OFFICE OF CHEMICAL SAFETY AND POLLUTION PREVENTION
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MEMORANDUM

SUBJECT: **Assessment of Usage and Benefits of Malathion for Vegetable Crops (PC # 057701)**

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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 vegetable crops, but usage of malathion on most surveyed vegetables is low. This memorandum provides detailed assessments of the benefits of malathion in cucurbits, onion, tomatoes, and asparagus use sites. Due to minimal reported usage of malathion in other registered vegetable crop use sites, which implies that growers have other cost-effect pest control options and/or target pests are not problematic, the Biological and Economic Analysis Division (BEAD) concludes that malathion is not an important tool for the control of target pests and has low benefits in the production of those vegetable crops.

BEAD determines that malathion provides low benefits to growers in onions, California tomatoes, and asparagus due to either (i) the abundance of efficacious alternatives of similar cost and/or (ii) minimal impacts on growers' net operating revenue. BEAD has determined that malathion provides moderate benefits to cucurbits while Florida tomatoes derive low to moderate benefits. The reason behind both determinations is due to limited available substitutes for malathion, each of which offer less application flexibility.

Mitigation measures under consideration, which include reducing the number of applications per year and the addition of spray drift mitigation language on all malathion product labels are expected to have low impacts for onions, California tomatoes, and asparagus, as BEAD has determined that the unavailability of malathion would have low impacts for these registered vegetable crops. In the case of cucurbits and Florida tomatoes, which were determined to have low to moderate benefits from malathion, impacts could be higher as a reduction in the number of allowable applications could force users to apply more expensive alternative chemistries for season-long control of target pests.

INTRODUCTION

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) 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 light of scientific advancements, changes in policy, and changes in use patterns that may alter the conditions underpinning previous registration decisions. In determining whether adverse effects are unreasonable, FIFRA requires that the Agency consider the risks and benefits of any use of the pesticide.

Although substantial mitigation on malathion use has been recently enacted based on Biological Opinions from the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, the Agency has identified additional ecological risks to non-target species associated with the use of malathion. As such, the agency is considering reducing the number of applications allowed per year and establishing wind speed restrictions on boomless sprayers to reduce spray drift.

This document describes malathion's use, usage, alternatives, and benefits in vegetable crops to inform the final risk and benefit decision. This memo is one of four documents assessing the use, usage, benefits, and alternatives of malathion. Other related assessments by the Biological and Economic Analysis Division (BEAD) include 1) an overview memo encompassing alfalfa, pine seedlings, and residential consumer uses, 2) wide-area mosquito adulticides and other state and federal pest control programs 3) and commercial fruit production. These complementary memos are available in the malathion docket (EPA-HQ-OPP-2009-0317).

METHODOLOGY

This document assesses the benefits of the use of malathion and the impacts of potential mitigation measures to growers of vegetable crops. 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 vegetable treated with malathion. BEAD assesses benefits at this unit of analysis both because vegetable 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 evaluates malathion usage data to identify use patterns 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. Together, this information establishes where, when, and how vegetable growers use malathion.

BEAD then evaluates the magnitude of benefits by assessing the biological and economic impacts that vegetable growers might experience should they need to employ alternative pest control strategies in the absence of malathion. BEAD identifies the likely alternative control strategies by reviewing extension recommendations, grower surveys, and considering economic factors. Impacts to a grower using the next best alternative to malathion include monetary costs (e.g., from using more expensive chemicals) as well as loss of utility in resistance management, simplicity of use, flexibility, and management and/or integrated pest management programs. There may also be impacts with respect to crop yield loss and/or quality reductions related to diminished pest control.

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 allowed) 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, 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 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 and is registered for use in a wide range of agricultural and non-agricultural use sites. Like most organophosphates, malathion acts via contact on 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 as a contact insecticide, it can provide quick reductions in pest populations in a variety of agricultural and non-agricultural settings.

USE AND USAGE

Use of Malathion in Vegetable Crops

Malathion is registered for use across a variety of commercially grown vegetables including numerous crops categorized as root and tuber vegetables, bulb vegetables, leafy vegetables, brassica vegetables, legume vegetables, fruiting vegetables, cucurbit vegetables, and stalk and stem vegetables.[1]

[1] Specifically, malathion is registered for use on the following vegetable use sites: amaranth, arugula, asparagus, beans (dry and succulent), beets (garden), broccoli, broccoli (Chinese), broccoli raab (rapini), brussels sprouts, cabbage, cabbage (Chinese), cantaloupe, carrot (roots), cauliflower, cavalo broccolo, celery, celtuce, chayote,

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. The highest allowable single application rate among vegetables is for use on cucurbits, specifically cucumber, squash, and chayote fruit (1.75 lb AI/A). The greatest number of applications allowed per year are on watercress (five applications), followed by four annual applications allowed on eggplant, tomato, okra, and tomatillo.

Usage of Malathion in Vegetable 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, as shown in Table 1, growers of surveyed vegetables reported applying over 56,000 pounds of malathion active ingredient (lbs AI) to at least 41,000 total acres treated (TAT) annually from 2017 to 2021 (Kynetec, 2022b; CDPR, 2023). Some small-acreage crops, such as kale or turnip, are not surveyed at a nationally representative level and are not included in this estimate; therefore, these national usage values may slightly underestimate total national malathion usage on vegetable crops. Malathion usage of all nationally surveyed vegetable crop sites are summarized in Table 1.

Among vegetable crops that were surveyed for insecticide usage between 2017 and 2021, malathion was not used on a substantial percent of national acreage of most vegetable crops for which it is registered. In terms of percent of crop treated (PCT), onions and asparagus reported the highest usage (7 PCT and 6 PCT respectively) (2017-2021, Table 1).[2] Tomatoes reported the highest average annual TAT with 12,000 acres treated with malathion per year. Tomatoes also reported the highest average number of applications at 2.6 applications per year (Table 1).

Additional usage data regarding regional patterns or timing of applications is provided, when relevant, in the crop-specific assessment sections below.

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chervil, chinese mustard (gai choy), chrysanthemum (edible), collards, corn salad, cucumber, dandelion, dock (sorrel), eggplant, endive, florence fennel (finnochio), garlic, horseradish, kale, kohlrabi, leek, lettuce (head and leaf), melon, mizuna, mustard greens, mustard spinach, okra, onion (bulb), onion (green), orach, parsley, parsnip, peas, peppers, potato, pumpkins, purslane (garden/winter), radish, rape greens, rutabaga, salsify, shallot, spinach, squash, sweet potatoes, swiss chard, tomatillos, tomato, turnip, watercress, watermelons, and yams.

[2] PCT calculations use base acres treated (BAT) rather than TAT. BAT is the measure of acres treated at least once; TAT is the measure of treated acres accounting for acres treated multiple times.

Table 1. National average annual agricultural malathion usage for surveyed vegetable crops, 2017-2021.

