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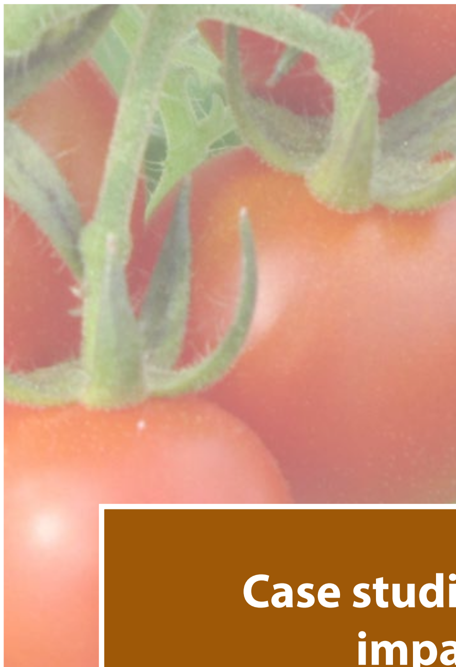
The value of pyrethroids in U.S. agricultural and urban settings:



Case studies of pyrethroid use patterns and potential impacts of regulatory changes on production of high value fruits and vegetables in primary U.S. production states



2016

This report series, researched and produced by AgInfomatics, LLC, is an independent and comprehensive analysis of the economic and societal benefits of pyrethroid insecticides (bifenthrin, cyfluthrins, cyhalothrins, cypermethrins, deltamethrin, esfenvalerate, fenpropathrin, permethrin, and tefluthrin). The research was sponsored by the Pyrethroid Working Group, an informal association of firms marketing products based on the above pyrethroid active ingredients. These products are used in agricultural, structural and landscape applications.

AgInfomatics, an agricultural consulting firm established in 1995, conducted an analyses exploring the answer to the question: *What would happen if pyrethroids were no longer available or restricted beyond the current situation?* Comparing this hypothetical future to the economics associated with current applications allowed AgInfomatics to derive an estimate of the value of pyrethroids.

This estimated value was based on robust quantitative and qualitative study methods including econometrics, modeling of insecticide use, crop yield data, market impacts, surveys of growers, surveys of professional applicators and in-depth case studies. All these data sources and methods were used to triangulate on the above question.

The value of pyrethroids in North American agriculture and urban settings

Reports include:

1. Executive summary
2. Methods and assumptions for estimating the impact of pyrethroid insecticides on pest management practices and costs for U.S. crop farmers
3. Summary of the use of pyrethroid insecticides by U.S. crop farmers and the impacts of non-pyrethroid scenario on insecticide use and farmer costs
4. Estimated yield benefits and efficacy of pyrethroid insecticides for major U.S. crops based on a meta-analysis of small plot data
5. Use and value of insect management practices in U.S. alfalfa corn, cotton and soybean production
6. Value of pyrethroid insecticides to urban pest management professionals
7. An economic assessment of the benefits of pyrethroid insecticides in the U.S.
8. Case studies of pyrethroid use patterns and potential impacts of regulatory changes on production of high value fruits and vegetables in primary U.S. production states
9. A case study of pyrethroid use patterns and potential impacts of regulatory changes on the control of mosquito vectors in Florida

For more information, please contact: AgInfomatics@gmail.com

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Executive summary

The case studies were conducted to determine the value of pyrethroids in specific specialty crop productions systems across the United States to help define the internal and external benefits of pyrethroid use. Specialty crops include fruits and vegetables and tree nuts, and crops of less than 300,000 acres nationwide. For these case studies, citrus fruit, tomato, sweet corn, potato and almond production systems were selected.

For specialty crop production, reoccurring themes surfaced from all regions, indicating that pyrethroids provided significant pest management and economic benefits to specialty crop agriculture. Benefits include:

- Ensuring return on investment to growers through continued low economical costs of pyrethroids.
- Maintaining of a range of tools and management options for emerging pests that have few alternative controls.
- Continuing broad-spectrum efficacy against existing and emerging pests where few alternative chemistries exist.
- Maintaining management options for multiple pests within cropping systems and in area-wide operations.
- Improving food security by providing continued pest management in multiple geographic agricultural production locations.
- Maintaining resistance management with multiple insecticidal options to use in rotations with lower-risk and selective insecticidal classes.
- Meeting the stringent damage-free marketing requirements for specialty crops through effective management tools with short pre-harvest intervals (PHIs) harvest.
- Using already existing globally established maximum residue levels (MRLs) to provide access to both U.S. based and export markets.
- Ensuring compatibility with other IPM tools including cultural and behavioral controls to enhance their effectiveness.
- Improving applicator/farm worker safety due to low mammalian toxicity.

The loss of pyrethroid active ingredients through regulatory action would quickly lead to significant impacts for the grower. In particular these include; increases in pesticide applications of possibly higher toxicity and more selective active ingredients, increases in the likelihood of resistance development for those other chemistries because of decrease in effectiveness with fewer chemistries available. The decrease in efficacy of pyrethroid alternatives combined with higher pesticide costs would reduce economic returns to growers and result in negative impacts on the agricultural economy . It is evident that pyrethroids continue to be one of the classes of insecticides in North American agriculture that will be an essential tool in future pest management.

Specific examples of benefits are highlighted below and further explanation can be found in the individual crop sections.

Main insights from Florida citrus production (see section 2.0)

- The Florida citrus industry must use chemical controls to manage the Asian citrus psyllid — the vector of Huanglongbing (HLB) disease (also known as citrus greening). Pyrethroids provide options for both efficacious control, cost-effective treatments and resistance management.
- Pyrethroid and organophosphate (primarily chlorpyrifos) insecticides are the most effective and economical active ingredients for adult psyllid control during the mid- to late growing season.
- Pyrethroids allow needed applications to be made close to harvest and have globally established MRLs that are required for export; many of the newer active ingredients materials lack established MRLs for key export markets.
- Pyrethroids have multiple use patterns and can be used at lower winter temperatures to provide control in area-wide dormant spray programs.
- The loss of pyrethroid insecticide use patterns for psyllid control would require a substantial shift to alternative active ingredients — resulting in increases in resistance, unsustainable control costs and accelerated loss of citrus acreage.
- Pyrethroids are also the main applications available for the management of other damaging pests in citrus production.

Main insights from California citrus production (see section 3.0)

- The loss of the broad spectrum insecticidal tools in pest management — such as pyrethroids, neonicotinoids and chlorpyrifos — would lead to significant increases in pesticide applications, resistance development, sharp rises in costs of production and eventual economic decline.
- Pyrethroids can be used for needed applications close to harvest and have globally established MRLs that are required for export; many of the newer active ingredients materials lack established MRLs for key export markets.
- Pyrethroids maintain psyllid suppression and manage resistance during the season and are effective as dormant sprays at lower temperatures during winter.
- Pyrethroids are essential alternatives for early season psyllid control if neonicotinoids are restricted.
- Soil treatment of pyrethroids (bifenthrin) as barrier sprays are the sole soil application option for control of Fuller rose beetles, an important quarantine contaminant for the export market.

- Pyrethroids can be used to manage the glassy-winged sharpshooter in citrus where the pest overwinters and is not a pest to prevent its movement to nearby grapes where it is a serious pest.

- Pyrethroids are important pest management options for several sporadically occurring pests in California citrus for which there are no effective alternatives, such as Fuller rose beetle.

Main insights from Florida fresh market sweet corn production (see section 4.0)

- The silk fly complex is the most economically important insect pest management challenge facing fresh sweet corn growers in south Florida and currently, pyrethroids are the only effective treatment; multiple applications are required to produce damage-free sweet corn.

- For fresh market blemish-free sweet corn, growers must manage the ear-feeding lepidopteran pests (fall armyworm and corn earworm); pyrethroids are the most effective materials in both adult and larval control of these pests.

- In Florida, soil inhabiting lepidopteran pests (lesser cornstalk borer and cutworm complex) need to be controlled; currently, the only effective active ingredients are pyrethroids and organophosphates.

- The conclusion from the case study with a major sweet corn and green bean grower in the Lake Okeechobee area is that production of fresh, winter vegetables in south Florida, which supplies the eastern U.S., would not be possible without pyrethroid insecticides.

Main insights from Florida fresh market tomato production (see section 5.0)

- Pyrethroids are cost effective insecticidal options for Florida tomato growers and are needed for resistance management programs.

- Multiple insecticidal tools are needed to manage whitefly populations to limit transmission of the devastating geminivirus. This is achieved using rotations of selective active ingredients with differing modes of action (MoA), but repeated use of these options has resulted in resistance and reduced effectiveness and often requires the addition of pyrethroids to extend effectiveness.

- As resistance has increased and the effectiveness of pyrethroid alternatives has decreased, new pest threats (thrips, leafminers) have emerged that require pyrethroids.

- Systemic neonicotinoids are essential in protecting transplants and early season field plants from whiteflies and virus transmission. If resistance to these active ingredients develops (which is probable) or regulatory restrictions are imposed, pyrethroids will be essential alternatives for use in foliar programs that rotate mode of action classes.

Main insights from California almond production (see section 6.0)

- Pyrethroids are needed to meet stringent standards for damage and aflatoxin contamination in both domestic and export markets.
- The export market for both almonds and pistachios requires all active ingredients that are used for navel orangeworm control have established MRLs in export destination countries. Since newer, more selective active ingredients may not have established MRLs in all export markets, the availability of selective alternatives to broad spectrum materials is reduced, and pyrethroids are essential.
- Pyrethroids are needed for use in rotation with other MoA groups to reduce the potential for resistance development in navel orangeworm management programs.
- Navel orangeworm is an area-wide pest, and in areas where damage potential is high, pyrethroids are needed for use in conjunction with both sanitation and mating disruption to reduce damage to acceptable levels.
- For some pests, there are no alternative control measures beside pyrethroids. For example in the southern San Joaquin Valley, both almonds and pistachios are grown, and growers apply 2-3 early season applications of pyrethroids to prevent damage to the developing nuts from a complex of hemipteran pests that move into orchards from surrounding vegetation.

Main insights from Washington potato and processing sweet corn production compared to Wisconsin and Midwestern production (see section 7.0)

POTATOES IN WASHINGTON AND THE PACIFIC NORTHWEST

- Pyrethroids are essential in early season potato pest management to control beet leafhopper and prevent early establishment of BLTVA (beet leafhopper-transmitted virescence agent). There are no alternatives for early beet leafhopper control. Applications also control psyllids moving into fields when systemic neonicotinoids are no longer effective and consequently, can reduce zebra chip transmission.
- Due to their short PHIs and established MRLs to meet export requirements, pyrethroids are the only effective materials for use on late season potatoes to manage potato tuberworm.
- Pyrethroids are needed for use in rotation with active ingredients with different MoAs to manage resistance in multiple pests — including Colorado potato beetle, psyllids and thrips.
- Pyrethroids are an effective alternative to manage emerging pest threats, such as lygus bugs and the brown marmorated stink bug.

