in berries for the control of spotted-wing drosophila (SWD; *Drosophila suzukii*, family Drosophilidae) through harvest due to its 1-day pre-harvest interval (PHI). SWD is a significant fly pest in all major blueberry regions of the US (Tait et al. 2021) and has led to some growers spraying more frequently during harvest season and selecting insecticides from a limited list with very short (1-day) pre-harvest interval (Rodriguez-Saona et al. 2019b, Tait et al. 2021). Female flies lay eggs in ripening fruit, where developing larvae feed resulting in brown or softened and unmarketable fruit (Tait et. al., 2022). Fruit injured by SWD are also more susceptible to fungi and bacteria (Rossi-Stacconi et al. 2022). Fruits become more susceptible to SWD as they begin to change color and ripening progresses (Rossi-Stacconi et al. 2019). SWD females laying over 300 eggs and maturation of eggs to adults can occur in only eight to ten days, which can lead to rapid increases in the pest population (Sial 2020).

BEAD also expects that growers use malathion for control of the blueberry maggot (BM). BM is a serious blueberry pest, and in some states, processors will reject any load in which even a single maggot is detected (Lynnae et al. 1999, Sial et al. 2023). Berries infested with BM cannot be separated from sound berries and adult flies may emerge upon fruit sale (Lynnae et al. 1999).

Blueberries can be produced either by growing cultivated varietals in a traditional agricultural operation, but they can also be produced by harvesting wild growing berries. Because of differences in end use and production practices between cultivated and wild blueberries, BEAD separately assesses the benefits of malathion in wild blueberry production and in cultivated blueberry production.

Cultivated Blueberry Production

The two major blueberry pests that growers likely use malathion to manage are SWD and blueberry maggot. BEAD assesses the benefits of malathion for the management of each of these pests below.

Spotted-Wing Drosophila

Cultivated blueberry production occurs in the Southeast, on the East Coast, in Michigan, and in the Pacific Northwest. Cultivated blueberry production does not use action thresholds (waiting for pest pressure to reach a certain point before treating) and instead utilizes preventative applications of insecticides for management of SWD; this zero-tolerance approach to SWD infestation is driven by the expectation that fresh market buyers will typically not accept any SWD damage in their berries (Burrack 2018, Yeh et al. 2020, Isaacs et al. 2022a). Insecticides from six modes of action (1A, 1B, 3A, 4A, 5, and 28) are recommended in some or all states for management of SWD in cultivated blueberries (Tables 2-3). Recent resistance screening studies have found that major insecticide classes used to control SWD remain effective in most US regions of fruit production but declining susceptibility to malathion has been documented in certain areas (Van Timmeran et al. 2023, Isaacs et al. 2022b). For use more than three days prior to harvest, growers have access to multiple organophosphate insecticides, including phosmet, which has efficacy equal to or greater than malathion for management of SWD. Because another insecticide with the same mode of action is available for SWD management early in the growing season, BEAD concludes that the benefits of malathion are low in cultivated blueberries more than three days prior to harvest.

During the harvest period, growers have fewer alternatives to malathion. Berries ripen over two to five weeks (Strik et al. 2014), and substantial damage or even rejection of the entire shipment can occur if SWD is not properly managed (UGA extension 2014, Stafne and Williamson 2019). Extension sources in the southeastern US (Sial et al. 2023), New Jersey (Rodriguez-Saona et al. 2019a), and Michigan (Isaacs et al. 2022a) recommend that preventative weekly insecticide applications begin when either local monitoring alerts for the first SWD trap catch occur or when fruit begins to change color. Re-applications of insecticides for SWD following rainfall are also recommended in these growing areas (Rodriguez-Saona et al. 2019a, Isaacs et al. 2022a, Sial et al. 2023). Therefore, the importance of insecticides with short PHIs of three days or less differs between growing regions based on seasonal rainfall patterns and harvest timing.

In the southeastern US, mild winter climates allow SWD pest pressure to be present year-round and infest fruit whenever they become ripe (Sial 2020). Southeastern coastal areas also receive the highest average precipitation in the US during summer months (NOAA-NCEI 2023). Within these areas, frequent thunderstorms are common (Bauer et al. 2020) where blueberries are grown in Georgia (UGA extension undated) and North Carolina (Cline et al. 2019). Since insecticide re-applications are recommended following rainfall to manage SWD (Sial et al.

2023), three applications may occur within a two-week harvest period if one rain event occurs between weekly scheduled treatments. North Carolina State extension recommends that growers plan to rotate between at least two different modes of action to reduce pesticide resistance pressure in SWD and select insecticides with PHIs of three days or less (Burrack and Cline 2019). When a 3-day PHI is sufficient, growers have multiple alternatives to malathion, including phosmet, another group 1B organophosphate with equal or better efficacy to malathion (Table 2).

However, southeastern growers who harvest every two to four days (Stafne and Williamson 2019) may need a pesticide with a 1-day or less PHI for the most flexibility in application timing between harvests and rain events. These growers do not have an alternative organophosphate with a PHI of 1-day or less, though they can utilize pesticides from groups 3A, 4A, 5 and 28 (Table 2). Lacking any organophosphates with as short a PHI as malathion, these growers may need to delay harvest to use phosmet (potentially resulting in overripe fruit or lower gross revenue) or leave their blueberries untreated (risking potential yield loss from uncontrolled SWD). Due to the potential for local differences in rainfall frequency and the duration of blueberry ripening periods, BEAD concludes that malathion provides moderate-to-high benefits for the management of SWD in blueberries grown in the southeast. The flexibility in application timing provided by malathion's 1-day PHI is highest for growers that harvest frequently (every two to four days) *and* apply insecticides frequently due to rainfall.

In New Jersey and Michigan, SWD is primarily a late-season pest, because these states experience less summer rainfall and harsher winters compared to the Southeast. Adult SWD typically become active in mid-June to early July when temperatures are more suitable for population development (Sial 2020). SWD pressure remains low for most berry varieties that ripen earlier in the harvest season (Longstroth and Hanson 2012, Michel et al. 2015, Isaacs et al. 2022a, Pavlis et al. 2023, Shope 2023), so malathion is not important early season. However, for varieties harvested later in the season, SWD pressure can be higher with increased rainfall and humid conditions (Michel et al. 2015, Isaacs et al. 2022a). Several alternatives (groups 3A, 4A, 5 and 28) with comparable efficacy ratings and a 1-day PHI are available to growers (Table 2), but several chemical classes for resistance management may be needed since extension sources recommend weekly preventative insecticide applications (Besançon et al. 2022, Isaacs et al. 2022a). Therefore, BEAD finds that malathion currently provides moderate benefits when used against SWD in New Jersey and Michigan blueberries.

Table 2. Efficacy ratings against spotted wing drosophila (SWD) and pre-harvest intervals (PHI)

in all major US areas of cultivated blueberry production.