Crop Group	Crop	Pounds AI Applied	Total Acres Treated[1]	Percent Crop Treated (PCT)[2]	Single Application Rate (lbs AI/acre)	Number of Applications
Root and Tuber Vegetables	Carrots	<500	<500	<1	1.00	1.0
	Potatoes	700	<500	<1	1.50	1.4
Bulb Vegetables	Garlic	<500	<500	NC	1.23	1.0
	Onions	10,000	8,400	7	1.24	1.0
Leafy Vegetables	Lettuce	5,600	3,400	1	1.64	1.2
	Spinach	<500	<500	<1	1.02	1.0
Brassica Vegetables	Broccoli	1400	1100	1	1.22	1.6
	Brussels sprout	4700	3700	NC	1.27	1.4
	Cabbage	600	<500	1	1.23	1.0
	Cauliflower	<500	<500	<1	1.23	1.0
Fruiting Vegetables	Peppers	1200	1000	2	1.12	1.2
	Tomatoes	18,000	12,000	2	1.50	2.6
Cucurbit vegetables	Cantaloupes	<500	<500	<1	1.00	1.0
	Cucumbers	7000	4000	2	1.75	2.0
	Honeydew	D	D	D	D	D
	Pumpkins	2000	2700	3	0.74	1.2
	Squash	900	800	1	1.15	1.7
	Watermelons	500	<500	<1	1.25	1.2
Stalk and stem vegetables	Asparagus	2,100	1,800	6	1.18	1.5
	Celery	600	<500	1	1.39	1.1

Sources: Honeydew data from USDA NASS 2023; Brussels sprout and garlic data from CDPR 2023; all other crops from Kynetec 2022b;

NC: not calculated. Due to reporting inconsistencies across CA counties, certain PCT values calculated from CDPR data are withheld.

D: indicates usage was reported to USDA-NASS, but values are withheld by USDA-NASS to avoid disclosing data for individual farms

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

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

SCOPE OF ASSESSMENT

Usage data presented above showing low PCT across the majority of surveyed vegetable crops suggests that malathion may not be of significant importance in many of the vegetable crops where malathion is registered. The USDA Office of Pesticide Management Policy (USDA-OPMP) submitted information indicating that malathion was important as a broad-spectrum control tool in unspecified specialty vegetables; however, OPMP primarily points to historical usage data to support this claim (USDA, 2023). Given recent available data, minimal reported usage suggests that either pests controlled by malathion are not problematic or that growers have other cost-effective methods to control those pests. Therefore, BEAD concludes that the benefits of the use of malathion are low in carrots, potatoes, garlic, lettuce, spinach, broccoli, Brussels sprout, cabbage, cauliflower, peppers, and celery.

USDA-OPMP also specified malathion as important for beetle management and broad-spectrum pest control in cucurbit production (USDA-OPMP, 2023). Therefore, although low usage was reported in surveyed cucurbit vegetables (cantaloupes, honeydew, watermelon, cucumber, squash, and pumpkin), BEAD provides a more detailed assessment of the benefits of malathion use in cucurbit vegetables in the next section of this document.

Higher reported usage on a few vegetable crops suggests that malathion may be an important tool for growers. The highest usage in terms of PCT is seen in onion and asparagus. Additionally, tomato production reported the highest number of total acres treated among surveyed vegetables. To determine the potential magnitude of benefits in these crops, BEAD provides a more detailed assessment of the benefits of malathion use in onion, tomato, and asparagus in the next sections of this document.

Other vegetables registered for malathion use but not surveyed for usage data or named as an important use site in public comment are not further assessed in this memorandum. BEAD concludes that malathion is also likely of low benefit to these sites due to the overall low usage in vegetable crops indicating that malathion is not frequently necessary in these production systems. However, this conclusion is uncertain due to lack of data and BEAD welcomes public comment identifying critical uses of malathion in other vegetable crops.

BENEFITS OF MALATHION

Cucurbits

Usage

Cucurbits account for at least $1.7 billion in average annual gross farm revenue nationwide (USDA NASS 2023).[3] Cucurbit crops surveyed nationally for usage (cantaloupe, cucumber, honeydew, pumpkin, squash, and watermelon) reported a relatively low reliance on malathion with pumpkin exhibiting the highest PCT among cucurbits (3 PCT, Table 1) (Kynetec, 2022b).

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[3] This estimate only includes cantaloupe, cucumber, pumpkin, squash, and watermelon for which USDA has economic survey data.

Target Pests

Top reported target pests for malathion in cucurbit crops include cucumber beetle, aphids, and silverleaf whitefly (Kynetec, 2022a).

Cucumber beetles (*Acalymma vittatum, Diabrotica undecimpunctata howardi, Diabrotica balteata*) can damage cucurbit crops throughout the entire production cycle, with adult beetles feeding on all parts of the plants (including fruits and flowers), and larvae feeding on roots and stems (Brust, 2018; Qureshi et al, 2001). Adult cucumber beetles can also transmit the causal agent of bacterial wilt (*Erwinia tracheiphila)*, which affects commercially important cucurbit species by causing plants to dry up and die (CU, 2019; Qureshi et al, 2001; Rojas et al., 2015).

Aphids, particularly the melon aphid (*Aphis gossypii*) and green peach aphid (*Myzus persicae*), are common pests in cucurbits which cause a reduction in the quality and quantity of the fruit (UCANR, 2013a; Griffin and Williamson, 2021). Aphids can affect cucurbits during all crop stages and transmit viruses which can infect all commercially grown cucurbits (Brust, 2018; Kucharek and Purcifull, 2001; Qureshi et al, 2001).

Silverleaf whitefly is not likely to be a major target pest for malathion users as it is not specifically labeled as a target pest in cucurbits, and malathion is only sometimes recommended for some whitefly species in other crops.[4] Furthermore, a recent extension report indicates that this chemical is not effective against this pest (Layton, 2020). However, Florida extension service's recommendation for whitefly control in cucurbits is drawn heavily from their recommendations for whitefly control in tomatoes. Specifically, it is recommended that a pyrethroid mixed with an OP (like malathion) can be used on whiteflies at the end of a season to reduce whitefly migration to other crops (Smith et al., 2019; Martini, 2022). This is consistent with recent usage data showing Florida as the only state that reported silverleaf whitefly as one of the target pests of malathion use in cucumbers (Kynetec 2022a).

Malathion is reported as offering good efficacy against cucumber beetles (80-90% control) and fair efficacy against aphids (70-80% control) (Bost et al., 2002; SUSVC, 2023; UK, 2021). Malathion is also mentioned as an available rotational treatment option for the mentioned pests (Bell and Waters, 2021; Griffin and Williamson, 2021; MVPG, 2023; Webb, 2006).

BEAD concludes that malathion target pests in cucurbit use include aphids and cucumber beetles while acknowledging that other minor or niche uses may exist, such as silverleaf

[4] Silverleaf whiteflies (*Bemisia argentifolii*) are still capable of causing damage to cucurbits. These pests feed on the sap of cucurbit plants, causing damage to plant structures, while also promoting the growth of sooty mold (Brust, 2018; Qureshi et al, 2001). In addition, silverleaf whiteflies are vectors of several plant viruses which affect cucurbits (Brust, 2018; Qureshi et al, 2001).

whitefly control in Florida. However, such niche uses are not included in the remainder of the benefit assessment for cucurbit vegetables.

Potential Alternatives

University extension guidelines mention a wide variety of active ingredients available for the control of aphids and cucumber beetle, but not all are reported to have been used in the last 5 years (Kynetec, 2022a). Based on malathion's reported usage on cucurbits and the recommended treatment options for target pests, BEAD considered other broad-spectrum insecticides which are effective against the aphids and cucumber beetles as alternatives for malathion in cucurbits. Registered pesticides belonging to the pyrethroid chemical group (IRAC Group 3A) (e.g., Lambda-cyhalothrin, bifenthrin), those belonging to the neonicotinoid chemical group (IRAC Group 4A) (e.g., acetamiprid, imidacloprid), and carbaryl (IRAC Group 1A) present possible effective alternatives to malathion in terms of efficacy (Table 2). Most pyrethroid alternatives have a similar price range to malathion, whereas carbaryl and neonicotinoid alternatives have a significantly higher cost (Table 2).