POTATOES IN WISCONSIN AND THE MIDWEST

- Pyrethroids are the most cost effective options to manage potato leafhopper, which annually migrates into the Midwest and can build to damaging levels that require a rapid control response.
- Colorado potato beetle resistance to neonicotinoids is now widespread in the Midwest, and pyrethroids are needed as rotation active ingredients with other MoA groups to manage resistance in foliar spray programs.
- Pyrethroids are good pest management tools that target sporadic lepidopteran infestations and emerging hemipteran pests.

SWEET CORN IN WASHINGTON AND THE PACIFIC NORTHWEST

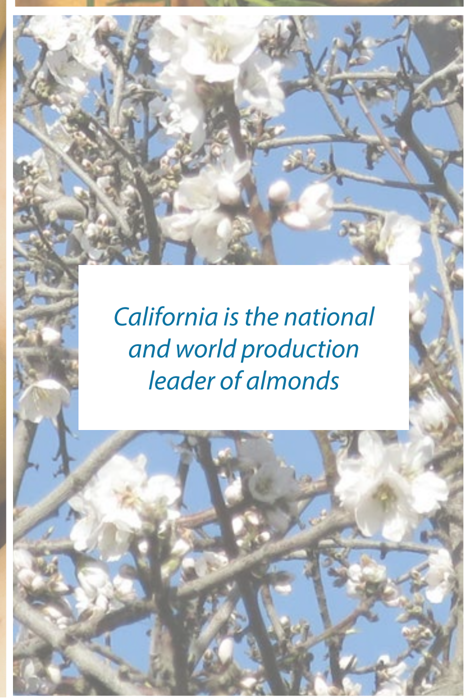
- The pyrethroids are the only active ingredients with sufficient adult knockdown and persistence on silks to control corn earworm and meet the zero tolerance requirements for damage and contamination in processed sweet corn.
- Pyrethroids meet the requirement for established MRLs in the export market.
- Currently, pyrethroids are the only effective alternative to manage a new pest — the brown marmorated stink bug, which is emerging as a key concern for the region.

SWEET CORN IN WISCONSIN AND THE MIDWEST

- Pyrethroids are the only materials that can provide sufficient adult knockdown and persistence on silk and leaf surfaces to control larvae of the complex of lepidopteran pests — corn earworm, European corn borer, fall armyworm and western bean cutworm — that must be managed to meet the zero tolerance for damage required by the industry.
- Use of pyrethroids in a pest management approach that targets applications to specific 'treatment windows' has proven very effective at achieving sufficient control with only 1-3 applications while other active ingredients often require 4-6 applications to achieve comparable control.
- In Wisconsin and the Midwest, pyrethroids are also essential in the management of other pests in the complex — including corn rootworm adults, corn leaf aphid and potential new threats, such as the brown marmorated stink bug. These pests are currently controlled effectively by pyrethroid regimes targeting lepidopteran pests.

Florida is the nation's leading producer of fresh tomatoes

Florida is the nation's leading producer of fresh sweet corn



California is the national and world production leader of almonds

1.0 Introduction

Case studies at the farm level provide valuable detailed information on the use of pesticides critical to specific crops and cropping practices. To better understand pyrethroid pesticide uses and benefits, AgInfomatics conducted case studies with individual growers in six different cropping systems across North America and interviewed several professionals representing all levels of expertise and experience in disease vector management in Florida.

Florida and California citrus represent 97% of national production

The agricultural case studies encompassed mid-sized and large producers growing crops that are essential components of fruit and vegetable production systems at both the state and national levels. Each case study is comprised of two parts: 1) A technical analysis of the production system and the pest management challenges faced by growers, drawn from the literature and interviews with research and extension specialists and pest control advisors working in the system; and 2) Interviews with specific growers to determine impacts at the farm level.

These consequences may be both economic and social and may impact at the farm level, locally with suppliers and affiliated businesses, in surrounding communities with reduced services and shrinking employment opportunities and regionally with lower economic performance.

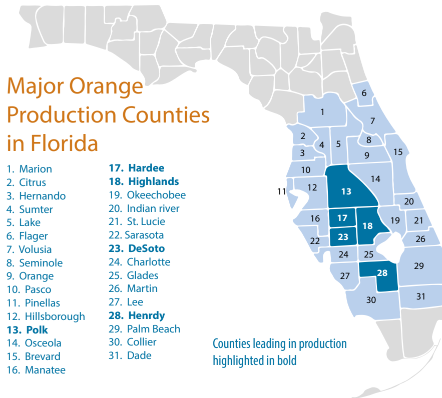
Agricultural case studies were conducted in the following systems: Florida and California citrus; Florida fresh sweet corn; Florida fresh tomatoes; California almonds and Washington and Wisconsin potatoes/sweet corn. These production systems, while relatively small crop acreages compared to large commodities like soybeans, represent critically important components of local and regional economies and are vital components of the nation's food supply. These crops represent systems facing serious existing and emerging pest threats that require intensive and flexible pest management approaches that often need to incorporate pyrethroid insecticides.

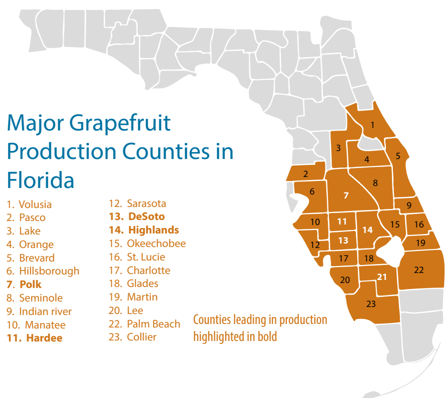
It is in such systems that the greatest unintended consequences of regulatory changes are most likely to occur. These consequences may be both economic and social and may impact the farm level and affiliated businesses in surrounding communities. Such insights should be taken into consideration by regulatory officials contemplating policies affecting their use.

These case studies were conducted from January to March, 2016. On-site interviews were conducted with individual growers, agricultural professionals and University research/extension specialists. Discussions involved details on how pyrethroid insecticides fit into ongoing pest management systems and included the potential impacts of changes in use patterns on production at the farm level and economic multiplier effects throughout rural communities.

Neonicotinoid and organophosphate insecticides are also undergoing regulatory review. Since active ingredients from these groups are often important components of pest management systems in these case study crops and are frequently used in conjunction with pyrethroids, growers were also asked to consider scenarios in which pyrethroid uses were changed both with and without the availability of neonicotinoid and organophosphate insecticides.

The vector case study was implemented in Florida in early 2016. Florida constitutes the 'front lines' in the management of mosquito-transmitted viruses. Experts from a variety of institutions were contacted and interviewed. This case study examines the background of endemic vector-borne diseases in the U.S., the risks associated with this vector, and how vectors are best managed. The discussions behind this case study also asked a critical question — what would happen, and how would users cope if pyrethroids were no longer available or restricted beyond the current situation? Answering this question involved of two-step process of initially learning how pyrethroids were currently employed and then inducing a thinking process on what changes would likely occur if access changed.





2.0 Florida citrus

Citrus is a valuable industry in the United States, with Florida and California being the two largest producing states. This case study examines the use and value of pyrethroid insecticides in citrus production in Florida and California which together produce 97% of the nation's citrus. Case studies were conducted with growers and specialists in both production areas and contrasting Florida, which is currently facing a crisis situation where a bacterial disease transmitted by an insect vector is widespread and threatening continued citrus production, with California, where the same pest and disease have only recently been introduced, and steps are being taken to manage its spread and impact.

Citrus represents a key component of Florida's agricultural economy with revenue and value-added impacts of over $13 billion and nearly 80,000 jobs based on production of over 203 million boxes in 2007-2008 (1). The Florida industry peaked in 1997 with over 800,000 acres producing close to 14 million tons; however, a series of natural disasters that included hurricanes, freezes and a disease epidemic (caused by bacterial canker) reduced production by over 30% over the next decade to 9 million tons on 540,000 acres in 2007 (2).

Nevertheless, in 2008-2009, Florida growers still produced 79% of the oranges and 69% of the grapefruit grown in the United States. Thirty Florida counties reported orange or grapefruit production in 2008-2009 with acreage concentrated in the central and southern areas of the state. Leading production counties are Polk, Hendry, Hardee, Highlands and DeSoto.

2.1 Pest management in Florida citrus prior to the introduction of the Asian citrus psyllid and Huanglongbing disease — the arthropod pest complex, management approaches and the role of pyrethroid insecticides

A diverse and potentially destructive complex of arthropod pests is present in Florida citrus groves that requires annual management to avoid economic loss (3,4). Prior to 2000, this pest complex that may be affected by pyrethroids consisted primarily of:

Homopteran sucking insects. Endemic in Florida citrus are scales (five armored scale and three soft scale species), the citrus mealybug, whiteflies (four species) and aphids (three species, including the brown citrus aphid that is particularly important as the vector of citrus tristeza virus). These Homopteran pests are widespread and normally held at sub-economic levels by natural enemies and soil application of systemic neonicotinoid insecticides, which are now widely applied to manage the Asian citrus psyllid. All homopteran pests are capable of rapid population increases to economically damaging levels; when this occurs, organophosphate and carbamate insecticides are recommended to reduce damage (6). These materials increase worker risk, and newer pyrethroid insecticides and several specific aphicides that provide control of certain homopteran pests are often employed by growers to increase worker safety. Pyrethroids are the most cost effective of these alternatives.

In 2009, 93 % of oranges and 94 % of grapefruit were treated with some type of insecticide. Commonly, citrus will receive 6-12 sprays per year.

http://www.nass.usda.gov/Statistics_by_State/Florida/Publications/Chemical_Use/citch00.pdf

Hemipteran plant bugs. Leaf-footed bugs, green stink bugs and the citron stink bug feed on a wide variety of plant species and can move into citrus groves in large numbers causing serious damage to developing fruit. Limited options exist for controlling these pests. Broad spectrum organophosphates (primarily chlorpyrifos) and pyrethroids are the most effective and least expensive options. In the event that chlorpyrifos registrations are lost, pyrethroid insecticides will be the only effective materials for managing this pest group (7). An extremely damaging exotic stink bug — the brown marmorated stink bug — has recently been introduced into North America and presents a potentially serious new threat to the citrus industry.

Chewing insects. A number of chewing insects, including lepidoptera and heteroptera (katydids, grasshoppers and crickets), can move into citrus in large numbers from surrounding grassland and abandoned citrus groves causing severe damage to new flush foliage and young fruit. Broad spectrum insecticides, such as chlorpyrifos and the pyrethroids, are the limited options open to growers to avoid economic loss.

Thrips. Several species of thrips are prevalent in citrus groves and attack flowers, reducing fruit set and quality. When populations exceed thresholds, the only recommended options for control are applications of pyrethroids or the organophosphates, chlorpyrifos or dimethoate (7) that increase worker safety risks.