Active Ingredient	IRAC MoA	2020 US Survey[1]	Southeast[2]	New Jersey[3]	Michigan[4]	Oregon[5]	PHI
Methomyl	1A	Good-Excellent	Very Good	Good	Excellent	High	3
Diazinon	1B	Good-Excellent	---	Moderate	---	---	7
Malathion		Good-Excellent	Good	Moderate	Good	Med.	1
Phosmet		Good-Excellent	Excellent	Good	Excellent	High	3
Bifenthrin	3A	Good-Excellent	Excellent	Good	Good	---	1
Zeta-cypermethrin		Good-Excellent	Excellent	Good	Excellent	Med.	1
Esfenvalerate		Good-Excellent	---	Good	---	---	14
Fenpropathrin		Good-Excellent	Excellent	Good	Good	Med.	3
Acetamiprid	4A	Fair	Mix	Little/no control	N/A	Med.	1
Imidacloprid		Weak	Mix	Little/no control	---	---	3† or 7‡
Spinetoram	5	Good-Excellent	Excellent	Good	Excellent	High	1* or 3
Spinosad		Good	Good	Good	N/A	High	1
Cyantraniliprole	28	Good-Excellent	Very Good	Good	---	Med.	3
Cyclaniliprole		Good-Excellent	Very Good	Good	Excellent	Low	1

Note: Pre-harvest interval (PHI) in day(s); '---' = Rating not provided (chemical not included in insecticide table or was listed but not rated); 'Mix' = should not be used alone for SWD. References: [1]Tait et al. 2021, [2] Sial et al. 2023, [3]Besançon et al. 2022, [4]Isaacs et al. 2022a (Rating converted as: '****' = Excellent, '***' = Good; '**' or '*' = N/A, not considered important), [5]Mermer et al. 2022 (Relative mortality rankings against SWD in soft-skinned fruits, including blueberry, cherries, blackberries, and raspberries).
†Foliar applied; ‡soil applied; * Recent special local need Section 24(c) labels allow for a shorter 1-day PHI (MI-170002, OR-170016).

In the Pacific Northwest, the 1-day PHI of malathion for SWD management is less important than in other production areas based on harvest frequency. In Oregon, a seven to fourteen-day harvest interval is considered adequate (Cai et al, 2021, DeVetter et. al 2022). Oregon State extension also recommends the use of active ingredients with the greatest efficacy (e.g., phosmet rather than malathion) as the first spray early in the harvest season to reduce the population of immature SWD life stages, and subsequently, reduce the adult population (Mermer et al. 2022). These growers would be able to replace malathion with phosmet in a resistance management program. Therefore, BEAD expects that malathion's benefits are low for SWD management in Pacific Northwest blueberries.

Blueberry Maggot

In the eastern US and the midwest (Michigan), another late-season target pest of malathion applications in cultivated blueberries is likely the blueberry maggot (*Rhagoletis mendax*; family Tephritidae) (Polk et al. 2021, Beckerman et al. 2022, Besançon et al. 2022, Isaacs et al. 2022a, Sial et al. 2022, Garcia-Salazar et al. 2023). While SWD is usually managed preventatively with insecticides every seven days or less, for blueberry maggot management, extension sources in New Jersey (Besançon et al. 2022) and the Midwest (Beckerman et al. 2022) recommends beginning applications ten days after the first adult catch and re-applying every ten days through harvest (Besançon et al. 2022). In the southeast, a similar treatment is recommended every seven days, but treatments may cease if no adults are detected (Sial et al. 2023).

Table 3. Efficacy ratings against blueberry maggot and pre-harvest intervals (PHI) in cultivated

blueberries of the Midwest, New Jersey, and the Southeast.

Active Ingredient	IRAC MoA	Midwest[1]	New Jersey[2]	Southeast[3]	PHI
Methomyl	1A	Good	Moderate	---	3
Diazinon	1B	Good	Moderate	---	7
Malathion		Good	Good	Good	1
Phosmet		Excellent	Good	Excellent	3
Bifenthrin	3A	Good	Moderate	Excellent	1
Zeta-cypermethrin		---	NR	Good	1
Esfenvalerate		Good	Moderate	---	14
Fenpropathrin		Good	NR	Good	3
Acetamiprid	4A	Good	Good	Very Good	1
Imidacloprid		Fair	Good	Very Good	3† or 7‡
Spinetoram	5	Fair	NR	Very Good	3
Spinosad		---	Little/no control	---	1
Cyantraniliprole	28	---	Moderate	---	3
Cyclaniliprole		Good	Moderate	Very Good	1
Cyazypr		---	Moderate	---	3

Note: Pre-harvest interval (PHI) in day(s); NR= Not recommended; '---' = Rating not provided (chemical not included in insecticide table or was listed but not rated). References: [1]Beckerman et al. 2022, [2]Besançon et al. 2022, [3]Sial et al. 2023. †Foliar applied; ‡soil applied.

The benefits of malathion for blueberry maggot management are not as variable as those for SWD since 3-day PHI insecticides would likely be sufficient for targeting this pest during the harvest season. Phosmet, which has a 3-day PHI, is equally or more effective than malathion for blueberry maggot management (Table 3). Other insecticides from Groups 3A, 4A, 5, and 28 have efficacy equal to or better than malathion and have a 1-day PHI (Table 3). For eastern US and Michigan growers, phosmet is likely a suitable replacement for malathion as an efficacious blueberry maggot management option and rotational tool for resistance management, so BEAD concludes that malathion has low benefits for blueberry maggot management for these growers.

Spotted-Wing Drosophila and Blueberry Maggot

Insecticides rated as effective for both SWD and blueberry maggot are recommended for use if both are present in the field near harvest time (Polk et al. 2021, Sial et al. 2023). Both flies infest ripening fruit (Sial et al. 2023). Less chemical options are as effective or more effective than malathion when targeting both pests than when either pest is targeted individually (Appendix A). However, unlike blueberry maggot, SWD can have multiple overlapping generations during the harvest season, and thus, may be a more problematic pest for resistance management in areas where they co-occur (Sial et al. 2023). Extension sources in the eastern US and Michigan recommend weekly preventative sprays with re-applications after rainfall to manage SWD, which is more intensive than the 7- or 10-day interval recommended against blueberry maggot (Beckerman et al. 2022, Besançon et al.2022, Isaacs et al. 2022a, Sial et al. 2023). In the absence of malathion, growers may be left with only two chemical classes (pyrethroids and diamides) that would provide a 1-day PHI and efficacy ratings of at least "good" against one pest and "moderate" against the other (Appendix A). Since few options for targeting both pests are available, BEAD concludes that malathion provides high benefits for targeting SWD *and* blueberry maggot in blueberries, particularly for southeastern growers that harvest frequently (every two to four days) or apply insecticides more than once per week due to rainfall.

Benefits Summary

The importance of insecticides with short PHIs of three days or less differs between growing regions based on seasonal rainfall patterns and harvest timing. Based on these factors, the benefits of malathion for targeting SWD differs between US production areas (moderate-to-high in the Southeast, moderate in Michigan and New Jersey, and low in the Pacific Northwest). The benefits of malathion are low when targeting blueberry maggot but are high when used against both SWD and blueberry maggot where they co-occur. Therefore, BEAD concludes that malathion provides moderate benefits overall for US cultivated blueberry production.

<u>Wild Blueberry Production</u>

Maine produces nearly all the wild blueberries in the United States (State of Maine 2023) and is the top blueberry-producing state in the US. Wild blueberries in Maine (mainly *Vaccinium angustifolium*) are not planted but inhabit large mountaintop fields and glacial outwash plains (Calderwood and Yarborough 2020). The large majority (~99%) of wild berries are harvested for the domestic processed frozen market while cultivated berries are mostly produced for the fresh market (Calderwood and Yarborough 2020, Yeh et al. 2020). While fresh market buyers typically have zero-tolerance to any infestation, processed (frozen) market buyers have some level of tolerance in harvested berries (Burrack 2018, Yeh et al. 2020, Isaacs et al. 2022a), likely attributing to the differences in SWD management between Maine and other states. While cultivated blueberries utilize preventative applications of insecticides, extension sources in Maine recommend insecticide applications based on action thresholds (treating only when certain level of SWD presence is detected in the fields) (Drummond et al. 2019, Calderwood et al. 2021). Drummond et al. (2019) found that insecticide applications decrease SWD infestations in Maine's wild blueberry but more than two applications targeting SWD during the growing season did not have added benefit towards this decrease. Since many of Maine's wild blueberry growers may not be spraying as frequently in the harvest season for SWD, a very low PHI (1-day or less) may be less beneficial in wild blueberry production compared to production of cultivated species.