However, the use of either chemical group alternative would depend on various factors, such as pest pressure thresholds, crop stage, integrated pest management (IPM) and resistance management (RM) practices, and/or environmental conditions among other factors. For instance, usage data indicate that malathion applications between emergence and vining account for 54% of total acres treated while applications between vining and harvest account for 44% of total acres (Kynetec 2022a). In the case of carbaryl and pyrethroids, users would be able to replace malathion applications with these alternatives on a one-to-one basis throughout the growing season. Neonicotinoids on the other hand could present limitations as alternatives due to proposed bloom restrictions[5] which would prohibit their application during the growing season (from plant emergence to vining). Neonicotinoids may also not be as effective as malathion due to resistance concerns (APRD, 2024), and/or may already being a part of existing rotational IPM and RM practices.

[5] EPA has proposed a crop stage restriction for both foliar and soil applications of some neonicotinoid insecticides, which would prohibit use from vining to harvest or after the emergence of the first true leaf in cucurbits (see, for example, Docket # EPA-HQ-OPP-2011-0581, available at regulations.gov)

Table 2: Chemical Alternatives – Cucurbits – Usage, Costs, and Efficacy

Active Ingredient	IRAC Group	Average Cost	Aphid		Cucumber Beetle	
			Avg TAT	RE[a]	Avg TAT	RE[a]
Malathion	1B, Organophosphate	$7	7,500	1	7,500	2
Carbaryl	1A, Carbamate	$12	170	-- [b]	10,000	2
Methomyl		$23	100	1	460	--
Bifenthrin	3A, Pyrethroid	$4	7,900	1	9,500	2
Cyfluthrin		$3	2,900	1	20,000	3
L-Cyhalothrin		$3	12,000	1	15,000	3
Esfenvalerate		$4	1,100	1	6,300	2
Fenpropathrin		$20	290	1	300	2
Permethrin		$3	11,000	1	23,000	2
Pyrethrins		$41	3,800	--	780	--
Z-Cypermethrin		$4	3,700	1	14,000	3
Acetamiprid	4A, Neonicotinoid	$15	38,000	3	4,800	2
Dinotefuran		$26	7,400	1	950	2
Imidacloprid		$9	22,000	3	12,000	3
Thiamethoxam		$11	9,500	3	5,100	2

Usage and cost estimate source: Kynetec, 2022a

Note: Other extension recommended chemical alternatives that do not appear in the usage data are omitted. Further, data presented in this table are for select states (CA, FL, IN, & OH) only.

[a] RE stands for rated efficacy. 0= Poor efficacy (<50% control); 1= Fair efficacy (70-80% control); 2= good efficacy (80-90% control); 3= excellent efficacy (90-100% control). Combined efficacy ratings obtained from: Bost, 2002; MVPG, 203; Paret et al., 2023; SUSVC, 2023; UCANR, 2016a; UK, 2021.

[b] -- No efficacy rating provided.

Benefits of Malathion

Malathion's overall reported low usage and the availability of alternatives with similar or greater efficacy ratings may suggest that it does not provide significant benefits to cucurbit growers. However, many alternatives (carbamates, neonicotinoids, and some pyrethroids) are more expensive than malathion, while some pyrethroid alternatives are less expensive. Neonicotinoid insecticides also present potential limitations as alternatives due to their already widely adopted use and proposed restrictions on application timing. Target pests may require management during certain stages of crop development, such as bloom, a point at which neonicotinoids have been proposed for prohibition by EPA or are already prohibited in California production areas. The option to use malathion for pest management in rotation with limited other MOAs at specific timings is important. Additionally, no other alternative with malathion's MOA (IRAC Group 1B) is currently registered for use in cucurbits, with the exception of dimethoate and diazinon in melons and watermelons. Hence, malathion could be significant chemistry in managing target pests in the cropping season during bloom and/or providing some degree of resistance management (RM) benefits as a rotational application partner against the mentioned target pests.

BEAD concludes that malathion provides moderate benefits to cucurbit growers. Malathion is the only organophosphate (IRAC Group 1B) registered for the vast majority of cucurbit crops, which may contribute to the effectiveness of RM programs. In the absence of malathion, it is expected that users would use a combination of alternative neonicotinoids (before bloom) and pyrethroids (after bloom). The cheapest pyrethroid-neonicotinoid combination consists of permethrin and imidacloprid, together a cost of $11 while the most expensive combination consists of pyrethrin and dinotefuran which has a combined cost of $71. Thus, growers who switch to a pyrethroid-neonicotinoid combination to replace malathion could see cost increases in the range of $4 to $54 which is equivalent to 2% to 27% of net operating revenue (University of Georgia, 2022).[6]

Onions

Usage

About 7% of dry bulb onion acres used malathion with an annual average volume of about 10,000 lbs (Table 1; Kynetec 2022b). Dry onion production is geographically concentrated on the West Coast of the US. The states with highest acres harvested are California (33% of national onion acreage), Washington (16%), and Oregon (13%); together these three states account for over 60% of all dry onion acres harvested nationwide (USDA NASS, 2024). In addition to these west coast states, Idaho, Texas, and Georgia are surveyed for insecticide usage on onion crops. However, only California and Oregon reported using malathion in onion production between 2017 and 2021 (Kynetec, 2022b).

Target Pests

Between 2017-2021, the only pest that surveyed onion growers reported using malathion to target was onion thrips (Kynetec, 2022a). Malathion constituted about 7% and 1% respectively of Oregon and California’s total onion acres treated for onion thrips (with any AI) between 2017-2021. Therefore, although thrips are the only reported target pest of malathion use in onions, malathion constitutes only a small share of all total acres treated for this pest.

Onion thrips (*Thrips tabaci*) are the most significant pest of onion crops (Schwartz, 2012), and cause damage to onions by feeding and depositing eggs on leaves, rendering green onions (scallions) to be unmarketable, and causing reduced bulb size, slowed growth, and decreased

[6] These calculations assume that malathion is applied once per season. Crop budget values are taken from the 2022 cucumber on plastic budget sheet.

yields in dry bulb onions (Bell and Waters, 2021; Gill et al., 2015; UWM, 2020). Onion thrips typically affect onions from the early vegetative stages (3- to 4-leaf stage) until harvest in nearly all onion-production regions in the U.S (Schwartz, 2012). Onion thrips can also transmit several pathogens that reduce onion bulb size and quality and are a vector of the iris yellow spot virus (IYSV) (Gill et al., 2015; UWM, 2020). IYSV is a significant disease which can stunt plant growth, cause foliage to die back prematurely and reduce bulb size (Schwartz, 2012).

Malathion is reported as having fair (70-80% control) efficacy against onion thrips (Schwartz, 2012; Murray et al., 2019; UK, 2021) and is only recommended to be applied in commercial production when pest pressure is low (Murray et al., 2019).

Potential Alternatives

Usage data on alternate chemistries used to target onion thrips are summarized in Table 3 (Kynetec, 2022a).