Citrus root weevils. Several root weevils, including the *Diaprepes* root weevil, blue green weevils, the little leaf notcher and the Fuller rose beetle are widespread in Florida citrus groves and can cause serious economic damage if uncontrolled (8). Adults feed on young tender shoots and leaves with damage being most severe on small replants, which can be killed. Larvae feed on citrus roots throughout the year and often cause devastating impacts on trees, ranging from reduced growth and lowered production to tree death. Larval feeding sites also predispose the root system to infection and girdling by *Phytophthora* spp., thereby exacerbating economic loss. Pest management for weevils is restricted to foliar sprays for adult control and egg suppression. Barrier sprays on the soil surface prevent newly hatched larvae from reaching roots. Soil drenches of the carbamate insecticide oxamyl (targeted at plant parasitic nematodes) have also been reported to suppress root weevils.

The foliar sprays to kill adult weevils in the tree canopy use knockdown insecticides — pyrethroids, organophosphates and carbamates. Pyrethroids are the safest, least expensive and most effective option available to growers. University of Florida research has shown conclusively that less root injury and improved tree health when two foliar applications are applied four weeks apart during the summer flush period (8). Chemical pyrethroid barrier sprays applied with high volumes of water to the soil are effective in killing larvae before they reach the roots and are particularly important in protecting valuable young resets in areas infested with *Phytophthora,* where root injury must be held to a minimum. The Fuller rose beetle is flightless, and barrier sprays are also effective in controlling adult beetles as they emerge from the soil and crawl up the trunk to feed on new flush leaves. Control of this species is particularly important when fruit is exported to

Insect Pests of Florida Citrus

Pests	When controls are applied	Importance of pyrethroids	Resistance concerns	Alternative management strategies	**Potential impacts of pyrethroid loss**
Key Pests					
Asian citrus psyllid and citrus greening disease are widely distributed	Non bearing trees, 1-5 years	Control of psyllids when neonics are not yet working or are running out	Concerns for resistance in neonics and pyrethroids but no good alternative	Alternative MoAs available but needed for bearing trees	Infected young trees, tree decline and death
	Bearing trees: Winter area-wide dormant sprays (November-March)	Pyrethroids are only AIs that are effective at low temps and economical for wide area programs to reduce psyllids	None	Organophosphates and carbamates	Higher psyllid populations entering citrus in spring, more sprays increased cost, increased worker safety and environmental risk
	In season (May-September)	Needed for rotation with other MoAs to control other pests and manage resistance in psyllids	Need to rotate with alternative MoAs to achieve efficacy and manage resistance	None	Faster resistance in alternate MoAs, more sprays at greater cost, more greening, lower yield
Hemipteran complex Leaf footed bugs , stink bugs and citron bugs	Spring-summer (May-June)	Safest and most effective option	None	Organophosphates and carbamates	Increased worker safety and environmental risk, increased fruit damage
Katydids, crickets	Spring-summer (May-June)	Safest and most effective option	None	Organophosphates and carbamates	Increased worker safety and environmental risk, increased fruit damage
Thrips	Flowering (May-July)	Only effective control	None	Organophosphates and carbamates	Increased worker safety and environmental risk, increased fruit damage, reduced fruit set and quality
Sporadic Pests					
Root Weevils	Early to mid-summer (June-August)	Pyrethroids needed to control adults on trees and larvae on roots, most effective AIs available	None but should be part of rotational program on trees to preserve psyllid effectiveness	Chlorpyrifos	Increased worker safety and environmental risk, more root injury, declining tree health, export contamination concerns-Fuller beetle

areas where Fuller rose beetle are not present, and quarantines are in effect. Currently the pyrethroid bifenthrin is the only registered insecticide for application as a barrier (8), and this use is of critical importance to the Florida citrus industry to control root weevils.

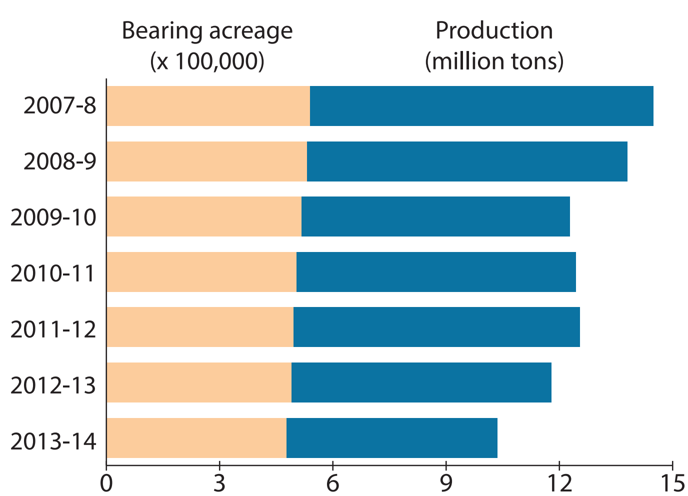
2.2 The introduction of the Asian citrus psyllid and Huanglongbing disease and the restructuring of pest management for Florida citrus

Prior to 2000, the extensive arthropod pest complex in Florida citrus was managed effectively using naturally occurring biological controls integrated with insecticides from a range of IRAC MoA groups that were used judiciously to avoid economic damage while managing resistance and minimizing disruption of natural controls.

In the late 1990s, however, the Asian citrus psyllid — a homopteran sucking insect closely related to aphids, which is distributed throughout Asia and Brazil — was introduced into Florida and unknowingly spread throughout citrus growing areas on ornamental host plants (10). The psyllid was not considered as a major threat to citrus initially as feeding damage is limited to new growth where leaves are distorted and curled due to saliva introduced during probing. Control recommendations were thus targeted to protect young trees where new leaf flush comprised the majority of the foliage (9). On mature trees, natural controls often provided sufficient suppression to avoid damage.

Huanglongbing disease (HLB or citrus greening) is caused by the bacterium, *Candidatus* Liberibacter asiaticus and vectored by the Asian citrus psyllid; it is an extremely destructive disease that is widespread in Asia and was isolated in Brazil in 2004 (10). HLB was first found in south Florida in 2005 and has since spread throughout commercial and residential sites in all citrus growing counties. Initial symptoms are manifested as yellowing of young leaves and shoots that spreads throughout the tree over several years causing twig dieback, reduced root growth, productivity decline, reduced fruit size, deformed fruit, bitterness, premature fruit drop and eventual tree death. Wherever HLB and the psyllid vector occur together, citrus production has been compromised with the loss of millions of trees (11).

Figure 1. Florida citrus acreage and production from 2007-2014.



Asian citrus psyllid adult
Photo from Wikimedia Commons

Since the introduction of HLB in Florida citrus, acreage and production has declined dramatically 539,000 acres producing 9.1 million tons in 2007-2008 to 476,000 acres producing 5.5 million tons in 2013-2014, (Figure 1) (2). The revenue received by Florida juice orange growers for the 5 year period following HLB introduction was reduced by $1.69 billion (16%) even though juice prices rose by 10-26% during that period in response to reduced supply. Employment in orange production and processing declined by over 8,000 full time jobs per year over this period (1).

HLB has had profound impacts on citrus production in Florida in the decade since its introduction and created a crisis situation, which now threatens one of the state's most valuable industries. National coverage of this disease epidemic has documented its widespread impacts on growers, their communities, the thousands of displaced workers and the adverse economic impacts on businesses and affiliated industries and to overall state gross domestic product (12, 13).

In response to the HLB crisis, the Florida citrus industry and its growers have dramatically restructured citrus pest management and have invested over $52 million since 2007 in an unprecedented research effort to combat the disease (14). Integrated pest management (IPM) practices are focused on a combination of 1) producing disease free nursery stock for replanting — it is now mandatory in Florida that nursery stock is produced in psyllid proof enclosures and certified as HLB-free; 2) Reduction of inoculum by frequent disease surveys and removal of infected trees; and 3) suppression of psyllid populations with aggressive insecticidal control programs (11).

Disease free nursery stock for replanting is an essential first step in re-establishing tree inventories following death or removal. Young trees are immediately exposed to infection by HLB infected psyllids, particularly as single resets in existing orchards. Solid plantings of healthy trees are less susceptible, but both solid plantings and resets must be aggressively protected from adult psyllids. Soil applications of neonicotinoid insecticides are critically important in providing systemic protection (11), but since it may require an extended period for the systemic to become fully distributed in the tree and there are limits on how much active ingredient can be used, foliar insecticides are also needed to protect young trees until the systemic is effective. Organophosphates (chlorpyrifos) and pyrethroids are the most effective alternatives in controlling adult psyllids (14,15) and providing this early season protection.

Young orange trees with symptoms of citrus greening

Scouting of groves to detect HLB-infected trees is done frequently to identify trees for removal, but since HLB can remain symptomless for some time following infection, it is difficult to achieve removal fast enough to avoid creating potential inoculum sources. Polyermase chain reaction (PCR) based diagnosis is available for early detection but is expensive and time consuming. When infected trees are removed, it is essential to kill adult psyllids on the tree to prevent movement to nearby trees; this is achieved most effectively with targeted pyrethroid applications (11). Aggressive tree removal protocols were developed to prevent spread of citrus canker (a quarantine disease), but since HLB-infected trees can often produce saleable fruit for several years after infection, these protocols were not implemented widely

for HLB. When infected groves were no longer economic, groves were often abandoned, creating large untreated reservoirs of both HLB and infected psyllids.

Soil-applied neonicotinoid insecticides are effective in protecting young trees from adult psyllid invasion and HLB infection, but this systemic activity is only effective for 60-80 days. It is therefore necessary to apply additional foliar insecticides for psyllid control during the growing season. An aggressive psyllid control program with the goal of reducing psyllid populations in commercial citrus groves to as low a level as possible and still remain economically viable is now the foundation of the Florida HLB management program (9). To achieve this goal, a broad array of insecticidal tools have been evaluated for psyllid efficacy (15), and a range of alternatives spanning several IRAC MoAs is now available to growers (16).

Most growers currently use a control program that involves 8-12 insecticidal applications to control psyllids at a cost of over $1,000 per acre with an additional cost of up to $600 per acre for foliar micro- and macronutrients to mitigate HLB symptoms and reestablish root systems that are severely reduced by HLB (17). The total cost of current psyllid/HLB programs ($1,600/acre) is now over twice the cost for both insecticides and soil-applied fertilizers pre-HLB ($800).

These psyllid control programs are implemented on both young, non-bearing trees (from planting to 4-5 years) and older bearing trees. On young trees, a systemic neonicotinoid is applied each year to the soil to provide protection for 60-80 days. Recently, an anthranilic diamide, cyantraniliprole has been registered as an alternative systemic for rotation with the neonicotinoids to manage resistance, although the higher cost (over $100/acre) has limited its use (15). Supplemental foliar sprays of broad spectrum pyrethroid or organophosphate insecticides are also applied when needed before and following the systemic activity periods (9).