Table 4: Efficacy ratings against spotted wing drosophila (SWD) & pre-harvest intervals (PHI) in Maine's wild blueberries.

Active Ingredient	IRAC MoA	Efficacy Rating	PHI
Methomyl	1A	---	3
Diazinon	1B	Not Recommended	7
Malathion		Effective	1
Phosmet		Highly effective	3
Bifenthrin	3A	---	1
Zeta-cypermethrin		Highly effective	1
Esfenvalerate		Not Recommended	14
Fenpropathrin		---	3
Acetamiprid	4A	Moderately effective	1
Imidacloprid		Moderately effective	3[†] or 7[‡]
Spinetoram	5	Highly effective	3
Spinosad		Effective	1
Cyantraniliprole	28	Effective	3
Cyclaniliprole		---	1

Note: Pre-harvest interval (PHI) in day(s); '---' = Rating not provided (chemical not included in insecticide table or was listed but not rated); Reference: [1]Fanning and Collins 2022 (Scale: very effective, effective, moderately, effective, slightly effective, not effective).
[†]Foliar applied; [‡]soil applied.

Growers who need to replace malathion for SWD management in wild blueberries can either replace malathion with phosmet, another group 1b insecticide, which has a 3-day PHI and efficacy greater than malathion (Table 4). Because wild blueberry producers do not need a PHI of less than 3 days, BEAD expects that Maine growers will neither suffer reduced management of SWD nor will they lose the ability to utilize group 1B insecticides for resistance management. Therefore, BEAD concludes that malathion provides low benefits when used against SWD in wild blueberry production.

Caneberries

Caneberries are berries that grow on hard, woody stems that are called canes, and include raspberries, blackberries, boysenberries, loganberries, dewberries and marionberries. Approximately 43,000 acres of caneberries are grown annually in the U.S. Over 95% of those acres are accounted for by blackberries and raspberries (USDA NASS, 2022). According to the 2022 Census of Agriculture, blackberries are predominantly grown in Oregon (26% of national acreage), California (19%), Georgia (9%), Texas (7%), and Washington (5%) (USDA NASS, 2022). Raspberries are primarily grown in Washington (46%), California (28%) and Oregon (8%) (USDA NASS, 2022).

Although available usage data sources for caneberries did not align in survey scope[1], significant state-level malathion usage was reported within each of the top three caneberry producing states: California, Oregon, and Washington (Kynetec 2022a, USDA NASS 2023). On average, 30% of California caneberries were treated with malathion from 2017-2021 (Kynetec, 2022a). A 2017 survey of blackberry growers in Oregon indicated malathion was used to treat 18% of acres grown (USDA NASS 2023). Surveys in Washington state for raspberries (years: 2017, 2019, and 2021) reported a maximum single year PCT with malathion near 70% (USDA NASS 2023). In states with available target pest information for caneberries (California and Oregon), malathion was used mostly to target SWD near harvest time – 93% of all caneberry acres treated with malathion were treated at harvest, and 98% of caneberry acres treated with malathion at harvest were treated for SWD (Kynetec 2022a). According to USDA-OPMP (2023), malathion is of critical importance in caneberries for the control of SWD through harvest due to its 1-day post-harvest interval (PHI). Frequent harvesting (every one to two days) can help reduce SWD damage in raspberries (Leach et al. 2017), and like blueberries, a very short PHI (1-day or less) would provide growers with the most flexibility in application timings between caneberry harvests. Therefore, BEAD evaluated the benefits of malathion compared to its alternatives by considering malathion's target pests, extension efficacy ratings, and PHI in major US areas of caneberry production (Table 5).

Damage by SWD in caneberries is similar to that described in blueberries (Bouska and Edmunds 2023) but caneberries are more susceptible to SWD (Rossi-Stacconi et al. 2019). Extension sources recommend that chemical controls be coupled with monitoring efforts for the management of SWD in caneberries; however, neither action thresholds nor application intervals were specified (UC IPM 2015, Bouska and Edmunds 2023, Walton 2023). BEAD notes that applications may also occur from bloom through harvest, and growers report malathion use against a wide variety of other pests that may also be present during these crop stages, including thrips, aphids, moths, leafhopper, and/or lygus bugs (Kynetec, 2022a). However, since malathion usage is largely skewed towards SWD during harvest (Kynetec 2022a), BEAD evaluated malathion's benefits for SWD management against the alternatives based on extension SWD efficacy ratings and PHI. Machine harvesters shake insects off plants during harvest but insecticide applications may be timed one day before (malathion) or during harvest (pyrethrin) to reduce this contamination in caneberries (Bouska and Edmunds 2023, Table 5). UC IPM also lists malathion among the active ingredients for use against SWD in caneberries (UC IPM 2015).

Growers frequently use group 5 (spinetoram and spinosad) and group 3A (pyrethrins, bifenthrin, and zeta-cypermethrin) insecticides for control of spotted wing drosophila (Table 5).

[1] Kynetec 2022b provides survey data from caneberry growers in California and Oregon during each year between 2017-2021; USDA NASS 2023 provides survey data from blackberry growers in Oregon in 2017; USDA NASS 2023 provides survey data from raspberry growers in California and Washington in 2017, 2019, and 2021.

Malathion is the only group 1B insecticide frequently used in caneberry production.

Table 5: Most frequently used insecticides for Spotted Wing Drosophila control in West Coast[1] caneberry at harvest, 2017-2020.

Active Ingredient	**IRAC MoA**	**Average Annual TAT for SWD**	**Cost Per Acre**	**Efficacy Ratings[2] (OR)**	**UC IPM[3] Lists?**	**PHI (d)[2, 3]**
Spinetoram	5	8,600	$43	High	Yes	1
Malathion	1B	5,600	$13	Medium	Yes	1
Pyrethrins	3A	4,800	$18	Not listed	Yes	0
Zeta-Cypermethrin	3A	2,900	$7	Medium	Yes	1
Spinosad	5	2,500	$49	High	Yes	1
Bifenthrin	3A	2,300	$18	Not Listed	No	3

Kynetec, 2022a. Usage information on application timing relative to caneberry harvest only available from 2017-2020.

[1]West Coast region includes California, Oregon, and Washington, however pest-specific usage data is only available for California and Oregon caneberry production.

[2]Relative mortality rankings by Oregon State University extension service (Mermer et al. 2022).

[3]Denotes if UC IPM (2015) extension recommends active ingredient against SWD in caneberry.

Spinetoram and spinosad (spinosyns, group 5) are more selective insecticides compared to malathion and are rated highest in effectiveness against SWD in caneberries in major caneberry-producing states (Table 5). Zeta-cypermethrin is the only pyrethroid (group 3A) broad spectrum insecticide recommended in Oregon and is rated lower than the group 5 chemicals, whereas UC-IPM lists both zeta-cypermethrin and pyrethrins against SWD in caneberries (Table 5). These group 3A active ingredients are notably less expensive than the group 5 chemistries (Table 5).

Malathion is the only organophosphate (group 1B) recommended for SWD management and is the active ingredient with the most usage in caneberries near harvest (Table 5). Zeta-cypermethrin, spinetoram, and spinosad are alternatives with comparable performance and PHIs (1-day or less) to malathion (Mermer et al. 2021). Pyrethrins are recommended by UC-IPM (Table 5) for organic caneberry production in California (UC IPM 2015). However, other extension sources have indicated potential SWD resistance against pyrethrins (Tait et al. 2021, Bouska and Edmunds 2023). In the absence of malathion, growers may be forced to rely more heavily on pyrethroids (group 3A) and increase the risk for resistance issues against this widely used chemical class or use spinosyns (group 5) and face higher pest control costs: spinosyns are about $30 per acre per application more expensive than malathion.