Extension production guidelines mention a wide variety of active ingredients available for the control of thrips in onion production, and the importance of utilizing insecticides of different chemical modes of action when needing to treat multiple times during a year to slow resistance development (Bell and Waters, 2021). Recommended chemical treatment options with a relatively equal or higher reported efficacy rating as malathion include methomyl, oxamyl, spinosad, spinetoram, abamectin, pyriproxyfen, tolfenpyrad, spirotetramat, and cyantraniliprole (Bell and Waters, 2021; Schwartz, 2012; UCANR, 2018) (Table 3)[7]. These alternatives provide growers season-long control of thrips populations since three applications per growing cycle is often enough (UCANR, 2018). Additionally, pyrethroids (chemicals belonging to IRAC group 3A), such as permethrin and zeta-cypermethrin, can also be considered as potential alternatives despite their relatively lower reported efficacy rating when compared to malathion (Table 3). This determination is based on available usage data which indicates that some of the mentioned pyrethroids have been used to treat more acres than malathion for onion thrips at a lower cost per acre (Kynetec, 2022a), suggesting some acceptable level of control.

[7] Pyriproxyfen only provides control of immature thrips as it is an insect growth regulator.

Table 3: Alternatives to Malathion for Control of Onion Thrips in CA & OR Onions (2017-2021)

Active Ingredient	IRAC Group	Annual Average TAT[a]	Average Cost per Acre	Rated Efficacy[a]
Malathion	1B	42,000	$9	1
Methomyl	1A	500,000	$26	2-3
Oxamyl		40,000	$29	1-2
L-Cyhalothrin	3A	120,000	$3	0-1
Permethrin		67,000	$5	0-1
Z-Cypermethrin		26,000	$4	0-1
Cypermethrin		6,500	$3	-- [b]
Imidacloprid	4A	8,200	$17	-- [b]
Spinetoram	5	400,000	$56	3
Spinosyn		57,000	$45	--
Abamectin	6	240,000	$6	2
Tolfenpyrad	21A	1,200	$31	2-3
Spirotetramat	23	320,000	$27	3
Cyantraniliprole	28	120,000	$44	2
Azadirachtin	Unknown MoA	110,000	$22	--[b]

Usage and cost estimate source: Kynetec, 2022a.

[a] 0= Poor efficacy (<50% control); 1= Fair efficacy (70-80% control); 2= good efficacy (80-90% control); 3= excellent efficacy (90-100% control). Combined efficacy ratings obtained from: Bell and Waters, 2021; Murray et al., 2019; Schwartz, 2012; UCANR, 2018; UK, 2021.

[b] -- No efficacy rating provided.

Benefits of Malathion

Malathion's usage in onions was lower than other more expensive alternatives in both states reporting malathion usage on onions (Kynetec, 2022a). This may be due to resistance development to malathion (Bell and Waters, 2021; Schwartz, 2012; UCANR, 2018) and/or higher relative efficacy of other more expensive alternatives (unrelated to resistance). Furthermore, malathion is not currently listed as a recommended insecticide for thrips control in western commercial onion production (Bell and Waters, 2021; UCANR, 2018). The estimated returns net of operating costs of a typical onion acre grown in Malheur County, Oregon are about $211/acre where such grower spends roughly $320/acre on insecticides (Greenway, 2022). If a grower would need to replace one application of malathion with methomyl (a $16 increase in insecticide costs), then their insecticide costs would increase by 8% of net operating revenue.

However, the crop budget used does not actually specify malathion as one of the chosen insecticides, and the costs of the alternatives (spinetoram, spirotetramat, methomyl, and azadirachtin) appear to be much cheaper than Kynetec's data. The cost data for alternatives from the crop budget appear to be more consistent with Kynetec's usage data since Table 3 indicates that the alternatives are used much more than malathion despite their much higher prices.

Therefore, BEAD concludes that malathion has low benefits to onion growers due to the availability of effective alternatives throughout the growing season and because malathion's alternatives are much more frequently used and may not be as expensive (if at all) as the usage data would suggest.

Tomatoes

Usage

Approximately 2% of national tomato acreage used malathion with an annual average of 18,000 lbs applied to 12,000 treated acres (Table 1, Kynetec 2022b). U.S. total production of tomatoes averaged $1.65 billion (USDA NASS, 2023) and is geographically concentrated in California and Florida which account for 77% and 9% (respectively) of nationwide tomato acres harvested (USDA NASS, 2022). Almost all tomato acreage in Florida is sold as fresh market produce making Florida the top producing state for fresh market tomatoes (USDA NASS, 2022). Between 2017-2021, approximately 12% of Florida tomato acreage was treated with malathion (Kynetec, 2022b). Conversely, California accounts for about 90% of the nation's production of processed tomatoes (Hartz et al., 2008) and less than 1% of tomato acreage was treated with malathion. Malathion applications in both states occurred throughout the growing season; usage data shows that application timing ranges from crop emergence to harvest (Kynetec, 2022a).

Target Pests

Only California and Florida were surveyed for tomatoes grown and both reported using malathion on tomatoes. Reported usage suggests that aphids are the primary target pest in both states (Kynetec, 2022a). California tomato growers also reported targeting thrips simultaneously with aphids, while growers in Florida reported targeting mites and whiteflies along with aphids (Kynetec, 2022a). For California, malathion is a recommended treatment for early season aphids and thrips control (Martin et al., 2021; UCANR, 2013b). Aphids, thrips, mites, and whiteflies can affect tomato crops throughout the entirety of the growing season (Martini et al., 2021; UCANR, 2023).

Malathion is reported as having fair (70-80% control) to good (80-90%) efficacy against thrips, and fair efficacy against aphids (SUSVC, 2023; UK, 2021). Referenced extension sources do not provide efficacy rating against whitefly or mites within tomato use sites. However, malathion is mentioned by university extension sources as a recommended treatment to be applied in combination with a pyrethroid against whiteflies at the end of the growing season as part of IPM and RM programs (Smith et al., 2019; UCANR, 2013e).

Aphids

Various aphid species are reported to cause damage in tomato crops. The green peach aphid is an early-season pest of tomatoes and can cause stunting, leaf distortion, delayed fruit maturing and reduced fruit set (Martini et al., 2021; UCANR, 2013b). Green peach aphid affects tomato crops early in the season and also vectors plant viruses, such as the alfalfa mosaic virus and tobacco etch virus (Martini et al., 2021; UCANR, 2013b). Potato aphid (*Macrosiphum euphorbiae*) affects tomato crops later in the season (6 to 8 weeks before harvest) and is capable of producing yield losses during this period (UCANR, 2013c). Aphids secrete honeydew that promotes development of sooty mold on foliage and fruit (UCANR, 2013c), leading to reduced yields and lower quality fruit.

Other Accompanying Pests

Thrips: The following species of thrips are reported to damage tomato crops: onion thrips, western flower thrips (*Frankliniella occidentalis*), melon thrips (*T. palmi*), chilli thrips (*Scirtothrips dorsalis*), eastern flower thrips (*F. tritici*), Florida flower thrips (*F. bispinosa*), and tobacco thrips (*F. fusca*) (Martini et al., 2021; UCANR, 2013d). Western flower thrips are also a vector of the Tomato spotted wilt virus (Martini et al., 2021; UCANR, 2013d). Thrips damage can also cause plant growth distortion, stunted leaves and terminals, scarred and deformed fruit, and plant tissue discoloration (Martini et al., 2021; UCANR, 2013d), leading to reduced fruit quality and yields.