On bearing trees, broad spectrum sprays are most effective during tree dormancy in winter prior to the presence of new flush when adult psyllids are not reproducing, and natural predators are not present in the groves. Two dormant sprays were shown to provide excellent reduction in psyllid populations for extended periods prior to their reproduction on new growth in spring. Pyrethroids are the most effective dormant sprays as they are active at lower temperatures than other broad spectrum materials, and the dormant spray tactic has now been implemented as a key component of an area-wide psyllid management program in Southwest Florida (18, 19). Aerially-applied dormant sprays of pyrethroids (coordinated by the Gulf Citrus Growers Association and the Florida Department of Agriculture) treated over 80,000 acres of citrus in 2008-2009 and reduced psyllid populations by 71-88% compared to untreated groves in the spring of 2009.

In addition to the dormant sprays in winter, it is also necessary to manage psyllids during the growing season, which lasts from spring flush through mid-fall. Trees are sampled frequently by inspection and with sticky traps. Foliar sprays are applied when psyllids are detected. Insecticide alternatives with at least 8 IRAC MoAs are available for in-season control (9), but tim-

The Insecticidal Resistance Action Committee (IRAC) has developed Modes of Action (MoAs) list and numbering systems to determine resistance management strategies and risk.
Maintenance of multiple categories is necessary to prevent the onset of resistance to many species, and multiple MoAs and tactics help delay resistance for insect pests.

ing and choice of products varies between growers based on factors that include overall budget, material cost, efficacy, pest pressure, conservation of natural enemies and resistance management (15). Alternatives include foliar neonicotinoids (group 4A), which should not be used following soil applications of group 4A materials to conserve efficacy on young trees; diflubenzuron (group 15) and fenpyroximate (group 21A), which control only nymphs and should be applied only during leaf flush/flowering; spirotetramat (group 23), which controls only nymphs but cannot be applied during bloom; spinetoram (group5), which has a limit of three applications; abamectin (group 6) with applications 30 days apart; cyantraniliprole (group 28),which has a high cost (over $100/acre); organophosphates, primarily chlorpyrifos (group 1), which is toxic to bees and natural enemies; and pyrethroids (primarily fenpropathrin) (group 3), which is toxic to bees and natural enemies.

All alternative active ingredients for in-season psyllid control, both selective and broad spectrum, are needed to manage resistance, conserve natural enemies, protect bees, improve worker safety and lower economic cost. Chlorpyrifos is effective and inexpensive but should not be used when bees or natural enemies are present or when workers are active in groves for maintenance and harvest. The pyrethroids are most suited for use in late season on bearing trees. At this time, trees are not in flower, natural enemies are less important, and a good worker safety record with short PHIs and re-entry intervals (REIs) do not impact harvest, which is done by hand. The low cost and efficacy of pyrethroids are important grower considerations and the MRLs established globally for many pyrethroid insecticides are critical in fresh citrus for export.

2.3 Main insights from Florida citrus production

- The Florida citrus industry is in a crisis situation in which the bacterial disease, Huanglongbing (HLB, citrus greening) that is vectored by the Asian citrus psyllid in combination with a failed citrus canker eradication program has cut citrus acreage and production dramatically since its introduction in 2005 and currently threatens continued citrus production in the state.

- There is currently no cure for HLB, and the sole approach to managing disease spread is to implement intense chemical control of the psyllid vector. This approach requires multiple insecticide applications throughout the year to hold psyllid populations in check and has necessitated a restructuring of citrus pest management that prior to HLB, featured a balance of naturally occurring biological controls and judicious insecticidal use.

- A range of insecticide active ingredients with psyllid efficacy encompassing several IRAC MoAs is available to growers to manage resistance, but the year round need for psyllid management and the continual re-infestation potential resulting from untreated and abandoned groves forces growers to use all available chemical classes.

- Pyrethroid and organophosphate (primarily chlorpyrifos) insecticides are the most effective and economical active ingredients for adult psyllid control during the mid- to late growing season. Worker safety concerns

(5 day REIs), bee toxicity and a 21 day PHI limit chlorpyrifos availability during the season while pyrethroids with good worker safety (12-24hr REIs, 0-3 day PHIs) enabling harvest and established MRLs allowing export are critically important components of citrus pest management programs in the HLB era.

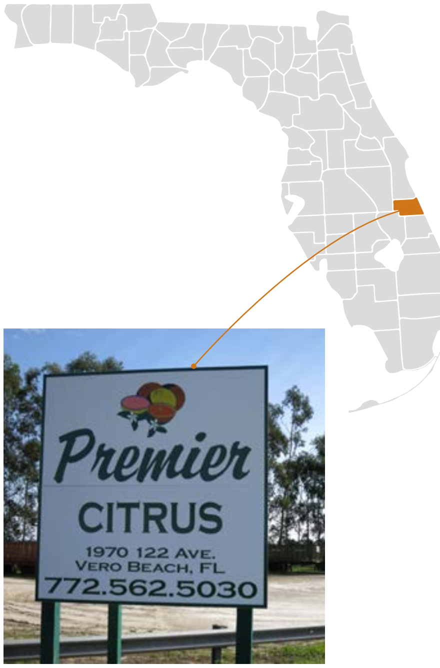
- Insecticidal active ingredients with a range of IRAC MoAs are essential and used in conjunction with pyrethroids to maintain psyllid suppression and manage resistance with each having advantages and disadvantages that dictate their use patterns. During bloom, diflubenzuron (group 15) and fenpyroximate (group 21A), which control only nymphs, are registered. During the season, foliar neonicotinoids (group 4) cannot be used on trees treated with group 4A soil applications to preserve efficacy in protection of young trees. Abamectin (group 6) has only short term psyllid efficacy. Spirotetramat (group 23) controls only nymphs, and spinetoram (group 5) should not be used during bloom, which is often extended in HLB infected trees. Newer active ingredients such as spirotetramat and cyantraniliprole are expensive compared to pyrethroids ($5-6/acre) which further limits their effectiveness.

- Dormant sprays during winter when psyllids are not reproducing and natural enemies are not present in groves are extremely effective in reducing overwintered psyllid adults prior to spring flush. Pyrethroids, which are active at lower winter temperatures, are essential for this use pattern and are currently used effectively in area-wide dormant spray programs.

- Neonicotinoids are of critical importance as soil applications providing systemic control of psyllids on young trees in resets and solid plantings. Pyrethroids may also be required to provide psyllid control prior to establishment of neonicotinoid systemic activity, as an alternative mode of action in between neonicotinoid applications for resistance management, and after systemic protection has expired on young non-flowering trees. In a scenario where neonicotinoid use patterns on citrus are withdrawn, all psyllid protection would need to be achieved with foliar insecticides that would result in significant increases in insecticidal applications, increased resistance and loss of efficacy in alternative active ingredients and unsustainable increases in the cost of control programs. This would likely result in accelerated loss of citrus acreage and production.

- The loss of pyrethroid insecticide use patterns for psyllid control would require a substantial shift to alternative active ingredients with resulting increases in resistance, unsustainable control costs and accelerated loss of citrus acreage.

- In addition to their role in psyllid management, pyrethroids are also the sole alternatives in the management of other damaging pests in the citrus pest complex including barrier soil applications and foliar sprays for root weevil management; foliar sprays for thrips; control of katydids and grasshoppers invading groves; and control of hemipteran bugs entering groves from untreated areas. The organophosphate chlorpyrifos, which is under review, is the only effective alternative material to pyrethroids for these uses that can cause serious economic damage if uncontrolled.



2.4 Impacts of pyrethroid insecticides at the farm level: A case study, Premier Citrus, Vero Beach, Florida

It's not hard to sense that something is amiss as you drive North on Interstate 95 through Indian River County, the heart of Florida's renowned grapefruit country. Instead of picturesque groves of neatly kept citrus, you see abandoned groves of dead and dying trees and rank vegetation. Even the producing groves are often filled with a mix of mature trees and young replants; the young trees filling the gaps created by tree removal programs designed to curtail the spread of citrus greening — a devastating bacterial disease that is threatening to end Florida' long tradition as the nation's leading citrus producer.

Premier Citrus in Vero Beach is fighting this battle in the trenches, determined to keep production flowing until science finds a cure, and the industry can begin rebuilding to its former preeminence. Premier Citrus is one of Florida's leading producers — growing, harvesting, packing and shipping 20,000 acres across six counties in the citrus belt. Two thirds of Premier's production is devoted to round oranges grown for juice, and the remaining third, primarily grapefruit, navel and Valencia oranges and tangerines are packed in one of Florida's newest and largest plants and sold fresh throughout the U.S. and abroad. Premier Citrus was started by Gaylon Lawrence, a corn and soybean farmer, who began growing citrus in Florida in the 1970s and with his son Gaylon Jr., quickly became the state's largest producer with 30,000 acres. The company's success is built on vertical integration involving land preparation, planting, grove maintenance, harvesting, packing, marketing and shipping. They also manage their own real estate, converting unproductive groves into developments or re-purposing agricultural land from citrus into other tree crops (Premier is now the largest producer of early market peaches in Florida with 150 acres) or in some cases, returning it to row crop silage corn for the dairy industry.

To examine the challenges facing the citrus industry in dealing with the citrus greening epidemic, we went to one of the state's leading experts, David Bass, a veteran of 35 years in citrus production and pest management. David oversees all of Premier's citrus acreage from his bustling farm headquarters in Vero Beach with the help of five grove managers, each responsible for 5,000 acres scattered across six counties. We asked David what his primary challenges were in dealing with the Asian citrus psyllid and HLB , how he approached the problem, what tools were available to him, what impacts HLB was having in the local economy and finally where he saw the industry headed in the future.

There is no cure for the tree once it is infected by HLB, and David estimates that a remarkable 100% of the trees in his groves, from young to mature trees, are already infected. Many trees will continue to produce for a few years but with declining yield and quality. Looking at a mature grapefruit grove next to the farm headquarters, David estimated that he needed to yield 300 to 400 boxes/acre just to break even on his production costs of $2,000/acre.

"All these rows here used to do 800-900 boxes without batting an eye, now they are all teetering at 350 to 400 because of the disease."

The only option for growers is to control the psyllid vector and to cut down on further spread of the disease between trees by protecting young replacement trees for as long as possible. David knows that psyllid populations increase quickly on new flush leaves and in the past, that was a good cue to apply controls but that has changed as a result of HLB.

"You'd have spring, summer and fall flush, and you could time applications. Now, they are flushing all the time because of the disease. You want to keep the population down from day one, but there's constant flushing, so we have to constantly spray for the psyllid. We are spraying 10 to 12 times a year, and some are spraying up to 18 times a year."