According to USDA NASS (2023), from 2017-2021, raspberry producers had an average gross revenue of $24,000 per harvested acre; BEAD anticipates that fresh market revenues are likely higher than this number, while processing revenues are likely lower. However, according to the 2023 University of California crop budget for fresh market raspberry production, raspberry operating costs are almost as large as raspberry gross revenues, and growers must account for establishment costs before they can start harvesting (Bolda et al, 2023). The University of California budget suggests that fresh market raspberry net operating revenues range from a loss of nearly $14,000 per acre in the establishment year, up to a positive net operating revenue of over $9,000 per acre in the second year of fruit production, with a total four-year net operating revenue of $1,479 per acre over one establishment year and three production years. Four years after planting, the full crop cycle is completed with postharvest removal and preparation for the following crop cycle. If fresh market raspberry growers must replace one application of malathion with spinosyns three times (once in each production year), this is a cost increase of $90 per acre, equivalent to a 6% decrease in net operating revenue over four years. The University of California crop budget also notes that "the risks associated with producing and marketing fresh market raspberries are considered high" (Bolda et al, 2023). BEAD expects the benefits of malathion to be more important for growers who produce lower-revenue processing caneberries than for growers who produce higher revenue fresh market caneberries.

Similar to malathion's use in blueberries, malathion's highest rotational benefits for resistance management may be in areas that use frequent insecticide applications to target SWD in caneberries, due to high potential for resistance developing in intensive insecticide regimens. However, extension sources did not specify the frequency of insecticide applications during the harvest season in California and the Pacific Northwest. Furthermore, there are only five comparable alternatives from two other chemical classes and replacing malathion with one of those two chemical classes could substantially reduce grower net operating revenues. Therefore, BEAD concludes that malathion likely provides moderate-to-high benefits as an economical rotational tool for resistance management when used to target SWD infestations in all major US caneberry production areas.

Strawberries

The majority of strawberry production in the United States occurs in California (64% of acres grown) and Florida (19%) (USDA NASS, 2022). While about 20% of California strawberry acres were treated with malathion from 2017-2021, less than 2.5% of Florida strawberry acres were treated with malathion (Kynetec, 2022b). Because malathion is rarely used in Florida strawberry production, BEAD concludes that growers have sufficient alternatives to malathion, and that the benefits of malathion are low in Florida strawberry production. BEAD focuses its analysis on the benefits of malathion use in California strawberry production. Strawberries are grown in five regions of California (Watsonville/Salinas, Santa Maria, Oxnard, Orange County/San Diego, and the Central Valley), and between these growing regions and crop cycles, strawberries are harvested year-round in the state.

In California strawberries, the vast majority (89%) of acres treated with malathion are treated after first harvest, with a minority (11%) of applications being made after transplanting to first harvest (Kynetec, 2022a). Multiple harvests occur over the harvest period, which ranges from three to seven months (USDA 2021). For applications after first harvest, 79% of acres treated with malathion are targeting lygus bugs also known as the western tarnished plant bug, *Lygus hesperus*) (Kynetec, 2022a, UC-IPM 2018b). Strawberries are hand-harvested every three to five days during peak harvest, which may explain extension recommendations for the use of active ingredient with PHIs of three days or less (USDA 2021). Fruit are transferred to a cooling facility within two hours of harvest and are shipped the same day on refrigerated trucks. According to USDA-OPMP (2023), malathion is of critical importance in berries for the control of SWD through harvest. However, SWD (*D. suzukii*), vinegar flies (*D. melanogaster*; this species and SWD are both fruit flies in the family Drosophilidae), aphids, and thrips are only considered secondary strawberry pests in California (USDA 2021, UC-IPM 2018a,c). Therefore, BEAD focuses on the benefits of malathion for the management of lygus bug in California strawberry acres after first harvest.

Lygus bugs can cause irregularly shaped ("cat-faced") strawberries, distorting fruit, and rendering it unsaleable (USDA 2021). Lygus bug damages are estimated to cause $100 million in economic losses to the strawberry industry annually (USDA 2023). Malathion is used to target the first three nymphal instars of lygus bugs in California, but very high levels of resistance to malathion have been identified in some California growing areas (UC-IPM, 2018b). Insecticide sprays are recommended to be timed to control early nymphal stages of lygus bugs, as registered insecticides are not very effective on adults (UC-IPM 2018b). The only other IRAC Group 1B alternative registered for lygus bug control is naled, but many other alternatives belonging to other IRAC MOA groups are available, such as fenpropathrin and bifenthrin (group 3A), thiamethoxam, and acetamiprid (group 4A), flonicamid (group 29), flupyradifurone (group 4D), and novaluron (group 15), azadirachtin (MoA unknown) (UC-IPM 2018b, USDA 2021, Table 6). In California, growers report using all these pesticides to target lygus bugs (Table 6).

Table 6: Most Frequently Used AIs For Lygus Bug Control in California Strawberry Acres After First Harvest, 2017-2021

Active Ingredient	IRAC MoA	Average Annual TAT for Lygus Bug	Cost Per Acre	Lygus Bug Efficacy Rating
Novaluron	15	33,000	$21	+++
Acetamiprid	4A	18,000	$25	Not listed
Flonicamid	9C	17,000	$26	+++
Azadirachtin	Unknown†	14,000	$24	+ to ++
Bifenthrin	3A	14,000	$18	++ to ++++
Thiamethoxam	4A	10,000	$12	++
Malathion	1B	10,000	$14	+ to +++
Naled	1B	10,000	$13	++
Flupyradifurone	4D	9,000	$29	Not listed
Fenpropathrin	3A	7,000	$16	++ to ++++

Kynetec, 2022a. Usage information on application timing relative to strawberry harvest only available from 2017-2020.

Targets and Control Rating: ++++ = excellent; +++ = good and reliable; ++ =moderate and variable; + = poor; +/- = minimal and often ineffective; ---- = ineffective (USDA 2021). Not listed = the target pests were not listed by in the insecticide efficacy rating table (USDA 2021). †https://irac-online.org/active-ingredient/azadirachtin/

Strawberry growers currently struggle to control lygus bugs in California (USDA 2021). Limited chemical options provide even moderate or varied levels of efficacy, due to local resistance issues in currently registered products (USDA 2021). As chemical control options have become less effective, over 80% of growers in all production districts use bug vacuums against lygus bug (USDA 2021). Novaluron, flonicamid, and flupyradifurone are newer chemistries available to growers as alternatives to malathion (USDA 2021). Novaluron is the chemical with the highest usage (Table 6). As an insect growth regulator, novaluron is best used when applied to nymphs earlier in the season before populations become high, with extension sources recommending timing initial applications prior to egg hatch, when adults are first sighted (UC IPM 2018b, USDA 2021). Flonicamid has a mode of action that affects pest feeding ability, which does not provide immediate reductions of lygus bugs (USDA 2021). Therefore, novaluron and flonicamid may have limited utility within the harvest period when immediate pest reductions are needed between harvests. Flupyradifurone is listed as a chemical option by UC-IPM (2018b), but has low usage compared to other alternatives (Table 6).