Mites: The tomato Russet mite (*Aculops lycopersici*), two-spotted spider mite (*Tetranychus urticae*), and broad mite (*Polyphagotarsonemus latus*) are reported being tomato pests, with the two-spotted spider mite as being the most significant (Martini et al., 2021; UCANR, 2016b). Spider mites usually occur mostly at the end of the season when weather conditions are hot and dry (Martini et al., 2021; UCANR, 2016b). Mite feeding causes yellowing of the leaves that eventually die and drop from the plant, which can eventually lead to yield loss (Martini et al., 2021; UCANR, 2016b). Spider mites can also cause direct damage to tomato fruit by producing a cosmetic blemish known as gold fleck that decreases marketability of the tomatoes (Martini et al., 2021).

Whiteflies: The Bandedwinged whitefly (*Trialeurodes abutilonea*), greenhouse whitefly (*T. vaporariorum*), sweetpotato whitefly (*Bemisia tabaci*), and silverleaf whitefly (*B. argentifolii*) are reported as tomato pests (Martini et al., 2021; UCANR, 2013e). Whiteflies cause damage to tomatoes by being vectors of tomato viruses, feeding, and the production of honeydew which leads to the development of sooty mold (Martini et al., 2021; UCANR, 2013e). Sweetpotato whitefly feeding can also cause fruit to ripen unevenly (UCANR, 2013e), which can complicate harvest operations.

Potential Alternatives

For California, usage extension sources mention spirotetramat, flonicamid, and pymetrozine as recommended treatments for aphid control; oxamyl and pyrethrins for early-season aphids, and methomyl and dinotefuran for thrips control (UCANR, 2013bcd) (Table 4). Usage data suggests that none of the recommended options for aphid control show any significant usage, including malathion. Instead, imidacloprid is reported as the most used, followed by dimethoate to target both aphids and thrips (Kynetec, 2022a). Then this is followed by pyrethroids (e.g., bifenthrin, l-cyhalothrin, cyfluthrin, etc.) for aphids and spinetoram and pyrethroids (e.g., l-cyhalothrin and cyfluthrin) for thrips. These chemistries are rated at least as efficacious as malathion.

Table 4: California Tomatoes – Select Alternatives' Usage, Cost, and Efficacy

Active Ingredient	IRAC Group	Average Cost	Aphid		Thrips	
			Average TAT	RE	Average TAT	RE[a]
Malathion	1B	$11	3,000	1	3,000	1
Methomyl	1A	$26	100	--[b]	700	--
Dimethoate	1B	$5	30,000	3	30,000	3
Bifenthrin	3A	$4	40,000	1	10,000	1
Cyfluthrin		$3	16,000	--	12,000	--
L-Cyhalothrin		$2	17,000	1	16,000	1
Pyrethrins		$49	3,000	--	-	--
Dinotefuran	4A	$29	500	1	-	2
Imidacloprid		$7	120,000	3	40,000	2
Spinetoram	5	$32	3,000	3	30,000	3
Pymetrozine	9B	$15	300	3	-	--
Methoxyfenozide	18	$13	6,000	--	12,000	--
Spirotetramat	23	$33	6,000	3	2,000	--
Flonicamid	29	$32	200	3	-	2

Usage and cost estimate source: Kynetec, 2022a
Combined efficacy ratings obtained from: Bost, 2002; MVPG, 203; Paret et al., 2023; SUSVC, 2023; UCANR, 2016a; UK, 2021.
[a] RE stands for rated efficacy. 0= Poor efficacy (<50% control); 1= Fair efficacy (70-80% control); 2= good efficacy (80-90% control); 3= excellent efficacy (90-100% control). Combined efficacy ratings obtained from: Bost, 2002; MVPG, 203; Paret et al., 2023; SUSVC, 2023; UCANR, 2016a; UK, 2021.
[b] – No efficacy rating provided.

Multiple insecticides, including dimethoate and pyrethroids such as bifenthrin, cyfluthrin, and lambda-cyhalothrin, have similar rated efficacy (RE) and are already commonly used, in terms of acres treated, for both aphid and thrips. They appear to be less costly than malathion, indicating that they may not fit with malathion user current production or pest control practices. Therefore, if malathion users turn to these alternatives, they may need to make other adjustments to their pest control and/or production practices. Imidacloprid may also not represent a suitable alternative to malathion as it already seems to be the main treatment option against thrips and aphids during the early crop season based on reported usage data. In addition, California has also instituted a prohibition on foliar applications of imidacloprid.[8] Foliar applications account for the vast majority of malathion use in California tomatoes. Other chemicals like spinetoram and spirotetramat are more expensive and thus, if growers switch to these two chemicals, then they will incur much higher pest control costs.

Florida tomato growers (Table 5) reported using malathion on different secondary target pests than California growers (Kynetec, 2022a) with potential niche uses that are not easily captured with the available usage data. Furthermore, there appears to be fewer reported insecticides being used in Florida (compared to California) especially when targeting aphids (Kynetec, 2022a). Aside from the differences in pest pressure between states, the differences in availability of alternatives can also be attributed to the fact that Florida growers are primarily fresh market suppliers and may be more particular about their pest control strategies since visible damage reduces their marketability significantly more than processing tomatoes. Many of the reported alternatives in Florida do not appear to be efficacious against the whole suite of target pests like malathion is. However, extension literature indicates that there are many chemistries that are efficacious against both aphid and mites (IRAC group 3A) as well as aphids and whiteflies (IRAC groups 4A, 4C, 4D, 9A, 9B, 9D, and 29). Spirotetramat is rated as effective against all three pests, though it is almost three times more expensive than malathion. Thus, it is likely that in order to replace malathion, Florida growers would need to employ multiple chemistries or use the much more expensive spirotetramat.

[8] As of June 2023, the California Department of Pesticide Regulation has adopted regulations limiting neonicotinoid pesticide use in the production of fruiting vegetable crops, including tomatoes. As part of such regulations, foliar applications of clothianidin, dinotefuran, imidacloprid and thiamethoxam are prohibited throughout the entire crop cycle. Additional information may be found at: https://www.cdpr.ca.gov/docs/enforce/neonicotinoid/fruiting_vegetable_crops.pdf.

Table 5: Florida Tomatoes – Select Alternatives' Usage, Cost, and Efficacy

			Aphid		Mite		Whitefly	
Active Ingredient	IRAC Group	Avg Cost[a]	Avg TAT	RE[b]	Avg TAT	RE[b]	Avg TAT	RE[b]
Malathion	1B	$8	9,000	1	4,000	3	1,100	--
Cyfluthrin	3A	$2	-	--[c]	6,000	--	11,000	--
L-Cyhalothrin		$2	80	1	-	1	30,000	--
Dinotefuran	4A	$33	-	1	-	--	13,000	3
Thiamethoxam		$14	4,000	3	-	--	4,000	3
Abamectin	6	$7	-	--	4,000	3	4,000	3
Bifenazate	20D	$45	-	--	60	3	-	--
Spirotetramat	23	$34	-	3	4,000	2	10,000	2

Usage and cost estimate source: Kynetec, 2022a

Combined efficacy ratings obtained from: Smith et al., 2019; SUSVC, 2023; Paret et al., 2023; UCANR, 2013bcde; UK, 2021.

[a] Avg. cost per treated acre is based on 2017-2021 Florida tomato usage data across all target pests in the table.

[b] RE stands for rated efficacy. 0= Poor efficacy (<50% control); 1= Fair efficacy (70-80% control); 2= good efficacy (80-90% control); 3= excellent efficacy (90-100% control). Combined efficacy ratings obtained from: Smith et al., 2019; SUSVC, 2023; Paret et al., 2023; UCANR, 2013bcde; UK, 2021.

[c] -- No efficacy rating provided.