To eliminate unneeded sprays David has every acre scouted every two weeks for psyllids. He uses Glades Crop Care, the leading independent crop consultant in Florida, to provide in-depth assessments, but he still needs to use all of the pesticide options open to him to stay ahead of the psyllid and manage resistance development. Even with psyllid monitoring now mandatory and conducted within irrigation districts to make sure that all growers are following good programs, groves that have become uneconomical due to HLB are abandoned and rapidly become untreated sources of infected psyllids that impact everyone.

In terms of what tools are used and how he manages resistance, David says:

"We try to be good stewards, we look ahead and do everything by the book. We definitely rotate the pyrethroids with imidocloprids, but what's getting taken away from us are the only things that work."

The prospect of losing the least expensive alternatives, such as chlorpyrifos, the pyrethroids or the neonicotinoids in David's opinion would be "crushing to the industry." In his management program, chlorpyrifos is versatile as a psyllid material with miticidal activity; three different pyrethroids are used if needed during the season and are particularly valuable in the fall and spring when temperatures are lower (dormant sprays); and neonicotinoids are essential tools as systemics to protect replants and young trees from infection.

Alternative insecticides are available for use in rotation with pyrethroids, organophosphates and neonicotinoids, and David employs them all, but each has restrictions that prohibit certain uses and all cost significantly more. HLB and high spring temperatures promote early and prolonged flowering and diflubenzuron (group 5) and fenpyroximate (group 21A), which only control nymphal psyllids, are the limited materials registered for bloom application. Sulfoxaflor (group 4C), which controlled both nymphs and adults and could be applied during bloom, was canceled in 2015 and is no longer available, leaving no alternative for adult control at a critical time when new flush and flowers are present. Alternative active ingredients during the season that are used at Premier include spinetoram (group 5), abamectin (group 6), which has limited psyllid efficacy, and spirotetramat (group 23),

David Bass inspects a young orange tree

which also controls mites, scales and mealybugs but costs $30-40/application (6-8x the cost of pyrethroids or chlorpyrifos). A newly registered alternative, cyantraniliprole, is planned for inclusion in the Premier 2016 program but is anticipated to be expensive, and establishment of MRLs will be important to allow its use on fruit for export.

With high levels of concern over the impact of insecticides on bees, David has implemented bee stewardship programs and works with beekeepers in his groves even though his varieties do not require pollination. David says:

"We use only bee-friendly chemistries and spray at night during bloom time, but with these prolonged blooms, it's difficult so we work with them, and they pull the bees out if we have to treat."

Although psyllids dominate the Premier spray programs, there are always challenges from other parts of the pest complex that must be taken into consideration. Root weevils are an excellent example with *Diaprepes* weevil being the most challenging. In David's words:

"Diaprepes is absolutely one of the most devastating insects you can get, you can't beat them; if it's on heavier soils, you'll lose."

Until 2015, David was using soil applications of the carbamate oxamyl in the anticipation of getting both nematode and weevil control. Oxamyl, which is highly toxic and susceptible to leaching, was not available in 2015, and the only alternatives in 2016 will be foliar sprays of pyrethroids or chlorpyrifos for adult control in trees, or the newly registered pyrethroid bifenthrin applied as a directed soil spray to control emerging adults and neonate larvae as they enter the soil.

When asked to sum up Premiers psyllid/HLB programs David states:

"We're in the fight of our lives, and it's very critical, there are a lot of people going out of business. Losing OPs [organophosphates] and pyrethroids right now could be the final straw that broke the camel's back on a lot of people."

"I would be willing to bet that if you could find ten other growers, you would be repeating this same conversation. Problem is, finding ten growers that are still in business, I can't. We are fortunate that we are diversified and vertically integrated and have great ownership. We are still in the game, but it hurts. We are having a really tough go of it in the citrus industry".

When asked what he sees as the impacts of the HLB epidemic, David says:

"When it first hit here, a lot of people were in denial, but once they started seeing the damage being done and finding there wasn't much that could be done about it, some of them got out".

Many growers either sold or abandoned their groves, and the peeling for-sale signs are now common sights along the rural backroads. Reduced production forced packing plants and processing facilities to consolidate or shut down. In a ripple effect, related businesses throughout the supply

chain, such as agrichemical and fertilizer dealers, truck dealerships, transport companies, equipment suppliers and others, were forced to downsize or close.

Perhaps the biggest impacts were felt in the local workforce, where 10,000 permanent jobs in Indian River County in the mid-1990s have now been reduced by more than half (20). On the farm at Premier Citrus, David remembers:

"Five years ago, I signed 180 checks a week for people that just worked in the field. Now we are down to 90 from just cutting back where you can and then just flat out loss of acreage."

Premier's round orange production for juice was 150 million boxes just three years ago, but now the 2016 forecast is down to 75 million boxes. David says:

"When that happens, you get down to where you can't keep the concentrate plants open; they have to have a certain volume to stay open. Your market starts seizing."

The results can be seen throughout the local community, from the pickups lined-up for sale at the grove entrances to the unoccupied houses.

The future may seem bleak, but Premier is betting on staying in business. They are working closely with and supporting the Citrus Research and Development Foundation that is investing millions of grower, state and federal dollars into research to find a cure for HLB. David shares that confidence:

"There are some things coming down the road that we are pretty confident about; we're going to get something this year that might have some effect."

He is referring to the exciting new prospects emerging from research labs for antibiotic treatments that will kill the bacteria in the trees. Premier is already planning for major new investments with new plantings of healthy trees that they can protect. David concludes:

"Scientists from all over the world are working on this. In the meantime, we are doing whatever it takes to hang on."

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Abandoned orchards and equipment for sale are a common site in Florida's citrus producing regions

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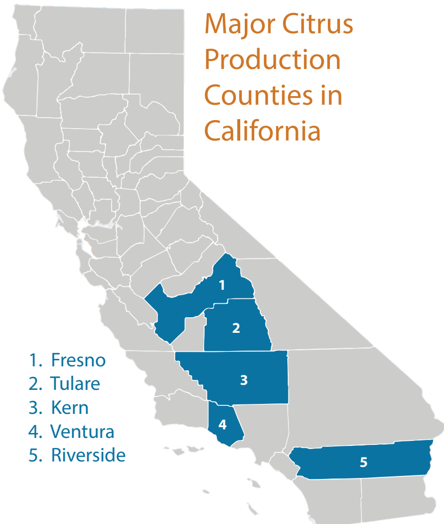


3.0 California citrus

Citrus is one of California's most important agricultural crops with 254,000 acres valued at over $2.4 billion in 2014 (1). Production of 3.5 million tons in 2013-2014 comprised 37% of the national output, and together, Florida and California grew 97% of U.S. citrus (2). Most California citrus is grown for fresh consumption with the primary crops being navel oranges (123,000 acres), Valencia oranges (34,000 acres), mandarins (44,000 acres), lemons/limes (42,000 acres) and grapefruit (8,000 acres) (3,4). Oranges ranked 7th in value among commodities grown in California with a significant portion of the crop exported to Canada, Asia, Australia and New Zealand (1). In contrast to citrus in Florida — where natural disasters, a failed citrus canker eradication program, and most recently, citrus greening disease have resulted in acreage and production declines — California citrus has remained relatively stable over the past six years with production increasing from 3.3 to 3.5 million tons and acreage increasing from 267,000 to 270,000 acres (2).

Citrus is grown in four distinct production regions throughout the state, which are somewhat isolated from each other and have differing climates and pest management challenges (1). The largest area with 75% of state production, primarily oranges and mandarins, is in the San Joaquin Valley in central California; citrus acreage is concentrated in Kern, Tulare and Fresno counties. This region has the greatest extremes of temperature and generally the most difficulty in establishing reliable biological control of insect pests. The coastal areas from Ventura County to San Jose, with 15% of state production, is devoted largely to lemons and oranges and has a moderate climate. The southern interior, encompassing Riverside, San Bernardino and San Diego counties, was once the center of the citrus industry, but demographics switched from agriculture to urban in the mid-1900s and most of the acreage has moved to the San Joaquin Valley, leaving approximately 5% of the state production in the southern valleys. The southernmost production area is in the desert valleys of Imperial County where 5% of the state citrus is still produced. Hot dry conditions prevail in the southern deserts, and due to its proximity to Mexico and Central America, this area is usually the first to experience introductions of exotic pests.

3.1 Pest management in California citrus — the arthropod pest complex, management approaches and the role of pyrethroid insecticides

As seen in Florida, a diverse and potentially destructive complex of arthropod pests is also present in California citrus that requires intensive annual management to avoid economic loss (5). In Florida, however, the exotic Asian citrus psyllid and the destructive citrus greening disease Huanglongbing (HLB) associated with it were introduced in the early 2000s and quickly spread throughout the citrus production areas, reaching a crisis situation in less than a decade. This introduction resulted in a complete restructuring of pest management in Florida and a transition from a largely biologically-based system to a completely insecticide based one. In contrast, the Asian citrus psyllid was not introduced into California until 2008, and although it has since spread throughout the state's main citrus production areas, HLB was not introduced until 2013 and has thus far been contained

close to the site of its introduction. California is only recently beginning to implement strategies to manage this destructive vector and disease combination and is working to achieve a balance between the well-established tradition of biologically-based pest management of the existing pest complex and the need to increase insecticide management of HLB and its psyllid vector. The greater geographic isolation of the California citrus production regions compared to the continuity of production in central Florida and the absence of catastrophic weather events that helped to distribute the vector/disease complex in Florida will likely result in slower disease movement and a more orderly transition in management systems in California.

California has also recently experienced a different exotic insect introduction, the glassy-winged sharpshooter, which was a minor pest of citrus but transmitted a serious bacteria- like pathogen causing Pierce's disease of grapes. This exotic pest/disease combination has several parallels to the psyllid/HLB introduction and also resulted in a rapid increase in insecticide treatments that disrupted established natural controls in California. The sharpshooter/Pierce's disease introduction is providing valuable insights into management of the ongoing psyllid/HLB introduction.

The broad insect pest complex in California is similar to that described in Florida with variability in individual species and pyrethroid management strategies noted below (1,5):

Homopteran sucking insects. A broad complex of homopteran pests are endemic in California citrus: scales (two armored scale and four soft scale species); the citrus mealybug; whiteflies (three species); and aphids (three species, all transmit tristeza virus) (9, 10, 11, 12). These homopteran pests are widespread and vary in importance between production areas. All are normally held at sub-economic levels by natural enemies, and growers and pest control advisors (PCAs) are endeavoring to time needed applications of broad spectrum insecticides, such as pyrethroids and organophosphates, to avoid disrupting natural enemy populations. Soil application of systemic neonicotinoid insecticides are now increasingly applied to manage the citrus psyllid and also provide early season control of aphids, whiteflies and some scales . All homopteran pests are capable of rapid population increases to economically damaging levels, and when this occurs, selective insecticides are recommended to reduce damage.

The citricola scale is controlled effectively by natural enemies in southern California production areas, but these are ineffective in San Joaquin where broad spectrum insecticides are often used to manage populations. Chlorpyrifos is effective in controlling citricola scale, but 40% of populations are resistant to this active ingredient, and other broad spectrum insecticides are often used when needed to obtain control (1, 13). Pyrethroid active ingredients with homopteran efficacy would be safer alternatives than the organophosphates and carbamates currently employed.