Among the older chemistries, bifenthrin and fenpropathrin (group 3A) are considered the most effective alternatives for lygus control but have had widespread resistance in many growing regions (UC IPM 2018b, USDA 2021). However, pyrethroid applications are recommended to be limited to no more than two applications per year to reduce resistance pressure in Lygus bugs and other target pests (UC-IPM 2018b). Pyrethroids tend to be more effective when mixed with neonicotinoids (group 4A), with extension sources specifically recommending acetamiprid and thiamethoxam but these tank mixes should be reserved for situations when one of these neonicotinoids is not effective by itself (UC IPM 2018b, USDA 2023). The efficacy ratings of malathion and other organophosphates (1B) ranges from “poor” to “good and reliable” for the management of Lygus bug, likely attributable to localized resistance from widespread historical use (Appendix 4 in USDA 2021). However, the organophosphates are less expensive compared to the three chemicals with the most usage (Table 6). The only listed IRAC Group 1B alternative for lygus bug control is naled (Table 6). Naled has comparable usage, cost, and performance ratings compared to malathion, but unlike malathion, naled can result in the bronzing of fruit (USDA 2021) and should not be applied in weather above 90º F (UC-IPM 2018b).

In summary, lygus bug is the primary insect pest in strawberries grown in California and is a difficult pest to control with currently available chemical tools. Malathion is relatively inexpensive, and compared to naled (group 1B), has less use limitations for use against lygus bugs. However, due to low usage, resistance concerns and the availability of six alternatives across six different modes of action, BEAD concludes that malathion currently has low benefits for the management of lygus bugs in California strawberries.

Cherries

The majority of cherry producing acres are in California, Oregon, Washington, and Michigan; sweet cherries are predominantly grown on the West Coast and tart cherries in Michigan (USDA NASS, 2022). According to market research data, from 2017-2021, about 20% of cherry acres in California were treated with malathion, while about 10% of Washington cherry acres were treated with malathion and less than 5% of Michigan cherry acres were treated with malathion (Kynetec, 2022a).

The vast majority of malathion applied to cherries is applied from shuck split to harvest (Kynetec, 2022a). Shuck split refers to the papery shuck leftover from flowering splitting away as fruit set begins and occurs after petal fall and just before fruit set (Grant et al., 2023). Malathion is listed as an effective insecticide in commercial settings for the control of SWD, aphids, leafrollers, and the western cherry fruit fly (Grant *et. al*. 2023; Thompson *et. al*., 2023; WSUE, 2023a). Cherry growers use malathion to target flies, including SWD and the western cherry fruit fly (*Rhagoletis indifferens*) (Kynetec, 2022a). Public comment claimed that malathion is critical for SWD control in cherries (USDA-OPMP, 2023). BEAD concludes that the main target pests for malathion in cherry production are spotted wing drosophila and the cherry fruit fly.

SWD damages cherries when females lay eggs in ripening fruit and larval feeding causes fruit flesh to turn brown and soft (Grant *et. al.*, 2022). The western cherry fruit fly results in similar damage to SWD. Western cherry fruit fly is not established in California but is a key direct pest in Michigan and Washington with a zero-tolerance due to quarantine regulations (Grant *et. al.*, 2022; WSUE, 2023a). If a crop is found to contain cherry fruit flies, it is deemed unmarketable and must be disposed of within a quarantine area (USDA-APHIS, 2022).

According to market research data (Table 6; Kynetec, 2022a), the most commonly used insecticides for cherry fruit fly and spotted-wing drosophila control are the pyrethroids (group 3A insecticides), particularly lambda-cyhalothrin and fenpropathrin, the neonicotinoids (group 4A insecticides), particularly imidacloprid, and the spinosyns (group 5 insecticides), spinosad and spinetoram (Table 7). Malathion is the main organophosphate (group 1B) insecticide used to control cherry fruit fly and spotted-wing drosophila, but it is rarely used compared to insecticides in group 3A, 4A, and 5. Despite its relatively low usage, malathion may still play a role in resistance management as the only organophosphate frequently used.

Table 7: Most frequently used AIs for Cherry Fruit Fly and Spotted Wing Drosophila control in California and Washington cherries from split shuck to harvest, 2017-2020

Active Ingredient	IRAC MoA	Average Annual TAT for Cherry Fruit Fly and SWD	Cost Per Acre	PHI (days)[1]
Spinosad	5	72,000	$50	7
Lambda-Cyhalothrin	3A	49,000	$5	3
Imidacloprid	4A	37,000	$3	7
Spinetoram	5	36,000	$51	7
Fenpropathrin	3A	23,000	$22	3
Malathion	1B	10,000	$6	3 (1 for aerial applications)

Kynetec, 2022a. Usage information on application timing relative to cherry harvest only available from 2017-2020.
[1]WSUE, 2023

Spinetoram and spinosad are recommended for use for SWD and cherry fruit fly over malathion due to their higher selectivity and lower impacts on beneficial insects (WSUE, 2023a). Lambda-cyhalothrin and imidacloprid are broad spectrum insecticides and are less recommended due to negative impacts on those beneficial insects that are natural enemies and the high potential for resistance development, however they are much less expensive than alternatives, which likely contributes to the high usage of these active ingredients (UC IPM, 2022; Kynetec, 2022a). Fenpropathrin is also broad spectrum but is more expensive than other group 3A and 4A alternatives, although still significantly less expensive than the group 5 insecticides. Based on extension recommendations from UC IPM (2022) and WSUE (2023a), BEAD expects that growers use multiple group 3A, 4A, and 5 insecticides in rotation.

Insecticide sprays are recommended every 7-21 days for SWD and cherry fruit fly management to ensure coverage of successive generations (WSUE, 2023a). Extension recommends rotating between various modes of action to prevent resistance development (WSUE, 2023a). Malathion is the only group 1B insecticide recommended for SWD or cherry fruit fly control and is the main 1B reported by growers, so it may be important for resistance management. In the absence of malathion, growers may rely more heavily on group 3A and 4A insecticides, increasing resistance risk, or may be forced to pay substantially higher insecticide costs to replace malathion with the group 5 insecticides spinetoram or spinosad.

Malathion has a shorter pre-harvest interval than other insecticides that growers frequently use to target SWD and cherry fruit fly, as it can be used up to 3 days before harvest (1 day for aerially applied ULV applications), while alternatives can only be used up to 7-14 days before harvest (WSUE, 2023a). Growers who need pest control with a short PHI cannot replace malathion with alternatives and may suffer yield or quality loss in the absence of malathion. Yield loss due to cherry fruit fly may be particularly severe as quarantine regulations have a zero-tolerance policy for infestation of packed fruit at market and could represent a total crop loss (WSUE, 2023a).

BEAD concludes that the benefits of malathion are high in cherry production, as in the absence of malathion, growers who currently rely on malathion for control of late season SWD and cherry fruit fly may be unable to control these important pests in the period immediately prior to harvest, facing yield or quality losses despite using more expensive alternative insecticides. For growers with Western cherry fruit fly, pre-harvest flexibility is critical for ensuring their crop is pest-free, as quarantine restrictions could result in an entire crop loss.

Figs

Fig production is concentrated in the state of California which accounts for 90% of the national bearing acreage (USDA NASS, 2022). Usage data from the California Department of Pesticide Regulation reported that on average 11% of fig acres in California were treated with malathion each year (2017-2021; CDPR, 2023) Public comment suggests that malathion is a critical need for fig production as the only available control for dried fruit beetles (USDA-OPMP, 2023). Malathion is listed as the only recommended insecticide for preharvest control of dried fruit beetles (*Carpophilus mutilates; C. hemipterus; C. freemani*), which affect fruit quality and can attract other pests due to fruit spoilage (UC-IPM, 2009). Insecticide applications are typically needed just before harvest, as this is when dried fruit beetles typically infest fruit and cause damage (UC-IPM, 2009). Secondary pests resulting from dried fruit beetle infestations include vinegar flies (*Drosophila melanogaster*) and navel orange worm (A*myelois transitella)*, which also receive some incidental control from malathion use. (USDA-OPMP, 2023; UC IPM, 2009). BEAD concludes that the main target pests of malathion in figs are dried fruit beetles.