BEAD concludes that the likely alternatives to malathion in Florida are thiamethoxam for aphid and/or whitefly control and abamectin for mite control; abamectin is cheaper while thiamethoxam is more expensive. Spirotetramat could also be considered an alternative for aphids, whiteflies, and mites, even though it comes at a much higher price point than malathion.

Benefits

Based on the availability of effective chemical alternatives against target pests across a range of costs, BEAD considers that malathion provides low benefits in tomato production in California. In the absence of malathion, users could possibly face increases in pest control costs since malathion usage is reported as playing a plays a minor role in aphid control (Kynetec, 2022a).

In contrast, Florida tomato growers may derive higher benefits from malathion use due to different pest pressures and subsequently different pest control needs related to fresh versus processing tomatoes. These differences exhibited by Florida growers result in fewer options with the similar broad-spectrum efficacy and cost per acre. Further, growers may need to use chemicals or one very expensive chemical to replace malathion's broad-spectrum value. Therefore, BEAD concludes that malathion has low to moderate benefits for Florida tomatoes due to existing efficacious alternatives but none of which have the same broad-spectrum efficacy and that aphid appears to be a relatively minor pest problem in Florida tomatoes.

Asparagus

Usage

Roughly 6% of national asparagus acres grown are reported to have used malathion (Kynetec 2022b). Asparagus is grown in all 50 U.S. states, but most commercial production occurs in Michigan (50% of national acres harvested) with California and Washington each producing about 11% of national acreage (USDA NASS, 2022). From 2017-2021, about 10% of California asparagus and 15% of Washington asparagus were treated with malathion; use of malathion was not reported in Michigan asparagus production (Kynetec, 2022b).

Target Pests

Of all the reported asparagus acres treated with malathion between 2017-2021, the majority of those acres solely targeted the asparagus aphid (Kynetec, 2022a).

Asparagus aphid (*Brachycorynella asparagi)* spends their entire life cycle on the asparagus plant (Bell and Waters, 2021), overwintering as eggs on asparagus residue in the field and hatching in the spring (MSU, 2011; UM, 2013). They feed on asparagus spears and ferns, injecting a toxin into the plant which causes shortened internodes, bushy and distorted branching, and yield loss for the subsequent crop cycle (MSU, 2011; UCANR, 2019a; UMA, 2013). Severe and continuous infestations can also lead to plant death (MSU, 2011; UCANR, 2019a; UMA, 2013).

Extension guidance for pest management of asparagus grown in the Pacific Northwest mentions malathion as one of several options recommended for control of asparagus aphid (Bell and Waters, 2021). For asparagus grown in California, malathion is not mentioned as a recommended control option for asparagus aphid (UCANR, 2019ab). Referenced extension sources do not provide efficacy ratings against the asparagus aphid in the Pacific Northwest. All asparagus growers surveyed reported applying malathion after foliage has emerged (spear and frond stages) to target asparagus aphid (Kynetec, 2022a).

Potential Alternatives

Extension guidelines recommend acetamiprid, carbaryl, permethrin, pyrethrin and pymetrozine, in addition to malathion, for asparagus aphid control (Bell and Waters, 2021). Reported usage data indicates that acetamiprid, pyrethrins, sulfoxaflor, l-cyhalothrin, and dimethoate are used to target asparagus aphids (Kynetec, 2022a). However, l-cyhalothrin does not represent a viable alternative to malathion as it is not currently registered in asparagus.[9] Dimethoate, which is reported as being used in Washington for asparagus aphid control, is not practical for controlling this pest prior to harvest due to its 180 PHI and is only recommended to be applied after the last harvest (UMA, 2023).

Therefore, based on the reported usage data for malathion target pests in asparagus, and the available recommended control options for such, acetamiprid, pyrethrins, pymetrozine, carbaryl, spinetoram, spinosyn and sulfoxaflor represent potential alternatives to malathion against asparagus aphid.

Benefits

The available usage information for malathion indicates that malathion has recently been used for asparagus aphid management in the Pacific Northwest with a relatively high TAT when compared to available alternatives. However, there are several effective chemical alternatives recommended by extension guidelines which are also reported as being used in the available usage data with no significant indication of a reliance on malathion. Yet, many of the reported alternatives in Table 6 are considerably more expensive than malathion.

[9] Reported l-cyhalothrin usage on asparagus may be due to six FIFRA Sec. 18 Emergency Exemptions which were granted for use against the asparagus aphid in Washington from 2016 to 2020, with an additional Sec. 18 that was also granted against the same pest for California in 2020. Additional information can be found in the EPA's Emergency Exemption Database at: https://ordspub.epa.gov/ords/pesticides/f?p=124:2.

Table 6: Most Frequently Used AIs for Aphids in Asparagus (2017 – 2021)

State	Product Chemistry	IRAC Group	Asparagus Aphid		
			Avg TAT	Avg. Cost per Acre	RE[a]
California (averaging 6,000 acres grown annually)	Malathion	1B	400	$8	1-2
	Neem Oil	UNE	900	$40	-[b]
	Acetamiprid	4A	400	$14	-
	Pyrethrins	3A	60	$36	-
	State Total[c]		**2,860**	**$18**	**-**
Washington (averaging 4,300 acres grown annually)	Malathion	1B	600	$9	1-2
	Sulfoxaflor	4C	900	$20	-
	L-Cyhalothrin	3A	700	$4	-
	Dimethoate	1B	500	$6	-
	Azadirachtin	UN	300	$55	-
	Acetamiprid	4A	100	$22	-
	State Total[c]		**3,600**	**$14**	-

Usage and cost estimate source: Kynetec, 2022a

Combined efficacy ratings obtained from: Bell and Waters; MSU, 2000; UCANR 2019ab.

[a] RE stands for rated efficacy. 0= Poor efficacy (<50% control); 1= Fair efficacy (70-80% control); 2= good efficacy (80-90% control); 3= excellent efficacy (90-100% control). Combined efficacy ratings obtained from: Bell and Waters; MSU, 2000; UCANR 2019ab.

[b] – No efficacy rating provided.

[c] State total average cost per acre is a TAT weighted average of the average cost per acre for each chemistry.

Consequently, in the absence of malathion, users would face cost per acre increases in the range of $6 to $28 per application. Although a $28 application cost increase seems high, BEAD expects the likely alternatives (sulfoxaflor and acetamiprid, due to lower cost and higher observed use) to fall closer to the $6/application figure. Furthermore, malathion is not recommended in California and is one of several available chemical control options in Washington. Though the alternatives in Washington tend to be more expensive, there is reported usage of those alternatives. Therefore, based on the available information, BEAD determines that malathion provides low benefits to asparagus growers.

IMPACTS OF POTENTIAL MITIGATION

EPA has already implemented substantial mitigation from the 2022 Biological Opinion to provide protection for species federally listed as threatened or endangered. Mitigation under consideration to further reduce potential ecological risks to listed and non-listed species associated with the use of malathion includes a reduction in the number of applications allowed per year, and mandatory spray drift language for boomless ground applications to reduce potential effects to non-target species.

Given that BEAD has determined that malathion offers overall low benefits for onion, asparagus and California tomatoes, the impacts of potential mitigations are expected to be low. However, for cucurbits and Florida tomatoes, impacts could potentially be higher due to the greater benefits malathion offers users in these use sites.