Hemipteran plant bugs. In contrast to Florida, plant bugs are not serious economic pests in California citrus. However, an extremely damaging exotic stink bug — the brown marmorated stink bug — has recently been

Insect Pests of California Citrus

Pests	When controls are applied	Importance of pyrethroids	Resistance concerns	Alternative management strategies	Potential impacts of pyrethroid loss
Key Pests					
Asian citrus psyllid established and spreading but HLB not yet on citrus	Fall , winter and spring (November-April)	Reducing populations before season, low temperature efficacy needed	None	Organophosphates and Carbamates	Increased worker risk, faster psyllid spread
	In season (May-October)	Low psyllid areas: eradicate at source, pyrethroids most effective	None for eradication	Other broad spectrum	Increased worker safety risks, failure to stop spread
		Established areas: disinfest to prevent spread to new areas	None	Rotate pyrethroids with other MoAs to manage resistance	Resistance in alternatives, faster spread to new areas, failure to meet quarantine
Glassy-winged sharpshooter	Winter (November-March)	Only effective dormant sprays at low temperatures	None	None	Movement to grapes and Pierce's disease, increased fruit damage
	Spring (April-May)	Supplement neonicotinoids		Organophosphates and carbamates	Increased worker risk, more damage to grapes
Thrips	After petal fall (May)	Only effective material to protect small fruit	Use for thrips early to preserve effectiveness of alternates for psyllids	Alternatives used for psyllids later	Increased psyllid resistance, faster establishment
Katydids	Petal fall (May)	Only alternative to protect small fruit	None	None	Increased damage
Diaprepes root weevil	Early season (May-July)	Soil barrier sprays to target emerging adults with follow up foliars to prevent egg laying	None until follow up sprays, which can impact psyllid AIs	None early, psyllid programs later	More root damage, reduced yields, more fruit damage
Fuller rose beetle	Mid-summer (July-August)	Only alternative as soil barrier spray to kill emerging adults	None	None for soil chlorpyrifos for adults on tree	Failure to meet quarantine for export to Korea, increased worker risk at harvest
Sporadic Pests					
Citricola scale (San Joaquin only)	All season (June- September)	Needed if chlorpyrifos not available	40% of populations resistant to organophosphates, pyrethroids are alternatives	Chlorpyrifos and carbamates	Reduced tree vigor, fruit quality, increased worker and environmental risk
Brown marmorated stink bug (potential)	Early season	Pyrethroids only effective option	None	None	Potentially serious fruit injury

introduced into North America and has been detected in the northern San Joaquin Valley. This exotic pest has an extremely wide host range and presents a potentially serious new threat to the citrus industry. Broad spectrum insecticides, such as the pyrethroids and chlorpyrifos, are the only effective controls for this pest threat, which further emphasizes the critical importance of pyrethroids.

Chewing insects. The fork-tailed bush katydid, a heteropteran pest resembling the grasshopper, can move into citrus from nearby vegetation and cause serious economic damage if not controlled (1,15). Katydids feed on developing fruit at petal-fall, causing scarring that distorts enlarging fruit. A single individual frequently feeds on a series of fruit allowing low populations to cause widespread damage. Katydid control is normally achieved with chlorpyrifos and carbamate sprays, but as these uses have been scaled back by regulation, katydid populations and damage have increased substantially. Alternative insecticides, such as spinosad or cryolite, do not provide effective control. As chlorpyrifos uses continue to decline, pyrethroids represent essential alternatives that are safe, effective and inexpensive. Timing pyrethroid applications following petal fall, when damage is occurring, would avoid bee toxicity and is early enough in the season to allow natural enemies to establish following treatment.

Thrips. Citrus thrips are a greater economic threat in California citrus than in Florida, with most severe damage occurring on San Joaquin navel oranges, desert citrus and coastal lemons (16). Larvae feed on developing fruit causing scarring from petal fall until fruit are one and a half inch diameter. Control alternatives for thrips in several IRAC MoA classes are available, but since these materials are also critically important for psyllid control, it is important to select materials that will not impact resistance management for psyllids. Selective materials for thrips control that preserve natural enemies for the entire pest complex include spinetoram, spinosad, abamectin and spirotetramat ; however, to avoid phytotoxicity, these materials, which are usually tank-mixed with oil, cannot be applied 30 days before or after sulfur sprays (frequently used for mite management). Applications to fruit less than one inch in diameter (when thrips control is essential) are also not recommended, which further restricts the availability of these active ingredients. The alternative active ingredients for thrips control are the pyrethroids, which provide excellent knockdown with good persistence and can be applied to small fruit after petal fall without bee toxicity or prolonged disruption of natural control.

Bean thrips are not a direct pest of citrus but can move into groves from surrounding crops and contaminate navel oranges in the San Joaquin and interior southern valleys. Adult bean thrips move into citrus in the fall and can enter the navels to overwinter, creating a contamination that is unacceptable for export and often requiring fumigation with methyl bromide. As fumigation alternatives become limited, targeted applications of pyrethroids, which have established MRLs, would be needed in late season to meet quarantine requirements.

Citrus root weevil. *Diaprepes* root weevil can be an economically important pest of citrus in California, but its distribution is limited and overall

Close to 90% of California's citrus acreage is located in the five leading counties, namely Fresno, Kern, Tulare, Ventura and Riverside

https://apps1.cdfa.ca.gov/FertilizerResearch/docs/Citrus_Production_CA.pdf

impact is less than in Florida (17). When the *Diaprepes* root weevil is present, both adults and larvae can cause economic damage. Adults feed on young shoots and leaves and lay eggs in the spring, and larvae drop to the ground and feed on young fibrous roots for 9-18 months. Since root feeding can cause serious damage to the trees, *Diaprepes* must be managed year round to be effective; pyrethroids are integral components in these programs. Two soil-applied barrier sprays of bifenthrin are timed to kill adults emerging from the soil in spring, and foliar pyrethroid sprays are effective in preventing adult feeding and egg laying. Larval control in the soil is also achieved with soil-applied systemic neonicotinoids applied early in the year when root growth is occurring. These neonicotinoid treatments are also key components in managing psyllid infestations in young trees, and if regulatory actions limit neonicotinoid use, psyllid management would require more foliar applications using pyrethroids, organophosphates and several alternative active ingredients. Such programs would be less effective, more expensive and result in multiple applications and accelerated development of resistance. Root drenches with parasitic nematodes to suppress larvae in the soil are an expensive alternative and are not readily available.

Fuller rose beetle. The Fuller rose beetle is flightless; adult beetles emerge from the soil in mid-summer, climb up the trunk, feed for a brief time on foliage and lay eggs under the button of the fruit. Eggs hatch in two weeks, and larvae drop to the soil and feed on the roots. The adult and larvae rarely cause economic damage, but viable eggs under the fruit button are a contaminant on fruit for export to Korea (a key export market) where Fuller rose beetle is not present and quarantines are in effect. Contaminant levels of one fruit infested with viable eggs in a 500 fruit sample are enough to result in rejection; thus strict control is essential when this weevil is present and fruit are exported to Korea.

Controls are targeted at adult beetles, which emerge year-round, but peak in August in the San Joaquin and a month later in the southern interior valleys. Soil applications of the pyrethroid bifenthrin are applied prior to peak emergence to kill adults before they climb to the foliage. If these treatments are not effective, 1-2 foliar sprays are needed to kill adults prior to egg laying. Currently, chlorpyrifos or the pyrethroid beta-cyfluthrin pre-mixed with a neonicotinoid or chlorantraniliprole are recommended. However, foliar sprays of neonicotinoid pre-mix should not be used to avoid resistance to systemic neonicotinoids, which are essential in protection of young trees from psyllids. The pre-mix with chlorantraniliprole is too expensive to be a realistic alternative.

Glassy-winged sharpshooter. The glassy-winged sharpshooter (GWS) is an exotic leafhopper pest that was introduced into Southern California in the late 1980s. It is currently distributed throughout southern fruit production areas and the south eastern San Joaquin Valley where it is confined to Kern and Tulare counties. The GWS continues to spread north in the San Joaquin, but infestations have so far been eradicated or suppressed and quarantine measures are in place to contain further spread (19).

The GWS is a phloem feeder that has a wide host range including citrus and grapes. High populations can reduce fruit quality and yield of citrus in

coastal and southern inland valleys, but populations rarely reach these levels now that citrus is routinely treated with insecticides to manage psyllids. In contrast, the GWS is a major economic pest of grapes as the vector of the Pierce's disease (bacterial), which blocks the conductive tissue and results in vine death.

Grapes and citrus must be closely linked together to manage the GWS and reduce the incidence of Pierce's disease in grapes. Currently, treatments are applied to citrus primarily 1) to reduce populations that overwinter and build-up in citrus and that then may move to grapes or 2) to disinfest citrus trees prior to harvest to avoid movement of GWS to un-infested areas on fruit (19). Quarantine regulations are now in effect that require areas of Kern and Tulare counties to be disinfested prior to harvest to prevent movement of GWS north on fruit to packing sheds in un-infested areas, which protects the large and economically important northern California grape and wine industry. These regulations are strictly enforced as an epidemic of Pierce's disease is occurring in Kern and southern Tulare counties.

For suppression, overwintered GWS is treated in citrus to prevent movement into grapes; soil-applied systemic applications of neonicotinoid insecticides are commonly used on citrus. Prior to the arrival of psyllids as a citrus pest, these neonicotinoid applications were primarily beneficial to grape producers. Now that psyllids have attained pest status, the systemic neonicotinoids are routinely used to manage psyllids. Since the systemic neonicotinoids take several days to become effective and distribution within and between trees is uneven, foliar sprays of pyrethroids are also essential in spring suppression of GWS. Early season pyrethroid sprays are particularly effective as their efficacy is retained in cool weather. Applications in early spring are also good pest management tools to suppress overwintering psyllids and are less likely to disrupt natural enemies. If neonicotinoid active ingredients are regulated, there would be a significant increase in pyrethroid, organophosphate and carbamate applications for GWS suppression and a greatly elevated risk of resistance in other pests, including psyllids and thrips.

For disinfestation of citrus to meet quarantine regulations, the recommended treatments are foliar applications of the pyrethroid beta-cyfluthrin or carbamate methomyl. Since much of the fruit packed in the San Joaquin is exported, it is essential that international MRLs are established for the active ingredients used. Methomyl has established MRLs, but its use when worker exposure is high during harvest should be discouraged; pyrethroids are then essential pest management tools for the lucrative export market.