Malathion is recommended for pre-harvest orchard sanitation to remove beetles from fruit immediately before harvest (UC IPM, 2009). BEAD concludes that malathion has high benefits in fig production because malathion is the only recommended chemical for preharvest treatment of dried fruit beetle in figs, and in the absence of malathion growers would likely incur economic losses due to reduction in fruit quality.

Other Tropical Fruits
Malathion is claimed to be of high importance for tropical fruits according to stakeholder comments (USDA-OPMP,2023). Tropical fruits are produced mainly in Florida, California, Hawaii, and Texas (USDA-NASS, 2022). Extension specialists from the Universities of Florida and Hawaii reported to USDA-OPMP that malathion is an important rotational product for avocado, guava, mango, papaya, passionfruit, and pineapple (USDA-OPMP, 2023). It was noted that due to the long growing season for many of these crops (e.g., guava, which is vulnerable to pests for 7 months from flowering to harvest), flexibility in the allowed number of applications is important (USDA-OPMP, 2023). Malathion is reportedly used in tropical fruits to target pests including scales, mealybugs, and lace bugs (USDA-OPMP, 2023).

<u>Various Tropical Fruits: Scale Insects</u>
Scale insects can be problematic pests in several tropical fruits including avocado, dragon fruit, lychee, longan, mango, and more (USDA OPMP, 2023; UF IFAS TREC, Undated). Scales feed on plant sap on fruits or stems and some can produce honeydew that results in growth of sooty molds. Fruit feeding can cause scarring to the fruit surface that lowers quality. Scale insects are typically well managed by healthy populations of natural enemies in most systems (Kabashima and Dreistadt, 2014). Events may occur that disrupt natural enemy populations, necessitating chemical control. Foliar sprays of broad-spectrum insecticides with residual activity, including malathion, are not recommended for scale insect control due to negative impacts on natural enemies which will exacerbate scale and other pest problems (Kabashima and Dreistadt, 2014). Instead, thorough plant coverage with non-residual contact insecticides including horticultural oil, insecticidal soap, neem oil and other botanical oils, is recommended (Kabashima and Dreistadt, 2014). Alternatively, soil applications or trunk sprays of systemic neonicotinoid insecticides can minimize environmental contamination compared to foliar sprays and may provide season-long control (Kabashima and Dreistadt, 2014). However, stakeholder comments from the Florida Fruit and Vegetable Association and University of Florida tropical fruit extension experts indicated that malathion is important for scale control in tropical fruits (USDA OPMP, 2023). BEAD is uncertain about the benefits malathion provides for scale insect control in tropical fruit and requests further input from stakeholders during the public comment period.

<u>Pineapple: Mealybugs</u>
Mealybugs also feed on plant sap and produce honeydew (Carrillo *et. al*., 2021). Pineapple mealybug, *Dysmicoccus brevipes*, is a major pest of pineapple due to direct feeding damage and vectoring of pineapple mealybug wilt-associated virus (Egelie and Gillett-Kaufman, 2022). Mealybugs are also typically controlled by natural enemies such as ladybugs, lacewing larva, spiders, and parasitoids (Carillo *et al*., 2021), however, Dole via USDA-OPMP reported that malathion use is critical for mealybug control in Hawaiian pineapples (USDA-OPMP, 2023). In Hawaii, malathion is applied to pineapples three times per year at the maximum allowed application rate (USDA-OPMP, 2023). Malathion's main alternative was, the organophosphate

diazinon in the 50W formulation, which was voluntarily terminated by the manufacturer in response to worker safety concerns (Joy at el., 2013). Growers are evaluating spirotetramat (IRAC group 23) as an alternative, but it is more costly than malathion (USDA-OPMP, 2023).

Avocado: Lace Bugs

Lace bugs on avocado are targeted with malathion (USDA-OPMP, 2023). University of Hawaii extension specialists reported that malathion is used to target the recently introduced avocado lace bug (*Pseudacysta perseae*). Avocado lace bugs are present in California and the southeastern US but were discovered in Hawaii in 2020 (Mead and Peña, 2020; Wright, 2020). Adult and juvenile life stages feed on plant sap from leaves, resulting in yellowing and leaf dieback in high infestations (Wright, 2020). This damage does not typically negatively impact tree health or yield, but heavy feeding can cause defoliation or reduce fruit yield (Wright, 2020; Matsunaga and Silva, 2022). Insecticidal soaps and oils are the preferred chemical control due to their gentleness on natural enemies but are typically only effective on low populations (Wright, 2020). Broad spectrum insecticides in general are recommended as a last resort due to negative impacts on beneficial organisms but may be necessary if populations become large (Wright, 2020). For large lace bug populations, systemic applications such as imidacloprid (IRAC group 4A) are also recommended for avocado lace bug control (Mead and Peña, 2020; Wright, 2020). Malathion is also recommended by extension as effective for lace bug control after flowering is completed to reduce impact on pollinators (Matsunaga and Silva, 2022).

Benefits Summary

Benefits of malathion for use by tropical fruit growers vary depending on the crop and pests. Although no quantitative usage data is available, and very limited extension information available, malathion is claimed to be of high importance by extension experts from Universities of Florida and Hawaii and other stakeholders (USDA-OPMP, 2023). Generally, extension recommendations suggest that most target pests of malathion in tropical fruits can be well managed by cultural controls and natural enemies, but if pest populations reach damaging levels, then malathion is an effective low cost control option. BEAD concludes that malathion is likely of moderate-to-high benefit for tropical fruit production, particularly for mealybug control on pineapple and lace bug on avocado. The Agency urges tropical fruit stakeholders to submit more evidence of malathion’s benefits during the public comment period.

Oranges

Most orange production occurs in Florida and in California, but malathion is rarely used in California orange production (Kynetec, 2022b; USDA NASS, 2022). From 2017-2021, about 10% of Florida orange acres were treated with malathion, while less than 1% of California orange acres were treated with malathion over the same period (Kynetec, 2022b).

Malathion is recommended as a broad-spectrum chemical control option for Heteropteran insects such as the citron bug (*Leptoglossus gonagra*), the leaf-footed plant bug (*L. Phyllopus* *and L. zonatus*), and the southern green stink bug (*Nezara viridula*) (Martini and Diepenbrock, 2023). However, Florida orange growers rarely reported targeting these pests (Kynetec, 2022a). Growers only sporadically reported targeting citrus mealybug and ants with malathion (Kynetec, 2022a), and malathion is not recommended for either of these target pests.

The majority (57%) of Florida orange acres treated with malathion from 2017-2021 were treated for Asian citrus psyllid (ACP; *Diaphorina citri*) (Kynetec, 2022a). ACP is a key pest in citrus because it vectors citrus greening disease, also known as huanglongbing (HLB). There is no known cure for HLB, which causes reduced fruit set and quality, extensive root damage, and can ultimately result in tree death in as little as five years (Dewdney *et. al*., 2023, Grafton-Cardwell *et. al*., 2023a). Keeping ACP numbers as low as possible is critical to prevent transmission of HLB, so citrus growers apply up to 15 applications of different broad-spectrum insecticides per year (Grafton-Cardwell *et. al*., 2023b). There are several broad-spectrum foliar insecticides of various modes of action that are recommended for this use including IRAC group 3A (fenpropathrin, beta-cyfluthrin, cyfluthrin, zeta-cypermethrin), group 4A (thiamethoxam), group 6 (abamectin) and group 28 (chlorantraniliprole) (Grafton-Cardwell *et. al*., 2023a).