Reduced Number of Applications per Year

To mitigate identified ecological risks, EPA may consider reducing the number of allowable applications of malathion per year. The expected impacts of this proposed mitigation measure would be low for onions and asparagus since BEAD has determined that the unavailability of malathion would have low impacts for these registered vegetable crops. In the case of cucurbits and Florida tomatoes, which were determined to have low to moderate benefits from malathion, impacts could be higher. The current allowed maximum number of applications for cucurbits is two applications. Recent usage indicates that cucurbit growers that used malathion made one to two applications per year (Table 1; Kynetec, 2022b). Therefore, any reduction in allowable applications below two would impact some growers. Similarly, surveyed tomato growers that used malathion reported an average of 2.6 applications a year (Table 1; Kynetec, 2022b). Currently, four applications of malathion are allowed per year on tomatoes. A reduction to three applications may not impact many growers, but further reductions would lower the limit to below the current reported average so larger impacts would be expected as growers may then need to replace one, maybe two, applications of malathion.

Spray Drift Mitigations

To mitigate identified ecological risks to taxa via spray drift, the Agency is considering limited application by boomless sprayers with the addition of mandatory spray drift language to be included on all malathion product labels. Updated spray drift mitigation language for boomless sprays includes limiting applications to when wind speed is less than or equal to 10 miles per hour, and restricting applications from occurring during temperature inversions. The mandatory spray drift language for boomless sprayers is expected to have minimal impacts on vegetable growers, as boomless sprayers are not typically used within commercial vegetable production.

CONCLUSIONS

Malathion is a broad-spectrum organophosphate (IRAC group 1B) insecticide registered for a broad range of vegetable crops. The Biological and Economic Analysis Division (BEAD) determines that malathion provides low benefits to growers in onions, asparagus, and California tomatoes due to either the availability of multiple efficacious alternatives of similar cost and/or insect control costs constituting a minor component of overall grower costs. BEAD has determined that moderate benefits are being derived from malathion for cucurbits while Florida tomatoes derive low to moderate benefits.

In cucurbit use sites, available usage data indicates that malathion is applied to primarily target aphids and cucumber beetles. Due to the unavailability of other insecticides with malathion's MOA (IRAC group 1B) and the limitation of neonicotinoid (IRAC group 4A) alternatives to be applied after plant bloom, BEAD concludes that malathion offers moderate benefits.

In Florida tomatoes growers have few options to replace malathion which offer similar broad-spectrum efficacy and cost per acre and may need multiple chemistries to replace malathion.

Mitigation measures under consideration, which consist of reducing the number of applications per year, and the addition of boomless sprayer spray drift mitigation language on all malathion product labels are expected to have low impacts in onion, asparagus, and California tomatoes. Increased impacts are expected in cucurbits and Florida tomatoes due to the higher benefits malathion offers users in these use sites.

REFERENCES

Arthropod Pesticide Resistance Database (APRD). 2024. *Aphis gossypii*. Michigan State University. https://www.pesticideresistance.org/display.php?page=species&arId=218 [June 2024]

Agency for Toxic Substances and Disease Registry (ATSDR). 2003. Toxicological profile for Malathion. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=522&tid=92. [October 2023]

Bell N, Waters T. 2021. Vegetable Crops. In: Pacific Northwest Pest Management Handbooks. https://pnwhandbooks.org/sites/pnwhandbooks/files/insect/chapterpdf/vegetable.pdf [October 2023]

Bost S, Grant J, Hale F, Haun G, Hensley D, Moneier R, Newman M, Parkman P, Robinson D, Shelton S, Stewart S, Straw A. 2002. Tennessee's Pest Management Strategic Plan for Cucurbits. Southern IPM Center. https://ipmdata.ipmcenters.org/source_report.cfm?view=yes&sourceid=1005 [November 2023]

Brust J. 2018. Viruses in cucurbits. Weekly Crop Update, University of Delaware. https://sites.udel.edu/weeklycropupdate/?p=12513. [November 2023]

California Department of Food and Agriculture (CDFA). 2023c. Public Notice Spring 2023. https://www.cdfa.ca.gov/plant/IPC/curlytopvirus/pdfs/2023/2023_Notice_of_Intent_BCTVCP.pdf [December 2023]

Chong JH, Klingeman B, Hale F. 2017. The Insecticide and Miticide Mode of Action Field Guide. University of Tennessee Extension and Clemson University. https://www.epa.gov/sites/production/files/2015-01/documents/rmpp_6thed_final_lowresopt.pdf [October 2023]

Cornell University (CU). Bacterial Wilt of Cucurbits: *Erwinia tracheiphila*. College of Agriculture and Life Sciences, Plant Disease Diagnostic Clinic. http://plantclinic.cornell.edu/factsheets/bacterialwiltcucurbits.pdf. [March 2024]

Gill HK, Garg H, Gill AK, Gillet-Kaufman JL, Nault BA. 2015. Onion Thrips (Thysanoptera: Thripidae) Biology, Ecology, and Management in Onion Production Systems. Journal of Integrated Pest Management 6(1):6. https://academic.oup.com/jipm/article-pdf/6/1/6/9663776/pmv006.pdf [November 2023]

Greenway, Gina. 2022. Cost of Onion Production in Eastern Oregon and Idaho. OSU Extension Service, Oregon State University. https://extension.oregonstate.edu/crop-production/vegetables/cost-onion-production-eastern-oregon-idaho [March 2024]

Griffin R, Williamson P. 2021. Cucumber, Squash, Melon & Other Cucurbit Insect Pests. Clemson Cooperative Extension, Clemson University. https://hgic.clemson.edu/factsheet/cucumber-squash-melon-other-cucurbit-insect-pests/ [November 2023]

Hartz, T., Miyao, G., Mickler, J., Lestrange, M., Stoddard, S., Nuñez, J., & Aegerter, B. (2008). Processing Tomato Production in California Production Areas and Seasons. University of California Division of Agriculture and Natural Resources. https://anrcatalog.ucanr.edu/pdf/7228.pdf [April 2024]

Kucharek T, Purcifull D. 2001. Aphid-Transmitted Viruses of Cucurbits in Florida. Florida Cooperative Extension Service, University of Florida. https://plantpath.ifas.ufl.edu/misc/media/factsheets/circ1184.pdf [November 2023]

Kynetec USA, Inc. 2022a. "The AgroTrak® Study from Kynetec USA, Inc." iMap Software. Database Subset: 2017-2021. [Accessed August 2023].

Kynetec USA, Inc. 2022b. "The AgroTrak® Study from Kynetec USA, Inc." Microsoft Access Database. Database Subset: 2017-2021. [Accessed August 2023].