3.2 The emerging threat of the Asian citrus psyllid and Huanglongbing disease in California citrus

In California, the psyllid and HLB have only recently been introduced and pest management strategies are evolving to manage psyllids and HLB without sacrificing the well-established biological controls (20). This is in contrast to the Florida citrus, where the Asian citrus psyllid and HLB were introduced over a decade ago and have now spread throughout the citrus production area, reducing production to crisis levels and resulting in the complete restructuring of citrus pest management.

Asian citrus psyllid adult
Photo from Wikimedia Commons

The Asian citrus psyllid arrived in California from Mexico in 2008; it was detected in San Diego County and the southern desert valleys. The psyllid has annually increased its range northward, and by 2012, it was prevalent throughout southern production areas and as far north as Santa Barbara in coastal areas (21). First detections in the main citrus areas of central California were in the eastern San Joaquin Valley in Tulare county in 2012. By 2014, psyllids were detected throughout Kern, Tulare and parts of Fresno counties in the southern San Joaquin Valley and in isolated locations in San Jose, Stockton and Sacramento in the northern valley. The California Department of Food and Agriculture manages an extensive Asian psyllid surveillance network throughout the state in residential areas and commercial groves. Inspectors examine foliage, check sticky traps and test both psyllids and trees for HLB. Quarantine areas are established around all psyllid finds that require chemical control and releases of natural enemies (21). Psyllid quarantine areas have now been established in 17 counties that prohibit movement of all plant parts except fruit to slow psyllid spread.

When grown for fresh production, more insecticides are used due to the need for defective-free fruit

HLB was first detected in California in 2012, when it was isolated from a residential area in Los Angeles County. No further detections were reported until 2015 when five additional infected trees were found 15 miles from the initial site (22). As of February 2016, a total of 14 positive detections have been reported with clear evidence that these resulted from two separate introductions and have not spread from the original site (Personal communication, J Morse, University of California, Riverside). Fortunately, all of the detections have been concentrated in urban Los Angeles County, and HLB has not yet been found in commercial citrus. The citrus industry is prepared for invasion and spread of HLB into commercial groves; strict control measures are being adopted by growers to suppress psyllid populations to limit the chance of HLB spread.

Currently, treatments that are applied to California citrus groves are designed to disinfest trees prior to harvest and thus, minimize the risk of moving psyllids in bins of harvested fruit. In areas of new infestation, when psyllid numbers are low, populations can be potentially eradicated locally if treated aggressively within 800 meters. Soil-applied systemic neonicotinoids applied June through September are effective at holding populations down but should be combined with foliar sprays of broad spectrum insecticides that provide good knockdown, long residual, worker safety and efficacy against all developmental stages. Pyrethroids are the most effective materials; four pyrethroid active ingredients are recommended by the University of California as having the greatest IPM value when applied in this use pattern (20). Neonicotinoid foliar sprays, alone or in premixes with other active ingredients with differing IRAC MoAs, are also effective but should not be used when soil-applied neonicotinoids are used.

For areas where psyllids are already established, such as the southern deserts and inland valleys, insecticides should be applied routinely throughout the season and also during fall and winter to achieve suppression using a range of active ingredients that will control psyllids while causing minimal

disruption of natural enemies. The most effective time to suppress populations is in late fall (October-December) when trees are dormant, adult psyllids are slow moving in cooler weather, and natural enemy populations are low. Broad spectrum pyrethroids, which work well at low temperatures, are the most effective pest management tools at this time. Chlorpyrifos, dimethoate and carbaryl are also recommended, but these present higher risks for grove workers and are not as effective as the pyrethroids.

Winter sprays (January-February) — before the new leaves flush and psyllids begin to reproduce and natural enemies re-enter the groves — are the next most effective times to suppress psyllids. Foliar pyrethroids with good cold weather efficacy are the most highly recommended pest management options at this time (20).

In-season psyllid management programs should be designed to protect natural enemies, manage resistance and hold psyllid populations at low levels to minimize movement. Soil-applied systemic neonicotinoids should be used to protect trees from March-June, and selective insecticides with differing IRAC MoAs should be rotated as foliar sprays to avoid resistance and promote natural control. Sufficient insecticidal modes of action are available to achieve these goals as described above in the Florida psyllid section.

California pest management is currently balancing a tradition of biologically-based tactics with the need to contain rapidly spreading exotic pests that vector serious diseases. Fortunately, the citrus production areas in California are isolated; HLB has not yet established in commercial plantings, and the combination of biological control, selective insecticides and carefully timed and targeted broad spectrum insecticides is allowing this balance to be maintained. Pyrethroid active ingredients are essential and effective pest management tools in this endeavor. Regulation of their use or that of the systemic neonicotinoids would result in a rapid escalation of insecticidal applications, development of resistance, loss of the ability to manage specific pests and ultimately, an economically unsustainable pest management system.

All alternatives for psyllid control are needed to manage resistance, conserve natural enemies, protect bees, improve worker safety and lower economic cost. Chlorpyrifos is effective and inexpensive but should not be used when bees or natural enemies are present or when workers are active in groves for maintenance and harvest. The synthetic pyrethroids are most suited for use in late season on bearing trees when trees are not in flower, natural enemies are less important and short PHIs and safety do not impact harvest. The low cost and efficacy of pyrethroids are important grower considerations, and MRLs established globally for many pyrethroid insecticides are critical in fresh citrus for export.

3.3 Main insights from California citrus production

- California is not yet in the crisis mode seen in Florida, and the geographical isolation between its production areas is helping to slow movement of both Asian citrus psyllid and HLB. Statewide surveillance and detection programs by the California Department of Food and Agriculture

In 1994, it was estimated that California citrus growers saved $900,000 by using cyfluthrin instead of making the extra applications of less effective insecticides

http://www.ncfap.org/documents/trendsreport.pdf

accompanied by tree removal and quarantine areas for treatment of psyllids are helping to slow disease progression.

- Pest management is at a tipping point in California where traditionally successful biological control approaches are being disrupted by the need to control psyllids year round using multiple insecticidal applications. The loss of the broad spectrum insecticidal tools in the pest management, such as pyrethroids, neonicotinoids and chlorpyrifos, would quickly lead to significant increases in pesticide applications, resistance development, sharp rises in costs of production and eventual economic decline.

- A range of insecticide active ingredients with psyllid efficacy encompassing several IRAC MoAs is available to growers to suppress populations and manage resistance, but the year round need for psyllid management and the continual re-infestation potential resulting from untreated residential citrus plantings requires growers to use all available chemical classes, both selective and broad spectrum.

- Pyrethroids and organophosphates (primarily, chlorpyrifos) are the most effective and economical active ingredients for adult psyllid control during the mid-late growing season when they can be used without irreparable disruption of natural control. Worker safety concerns (5 day REI and 21 day PHI) limit chlorpyrifos availability during late season. Pyrethroids, which have good worker safety profiles during harvest (12-24 hour REI and short PHI of 0-3 days) and established MRLs allowing export, are critically important components of citrus pest management programs in the psyllid era.

- Insecticidal active ingredients with a range of IRAC MoAs are essential and used in conjunction with pyrethroids to maintain psyllid suppression and manage resistance during the season — each has advantages and disadvantages that dictate their use patterns, and many of the newer materials are prohibitively expensive and lack established MRLs that limit use to non-export crops.

- Dormant pyrethroid sprays during winter ,when psyllids are not reproducing and natural enemies are not present in groves, are extremely effective in reducing overwintered psyllid adults prior to spring flush.

- Neonicotinoids are of critical importance as soil applications that provide systemic control of psyllids in early season on young trees. Pyrethroids may also be required at this time to control adult psyllids prior to establishment of neonicotinoid systemic activity.

- In California citrus for export, pyrethroid (bifenthrin) barrier sprays to the soil are needed mid-season to control adult Fuller rose beetles before they climb to foliage and fruit where oviposition under the fruit cap results in failure to meet quarantine requirements for export to Korea. Foliar sprays may also be required to prevent egg laying, and these normally use the neonicotinoid thiamethoxam. However, where a class 4A active ingredient is used as a systemic, it should not be followed by a foliar treatment from the same MoA class, and pyrethroids are then the only effective material.

- In California, an additional exotic pest must be managed — the glassy-winged sharpshooter. It does not cause significant damage to citrus but can move to grapes where it transmits a serious bacterial pathogen causing Pierce's disease. It is frequently managed in citrus with neonicotinoids or pyrethroids to protect grapes.
- Pyrethroids are important pest management options for several sporadically occurring pests in California citrus for which there are no effective alternatives. These include: katydids, *Diaprepes* root weevil, bean thrips on oranges for export, citrus thrips, citricola scale and brown marmorated stink bug (potential new pest).
- As a result of the need to manage introduced pests, such as psyllids and glassy-winged sharpshooter, and meet quarantine requirements for other pests, such as Fuller rose beetle in the export market, pyrethroids, neonicotinoids and organophosphates have become essential pest management tools in California citrus industry. The loss of such active ingredients through regulatory action would quickly lead to significant increases in pesticide applications, more selective materials, rapid resistance development, sharp rises in costs of production and eventual economic decline.

3.4 Impacts of pyrethroid insecticides at the farm level: A case study, Washburn and Sons, Riverside, California

The bustling, dusty headquarters of Washburn and Sons — with its tractors, trucks and warehouses — looks almost out of place today in the suburbs of Riverside, a large urban city just 50 miles east of Los Angeles. In those days, the inland valley slopes were dominated by groves of lush orange and grapefruit trees; Washburn and Sons, citrus growers and pest control specialists, were already well established and providing leadership in citrus pest management. Founded in1921 by the Alan Washburn's great grandfather, this 3rd generation operation still provides everything needed by the citrus industry. They grow over 400 acres of grapefruit south of the city, serve as PCAs and pesticide applicators on close to 6,000 acres of citrus in the inland and desert valleys and provide one of the few remaining fumigation services needed to meet quarantine requirements for the export markets.

Citrus production in the inland valleys was once the 'poster child' for the science of biological control, and many of the early pioneers in the field were researchers at the Citrus Experiment Station. They worked hand in hand with citrus growers like the Washburns to import specialized natural enemies of citrus pests (from the countries where those pests originated) and release them into local groves where they provided long lasting biological control. This is the site of the famous releases of vedalia beetles brought from Australia to control the cottony cushion scale in the late 1800s and still providing control today! Citrus acreage has been replaced by urban development and gradually moved from the inland valleys to the large commercial groves in the San Joaquin Valley. However,10% of the state's production still remains, and the Washburns (and growers like them) are still actively working to preserve the biological control tradition. Most recently, by releasing the newly imported parasite (*Tamarixia radiata* from Pakistan) to

control the newest imported pest to threaten the industry, the Asian citrus psyllid. Alan says ruefully:

"We had things pretty much under control without much spraying before the psyllid arrived."

That was in 2008 when the citrus psyllid moved from Mexico into the southern deserts. This insect has since spread throughout southern California in both commercial and residential citrus. With the importation of HLB in 2012, the industry is on full alert to avoid the devastation now faced by Florida growers. Alan is in the thick of this emerging battle and serves as the Riverside County coordinator and grower liaison for the Citrus Pest and Disease Prevention Program and the California Citrus Quality Board of the Citrus Research Board. He also collaborates actively with University of California citrus research specialists and is a contributor to University of California-Extension pest management publications.