Florida orange growers reported using malathion to target ACP in 2017 and 2018 but not from 2019 through 2021 (Kynetec, 2022a). Malathion has been recommended for use against ACP in residential settings in California (University of California, Undated), but Florida extension recommendations (Diepenbrock *et al*., 2023), where the bulk of applications occur, do not recommended malathion for commercial production. Other IRAC Group 1B organophosphate insecticides are recommended for commercial management of ACP, such dimethoate and phosmet (Diepenbrock *et al.,* 2023). Organophosphate usage for ACP in Florida oranges declined between 2017 and2021, and in recent years organophosphates have been rarely reported to be used for control of ACP (Kynetec, 2022a).

Because orange growers infrequently report using malathion for any of the pests for which malathion is recommended, and due to the availability of efficacious alternatives which are more frequently used, BEAD concludes that malathion has low benefits in orange production.

Pears

Pear production mostly occurs in Washington (37% acres bearing), Oregon (32%), and California (19%) (USDA NASS, 2022). About 35% of Washington pear acres were treated with malathion from 2017-2021; use of malathion was not observed in California or Oregon during that same period (Kynetec, 2022b).

Malathion is typically applied to pears during dormancy or delayed dormancy (Kynetec, 2022a). These are plant growth stages that coincide with early season stages of the pear life cycle, before buds start to form. Pear growers mostly used malathion to target the pear psylla (*Cacopsylla pyricola*) (Kynetec, 2022a). Pear psylla is one of the most serious pests in commercial settings. Pear psylla vectors a bacterial disease (pear decline disease) that can cause loss of crop, tree vigor, or tree loss. Psylla feeding and honeydew production can degrade fruit quality or cause lasting stunting and defoliation (DuPont *et. al.*, 2023; Varela *et. al.*, 2012). Early season insecticide applications should occur as soon as possible to prevent pear psylla from colonizing the orchard (WSUE, 2023b). BEAD concludes that the main target pest for malathion in pear production is the pear psylla during dormancy and delayed dormancy in Washington.

Growers report using broad spectrum insecticides, including malathion and lambda-cyhalothrin, for control of pear psylla during the dormant and delayed dormant periods, but more frequently report using kaolin clay, petroleum oil, and sulfur (Table 8).

Table 8: Most Frequently Used AIs For Pear Psylla Control in Dormant and Delayed Dormant Stages in Washington Pears, 2017-2021

Active Ingredient	IRAC MoA	Average Annual TAT for Pear Psylla	AI Avg. Cost / Total Area (US$/acre)	Pre-Bloom* Efficacy Rating
Kaolin Clay	Repellant	28,000	73	4
Petroleum Oil	Membrane disruptor	19,000	18	4
Sulfur	Unknown	9,000	12	4
Malathion	1B	8,000	11	NR
Lambda-cyhalothrin	3A	8,000	5	1-2

Kynetec, 2022a. Usage information on application timing relative to pear dormancy only available from 2017-2020.
* "Pre-Bloom" includes dormant, delayed dormant, and tight cluster stages. Efficacy rated on a scale of 1-4 with 4 being the most effective; NR = not recommended. (WSUE, 2023b). Includes chemicals reported with a sample size > 1 farm and > 200 total area treated (acres).

Malathion is not recommended by extension for pear psylla management in Washington, Oregon, or California (WSUE, 2023b; Varela et. al., 2012; Thompson et. al., 2023). Rather than use broad spectrum insecticides for pear psylla control, extension recommends that narrower spectrum chemistries be prioritized for conservation of natural enemies (WSUE, 2023b). Although these softer chemistries are more expensive, if natural enemies are well conserved, they can provide excellent psylla control later in the season, lowering the need for later insecticide applications and saving costs in the long run (WSUE, 2023b). Softer chemistries applied during the dormant and delayed dormant seasons include particle films like kaolin, kaolin clay and diatomaceous earth. Particle film applications during dormancy and delayed dormancy repel pear psylla adults and are very effective at reducing pear psylla adult colonization and egg laying by 80-100% (WSUE, 2023b). Petroleum oil is also recommended for use against pear psylla in dormancy and delayed dormancy (WSUE, 2023b). Petroleum oil can be applied on its own but is often mixed with other chemistries such as lime sulfur to increase efficacy against pear psylla and/or target other pests such as mites, scales, and grape mealybug

(WSUE, 2023b). Kaolin, kaolin clay, diatomaceous earth, petroleum oil and lime sulfur are rated as highly efficacious (WSUE, 2023b).

Particle films are very effective at early season pear psylla control and can reduce the need for later season insecticide applications through conservation of natural enemies which provide excellent season-long psylla control. These films are more frequently used than malathion despite their higher cost, and malathion is not recommended for pear psylla control (Kynetec, 2022a; WSUE, 2023). BEAD concludes that malathion has low benefits for pear production.

IMPACTS OF POTENTIAL MITIGATIONS

EPA identified ecological risks of concern for non-target organisms. Potential mitigations include reducing the number of applications allowed and adding windspeed restrictions.

Malathion confers moderate to high benefits to blueberry, caneberry, cherry, fig and other tropical fruit production, so mitigations may have higher impacts in these use sites. The potential impacts of each of these is assessed by use site below. Malathion confers low benefits to other commercial fruit production sites where it is registered, so impacts of any mitigations are likely to be low.

Reduction to the Number of Applications Allowed

<u>Berries (Blueberries & Caneberries):</u>

Currently, registered malathion products allow for up to 3 applications of malathion per year on blueberries (Table 1). Recent surveys report that malathion was applied to blueberries an average of 2 times per year (USDA NASS, 2023). Malathion labels allow a maximum of 3-4 application per year on caneberries, depending on the geographic location. Surveys report that malathion was applied to blackberries an average of 1.3 times and raspberries and average of 1.5 times per year (USDA NASS, 2023). Malathion confers moderate to high benefits to blueberry and caneberry production as a cost-effective, short PHI chemical for SWD control close to harvest. Malathion is also important for co-occurring management of SWD and blueberry maggot in blueberries. Berries are harvested multiple times per season, so multiple applications of insecticides are needed to ensure each harvest is free of SWD. In the Southeast, insecticides are also recommended to be applied after each rain event, which typically results in multiple applications. Rotation among different modes of action is encouraged to prevent resistance development. Most alternatives also have short PHIs, so if the number of applications of malathion was reduced, growers would still have available alternatives to maintain adequate pre-harvest SWD control. However, the risk of resistance development to pyrethroids would increase, therefore costs of production may increase in the long term if spinosyns become the only remaining effective alternatives. BEAD concludes that reducing the number of allowed applications to two would have moderate impacts to berry production, and reducing to one would have high impacts on berry production. Impacts may be higher for

Southeast berry production where applications are recommended after each rain event.

Cherries:

Currently, registered malathion products allow for up to 4 applications per year on cherries (Table 1). Recent surveys report that malathion was applied to cherries an average of 1.1 times per year (Kynetec, 2022a). Malathion confers high benefits to cherry production for management of SWD and cherry fruit fly close to harvest. Cherry fruit fly is of particular concern, as it is a quarantine pest, so must be completely eliminated or an entire harvest could be rejected. Insecticide applications are recommended every 7-21 days for fruit fly management (WSUE, 2023a). Malathion's 1 day PHI for ULV applications is particularly critical for pre-harvest fruit fly management; harvest can last 7-14 days and repeated applications may be necessary to ensure a marketable crop (WSUE, 2023a). There are no available alternatives with a 1 day PHI. Reducing the number of malathion applications allowed could severely hinder growers' ability to control both SWD and cherry fruit fly, which would lead to severe reductions in crop value and marketability. However, because malathion is applied once per year on average, one application is likely sufficient in most cases. BEAD concludes that reducing the allowed number of applications to two would have moderate impacts, and reducing to one would have high impacts on cherry production.