Layton, B. 2020. Silverleaf Whitefly, Vol. 6, No. 22. In: Bug's Eye View. Mississippi State University Extension. https://extension.msstate.edu/newsletters/bug%E2%80%99s-eye-view/2020/silverleaf-whitefly-vol-6-no-22

Martin T, Swett C, Vinchesi-Vahl A, Parreira S. 2021 Pest Management Strategic Plan for Califronia Processing Tomato production. University of California Integrated Pest Management Program and University of California Agriculture and Natural Resources. https://ipmdata.ipmcenters.org/documents/pmsps/2021_07_22_Processing_Tomato_PMSP_final.pdf

Martini X, Funderburk JE, Webb SE, Smith H. 2021. Arthropod Management for Tomato, Pepper, And Eggplant. Florida Cooperative Extension Service, University of Florida. https://edis.ifas.ufl.edu/publication/IN169 [November 2023]

Midwest Vegetable Production Guide (MVPG). 2023. https://mwveguide.org/guide [October 2023]

Michigan State University (MSU). 2000. A Strategic Plan for the Michigan Asparagus Industry. https://ipmdata.ipmcenters.org/documents/pmsps/miasparagus.pdf [November 2023]

Michigan State University (MSU). 2011. Check your asparagus field for aphids. MSU Extension. https://www.canr.msu.edu/news/check_your_asparagus_field_for_aphids [October 2023]

Murray K, Reitz S, Jepson. 2019. An Integrated Pest Management Strategic Plan for Treasure Valley Onions in Oregon and Idaho. Oregon State University. https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9254.pdf [November 2023]

Paret ML, Frey C, Boyd NS, Wang Q, Desaeger J, Qureshi J, Meszaros A, Martini X. 2023. Cucurbit Production. Florida Cooperative Extension Service, University of Florida. https://doi.org/10.32473/edis-cv123-2023 [November 2023]

Qureshi JA, Seal DR, Webb SE. 2020. Insect Management for Cucurbits (Cucumber, Squash, Cantaloupe, And Watermelon). Florida Cooperative Extension Service, University of Florida. Publication #ENY-460. https://edis.ifas.ufl.edu/publication/IN168 [November 2023]

Rojas ES, Batzer JC, Beattie GA, Fleisher SJ, Shapiro LR, Williams MA, Bessin R, Bruton BD, Boucher TJ, Jessce LCH, Gleason ML. 2015. Bacterial Wilt of Cucurbits: Resurrecting a Classic Pathosystem. Plant Disease 99 (5): 465-574. https://doi.org/10.1094/PDIS-10-14-1068-FE. [March 2024]

Schwartz, H. 2012. Pest Management Strategic Plan for Dry Bulb Storage Onions in the United States. Western Integrated Pest Management Center. https://ipmdata.ipmcenters.org/documents/pmsps/USonionPMSP.pdf [November 2023]

Smith HA, Stansly PA, Seal DR, McAvoy E, Polston JE, Gilreath PR, Schuster DJ. 2019. Management of Whiteflies, Whitefly-Vectored Plant Virus, and Insecticide Resistance for Tomato Production in Southern Florida. Florida Cooperative Extension Service, University of Florida. Publication #ENY-735. https://edis.ifas.ufl.edu/publication/IN695. [November 2023]

Southern US Vegetable Crop Handbook (SUSVC). 2023. https://content.ces.ncsu.edu/southeastern-us-vegetable-crop-handbook [October 2023]

Talley, C., & Werling, B. (2016). Cost and returns for producing Michigan asparagus. *Michigan State Univ. Ext. E-3315*, *1*, 24. [April 2024]

Tindall, K. and Hanson, C. 2018. Qualitative Benefits and Usage Assessment of Diflufenzopyr (PC Code 005108) and Diflufenzopyr-Sodium (PC Code 005107). Available at https://www.regulations.gov/document/EPA-HQ-OPP-2011-0911-0022.

United States Department of Agriculture, Office of Pest Management Policy (USDA-OPMP). 2023. Information on Critical and High Benefit Uses for Three Organophosphate Insecticides: Malathion, Acephate, and Dimethoate. Available in the public docket: docket # EPA-HQ-OPP-2009-0317.

United States Department of Agriculture National Agricultural Statistics Service (USDA NASS). 2023. QuickStats. Database Subset: 2017-2021. Available at: https://quickstats.nass.usda.gov/ [Accessed January 2024].

University of Kentucky (UK). 2021. Vegetable Production Guide for Commercial Growers, 2022-23. University of Kentucky, Cooperative Extension Service. https://www2.ca.uky.edu/agcomm/pubs/ID/ID36/ID36.pdf [November 2023]

University of California, Agriculture and Natural Resources (UCANR). 2013a. Pest Notes: Aphids. UC ANR Publication 7404. https://ipm.ucanr.edu/PMG/PESTNOTES/pn7404.html. [October 2023]

University of California, Agriculture and Natural Resources (UCANR). 2013b. Pest Notes: Green Peach Aphid and Other Early-Season Aphids. UC ANR Publication 3470. https://ipm.ucanr.edu/agriculture/tomato/green-peach-aphid/ [November 2023]

University of California, Agriculture and Natural Resources (UCANR). 2013c. Pest Notes: Potato Aphid. UC ANR Publication 3470. https://ipm.ucanr.edu/agriculture/tomato/potato-aphid/ [November 2023]

University of California, Agriculture and Natural Resources (UCANR). 2013d. Pest Notes: Potato Aphid. UC ANR Publication 3470. https://ipm.ucanr.edu/agriculture/tomato/thrips/ [November 2023]

University of California, Agriculture and Natural Resources (UCANR). 2013e. Pest Notes: Whiteflies. UC ANR Publication 3470. https://ipm.ucanr.edu/agriculture/tomato/whiteflies/ [November 2023]

University of California, Agriculture and Natural Resources (UCANR). 2016a. Cucurbits: Pest Management Guidelines for Agriculture. UC ANR Publication 3453. https://ipm.ucanr.edu/legacy_assets/pdf/pmg/pmgcucurbits.pdf [November 2023]

University of California, Agriculture and Natural Resources (UCANR). 2018. Thrips. Agriculture: Onion and Garlic Pest Management Guidelines. UC ANR Publication 7404. https://ipm.ucanr.edu/PMG/PESTNOTES/pn7404.html. [October 2023]

University of California, Agriculture and Natural Resources (UCANR). 2019a. European Asparagus Aphid. UC IPM Pest Management Guidelines: Asparagus. UC ANR Publication 3435. https://ipm.ucanr.edu/agriculture/asparagus/european-asparagus-aphid/ [October 2023]

University of California, Agriculture and Natural Resources (UCANR). 2019b. Asparagus Beetles. UC IPM Pest Management Guidelines: Asparagus. UC ANR Publication 3435. https://ipm.ucanr.edu/agriculture/asparagus/asparagus-beetles/ [October 2023]

University of California, Agriculture and Natural Resources (UCANR). 2023. Tomato: Pest Management Guidelines for Agriculture. https://ipm.ucanr.edu/agriculture/tomato/ [November 2023]

University of Georgia, Agricultural and Applied Economics. 2022. Budgets: 2022 Cucumbers on Bareground. https://agecon.uga.edu/extension/budgets.html [December 2023]

University of Massachusetts Amherst (UMA). 2013. Aphid, Asparagus. Center for Agriculture, Food, and the Environment. https://ag.umass.edu/vegetable/fact-sheets/aphid-asparagus [October 2023]

University of Massachusetts Amherst (UMA). 2016. Asparagus Beetle, Common. https://ag.umass.edu/vegetable/fact-sheets/asparagus-beetle-commons [October 2023]

University of Massachusetts Amherst (UMA). 2023. Asparagus. In: New England Vegetable Management Guide. https://nevegetable.org/crops/asparagus [November 2023]

University of Minnesota Extension (UME). 2020. Asparagus Pest Management. University of Minnesota. https://extension.umn.edu/growing-guides/asparagus-pest-management [November 2023]

University of Wisconsin-Madison (UWM). 2020. Onion Thrips. Wisconsin Horticulture, Division of Extension. https://hort.extension.wisc.edu/articles/onion-thrips/ [October 2023]

USDA National Agricultural Statistics Service (USDA NASS). 2022 Census of Agriculture. Complete data available at www.nass.usda.gov/AgCensus.

Webb SE. 2005. Insect Management for Cucurbits (Cucumber, Squash, Cantaloupe, and Watermelon). Florida Cooperative Extension Service, University of Florida. https://doi.org/10.32473/edis-in168-2005 [November 2023]