Figs:

Currently, registered malathion products allow for up to 2 applications per year on figs (Table 1). Recent usage data indicate that malathion was applied to 11% of fig acres, and the average number of application per year was 1.1 (CDPR, 2023). Malathion confers high benefits to fig production for the control of dried fruit beetles before harvest. Figs must be free of dried fruit beetles at harvest to avoid a reduction in fruit quality or introduction of secondary pests that can lead to spoilage (UC IPM, 2009). Although available extension materials are limited, malathion is the only chemical recommended for this use (UC IPM, 2009). Figs are harvested multiple times per year, so it is possible more than one application of malathion may be needed. For the 11% of fig acres where malathion is typically used, BEAD concludes that reducing the allowed number of applications to 1 in figs would have moderate impacts due to the potential need for multiple pre-harvest treatments and no recommended alternatives.

Other Tropical Fruits:

The number of applications of malathion currently allowed per year varies across crops categorized as tropical fruit. Two applications are allowed on avocado; three applications are allowed on pineapple; 13 applications are allowed on guava, mango, papaya, and passion fruit. Malathion likely confers moderate to high benefits for various tropical fruits, particularly pineapple and avocado. Comments from industry stakeholders emphasized that due to the long growing season of most tropical fruits, retention of a large number of allowable applications is important (USDA OPMP, 2023). BEAD does not have usage data for many tropical fruit crops to inform how many applications tropical fruit growers are currently using, so impacts of reducing the number of allowed applications are uncertain.

Mandatory Spray Drift Management

To mitigate spray drift risk to non-target species, EPA is considering restrictions on wind speed and temperature inversion for boomless ground application. However, boomless sprayers are not used for production of fruits assessed in this document and therefore, these potential mitigation measures would have no impact on the growers.

CONCLUSIONS

Malathion is used in blueberries and caneberries to target primarily SWD, and there are alternatives from at least two other insecticide classes that provide comparable efficacy ratings and PHIs. Malathion provides high benefits in areas where SWD and blueberry maggot co-occur because few alternative chemical classes are available to manage both pests at the same time. Based on regional climate and harvest timings, malathion provides a range of benefits for managing SWD in ripening blueberries. As a resistance management tool, the benefits are moderate-to-high in the Southeast, moderate in the Northeast and Michigan, and low in the Pacific Northwest. Malathion also has low benefits against blueberry maggot due to the availability of several effective alternatives. Therefore, malathion provides overall moderate benefits against SWD across major US production areas of cultivated blueberries. In wild blueberries, malathion also provides low benefits because many alternatives are available to growers who are likely treating for SWD less frequently than cultivated berry growers.

For caneberries, malathion has moderate-to-high benefits as an economical resistance management tool in California and the Pacific Northwest. The 1-day PHI of malathion is most useful for growers that harvest caneberries every one to two days.

Malathion confers high benefits to cherry production, where it is used to target Western cherry fruit fly and spotted-wing drosophila (SWD), two of the key pests in cherry production. The main benefits of malathion for this use are resistance management, lower costs, and a shorter pre-harvest interval. Malathion is the only organophosphate recommended and used for SWD and cherry fruit fly in cherries. It is less expensive than the more selective group 5 insecticide alternatives. Malathion has a three-day PHI, which is shorter than alternatives which have 7- to 14-day PHIs. Growers who need to manage cherry fruit fly or SWD close to harvest would likely experience quality and/or yield losses in the absence of malathion. For cherry fruit fly specifically, quarantine restrictions could result in a total cop loss if adequate pest control was not achieved pre-harvest.

Malathion confers high benefits to fig production, where it is used in figs for control of dried fruit beetles at harvest, and there are no recommended alternatives for this use. Growers would likely experience quality and/or yield losses in the absence of malathion.

In other tropical fruits, malathion is recommended for control of scales, mealybugs, and lace bugs. Extension recommendations suggest that many of these pests are well controlled by healthy populations of natural enemies, and broad-spectrum foliar sprays including malathion are likely to cause more harm than good. In some severe cases where broad spectrum sprays are necessitated, malathion is an effective control option and is frequently used with few recommended alternatives. Stakeholder comments indicate that malathion is especially important for scale insect control, mealybugs on pineapple, and lace bugs on avocado. Although there is some uncertainty due to limited extension information and lack of usage data, BEAD concludes that malathion likely has moderate-to-high benefits in tropical fruit.

Malathion has low benefits in strawberries. It is primarily used for managing Lygus bugs in California. Several alternatives (with equal or greater efficacy than malathion) are available for use, including those from six different chemical classes. Malathion also has low reported usage and resistance concerns.

In pears, malathion is used to target pear psylla during the dormant and delayed dormant seasons in Washington. There are very efficacious and more selective and alternatives available for pear psylla during the dormant and delayed dormant seasons, and malathion is not recommended for pear psylla management. Malathion has low benefits for pear production.

Malathion usage in oranges seems to have diminished in recent years; malathion is not recommended for any important target pests in orange production and so malathion has low benefits in orange production.

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Appendix A. Efficacy ratings against spotted wing drosophila (SWD) & blueberry maggot (BM) and pre-harvest intervals (PHI)

Table A1. Efficacy ratings against SWD & BM and PHI in Michigan and eastern US blueberries.

Active Ingredient	**IRAC MoA**	**Midwest[1]**		**MI[2]**	**NJ[3]**		**Southeast[4]**		**PHI**
		SWD	***BM***	***SWD***	***SWD***	***BM***	***SWD***	***BM***	
Methomyl	1A	Excellent	Good	Excellent	Good	Moderate	Very Good	---	3
Diazinon	1B	x	Good	---	Moderate	Moderate	---	---	7
Malathion		x	Good	Good	Moderate	Good	Good	Good	1
Phosmet		Excellent	Excellent	Excellent	Good	Good	Excellent	Excellent	3
Bifenthrin	3A	x	Good	Good	Good	Moderate	Excellent	Excellent	1
Zeta-cypermethrin		Excellent	---	Excellent	Good	NR	Excellent	Good	1
Esfenvalerate		x	Good	---	Good	Moderate	---	---	14
Fenpropathrin		Excellent	Good	Good	Good	NR	Excellent	Good	3
Acetamiprid	4A	x	Good	N/A	Little/no control	Good	Mix	Very Good	1
Imidacloprid		x	Fair	---	Little/no control	Good	Mix	Very Good	3† or 7‡
Spinetoram	5	Excellent	Fair	Excellent	Good	NR	Excellent	Very Good	1* or 3
Spinosad		Good	---	N/A	Good	Little/no control	Good	---	1
Cyantraniliprole	28	Excellent	---	---	Good	Moderate	Very Good	---	3
Cyclaniliprole		Excellent	Good	Excellent	Good	Moderate	Very Good	Very Good	1

Note: 'SWD' = spotted-wind drosophila; 'BM' =blueberry maggot; pre-harvest interval (PHI) in day(s); '---' = Not listed as key insecticide for control or not mentioned. References: [1]Beckerman et al. 2022(x= "pest not on the label"), [2]Isaacs et al. 2022a (Rating scale converted as: '****' = Excellent, '***' = Good; '**' or '*' = N/A, not considered important), [3]Besançon et al. 2022, [4]Sial et al. 2023.

†Foliar applied; ‡soil applied; * Recent special local need Section 24(c) labels allow for a shorter 1-day PHI (MI-170002, OR-170016).