The threat of the psyllid and HLB has changed the pest management philosophy drastically for growers like Alan. Insecticides must now be applied routinely year-round to suppress the psyllid and slow its movement and the potential for HLB. We talked with Alan in February, normally a slow time in the inland valleys, but this year was exceptionally warm and activity was hectic as Alan's crews were already applying a second winter pyrethroid spray to knockdown overwintering psyllid populations before the spring flush. At the same time, his crews were gearing up to inject systemic neonicotinoids through the irrigation systems on thousands of acres of citrus to protect them from adult psyllids moving in and to suppress GWS and prevent them from moving to grapes. As Alan says:

"They probably don't need these apps to protect citrus from psyllid if the winter sprays did a good job, but the grape growers need them for sharpshooters."

All this is happening at the same time that word came in from the California Department of Food and Agriculture that an inspector has found a significant infestation of psyllids in citrus trees surrounding a residential area and golf course. Alan's helicopter crew is dispatched to start the tricky permitting and application process to apply fenpropathrin, a safe and effective pyrethroid in a residential neighborhood. Residential citrus is ubiquitous in southern California, and since it is largely untreated, it is a significant source of psyllids. Alan confirms:

"We need to get on these right away."

In late winter, Alan describes the wind-borne flights of psyllids coming over the mountains from the affluent desert communities to the southwest, where there is no commercial citrus, as

"Waves of them blowing into our citrus."

When he gets through the hectic spring with the psyllids and the sharpshooters to deal with, the citrus season is just beginning for Washburn and Sons as now they must now embark on the difficult task of balancing

natural controls for the traditional pest complex with the need to suppress psyllids during the season. They do this by rotating selective insecticides with different MoAs that are safer on natural enemies to manage resistance in psyllids and thrips. This is no easy task, as each new insecticide has drawbacks — some cannot be used during flowering; many do not have established MRLs and cannot be used on export fruit; some control only nymphs and are only effective in early season; and most are significantly more expensive than equally effective broad spectrum alternatives, such as pyrethroids and chlorpyrifos. For economic and simple efficacy reasons, Alan must use pyrethroids occasionally during the season, when they can be timed to minimize disruption of natural enemies. Late season is a good example, when adult psyllids can be controlled without impacting natural control.

If the fruit is destined for export to Korea, it is also necessary to apply a broad spectrum foliar insecticide at this time to manage the Fuller Rose beetle, which must be killed before it can lay eggs under the fruit cap — a condition that will deny access to the lucrative Korean market. The choice is between the foliar neonicotinoid thiamethoxam, which is contrary to the accepted resistance management practices, and a pyrethroid.

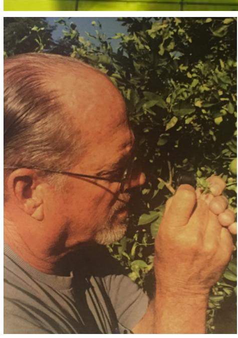
The Fuller rose beetle is such a concern in the export market that it is common practice in both the southern and central production areas to also use one and often two ground-applied pyrethroid barrier sprays of bifenthrin in mid-late summer to kill beetle adults as they emerge from the soil to prevent access to the foliage and fruit. As Joe Morse of UC Riverside states:

"For navels, Korea is by far our biggest foreign market, the prices are higher than the domestic market or even Japan — if you can't get into the Korean pool, you are in trouble".

Alan who is always looking for ways to balance the practical with the biological, described another ironic twist; flare-ups of pests like scales, which are normally under effective biological regulation, can be traced directly to ground nesting ants that climb the trees to feed on the sweet honeydew excreted by the scales. The ants actively protect these pests from the parasites that normally control them. The only effective and affordable solution is to control the ants on the ground. This can be done economically with a soil application of chlorpyrifos, but if this option were no longer available, then the choice for ant control would be pyrethroids or baits. Baits are difficult to apply, expensive and often ineffective.

For Alan, the future is uncertain. He is being successful so far in balancing his options, but to remain economically sustainable in the domestic market and to even compete in the foreign markets, he and his clients across southern California must rely on the continuing availability of three insecticide groups, organophosphates (primarily chlorpyrifos), neonicotinoids and pyrethroids, all of which are currently under review. Alan's stark conclusion is clear:

"If we lost all three of those, it's (citrus production) all going off shore."



Alan Washburn inspecting citrus for psyllid parasite

The on-farm impacts for Washburn and Sons, after close to a century of serving the California citrus industry, are bleak if that industry continues to decline. The broader economic impacts for citrus production in southern California are equally dismal as commercial citrus would likely decline to small, specialized production centers that would not sustain packing plants. Countless jobs would be lost, affiliated businesses, supply trucks, equipment, agrichemicals, fertilizers and all the needs of the industry would decline. The remaining citrus groves would be developed into more housing and harder to measure, a key component of the 'culture and history' of southern California would be lost.

An additional impact that can only be predicted is the effect that the movement of HLB into commercial citrus and/or the decline of citrus in southern California would have in the central and northern valleys where 70% of the citrus is already grown. Currently, there is geographical separation between the southern regions and the central valley; the intensive management in southern groves is keeping the psyllid and HLB suppressed and slowing its movement north. If southern citrus continues to move from managed commercial groves to unmanaged residential plantings and these become untreated reservoirs of imported pest problems (such as psyllids, HLB, GWS and Pierce's disease), it will only be a matter of time before the central valley become fully infested, and pest management is refocused from biological to chemical. Joe Morse, a 30 year veteran of citrus pest management from the University of California, Riverside predicts:

"If we lose the pyrethroids, I honestly think we might as well give up on the psyllid and the bacterium, and I think it means that the disease is going to move so quickly that it's over."

Justin Golding is in the trenches in the central valley with Wonderful Citrus, who alone manage 20,000 acres of oranges and mandarins in Kern and Tulare counties where maybe this is already happening. Justin now relies on chemical control as his primary pest management tool :

"We use neonics early and then pyrethroids - quarantine is a big driver, if we find a psyllid in a CDFA [California Department of Food and Agriculture] trap we treat everything in a five-mile radius, and pyrethroids are the only option. Wonderful relies on the export market for its navels and another pyrethroid, bifenthrin, is necessary on all those acres to meet quarantine."

The conclusion from the farm level is that California is not yet in the crisis mode seen in Florida, and the geographical isolation between its production areas is helping to slow psyllid and HLB spread. However, pest management is at a tipping point; much of its production is already relying on pyrethroids, neonicotinoids and organophosphates, and the loss of these materials will quickly lead to significant increases in pesticide applications, resistance development, sharp rises in costs of production and eventual economic decline.

But U.S. agriculture is resilient and has overcome many challenges. The California citrus industry is investing heavily in research to overcome this challenge with particular emphasis on early detection of HLB; genetic modi-

fication of citrus for HLB resistance; genetic modification of citrus to kill psyllids, genetic modification of psyllids to make them unable to transmit HLB; and development of antibiotic treatments to cure HLB-infected trees (21).

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4.0 Florida fresh market sweet corn

This study examines the use and value of pyrethroid insecticides in fresh market sweet corn in Florida, which is ranked 1st in U.S. production with 22% of national output. It is focused on winter and spring production in central Florida based on interviews with Paul Allen of R.C. Hatton Farms in Pahokee, Florida — the largest sweet corn grower and distributer in the U.S. Additional input was obtained from Charles Mellinger of Glades Crop Care, an independent crop consultant who has worked extensively with Hatton Farms designing and implementing pest management strategies and Dr. Gregg Nuessly of the University of Florida, Everglades Research and Education Center.

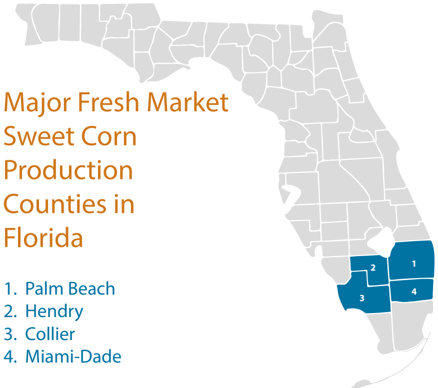
Florida is the leading producer of fresh market sweet corn in the U.S. with 22% of national production in 2012 valued at $180 million, which ranked 4th in value among vegetable crops in the state (1). Other significant fresh sweet corn production states in 2009 after Florida (6.7 million cwt) were California (4.5 million cwt), Georgia (3.3 million cwt), New York and Washington (2-3million cwt) and Colorado, Michigan and Ohio (1-2 million cwt)(2). Florida sweet corn acreage has been consistent in recent years with close to 42,000 harvested acres in 2010-2012, although productivity has increased from 140 cwt/ acre in 2010 to 150 cwt/acre in 2011 and 165 cwt/acre in 2012 (1). Crop value is market driven and fluctuated between $189 million in 2010, $174 million in 2011 and $180 million in 2012.

The principal fresh sweet corn production regions are in the south and southcentral everglades area with over 50% grown in Palm Beach County — taking advantage of the mild temperatures and off-shore breezes from Lake Okeechobee. Hendry and Collier counties to the southwest and Miami-Dade to the south produce another 25%, and northern counties account for a minor amount of production in late spring. Sweet corn is planted sequentially and can be harvested from mid-November through July with the most active harvest period occurring in April and May. Most Florida sweet corn is distributed throughout the U.S., and a small proportion may be exported to Europe.

4.1 Pest management in Florida fresh market sweet corn — the arthropod pest complex, management approaches and the role of pyrethroid insecticides

The warm, humid Florida climate is ideally suited for the rapid development and movement of insect pest populations, and sweet corn is subject to damage from a broad range of insect pests. Ninety five percent of sweet corn acreage is scouted regularly to determine the presence and abundance of pests, and potentially damaging populations are controlled using insecticidal applications (1).

Insect pests attack the ears, foliage and roots of sweet corn and routinely cause economic damage if left uncontrolled. The most important pest groups attacking sweet corn in Florida are lepidopteran larvae with the fall armyworm and corn earworm feeding on ears; the lesser cornstalk borer boring into stems and the cutworm complex feeding on young plants;



Major Fresh Market Sweet Corn Production Counties in Florida

1. Palm Beach
2. Hendry
3. Collier
4. Miami-Dade

Growers must minimize damage from fall armyworm and/or corn earworm in order to receive the high USDA grading needed to market their crop

Nearly two-thirds of Florida sweet corn growers alternate pesticides to avoid resistance

FL Crop Pest Profile: http://edis.ifas.ufl.edu/pi034

diptera with several species of corn silk flies; the coleoptera with cucumber beetles feeding on silks, and wireworms attacking roots; and aphids feeding on stems and leaves. Less common sporadic pests include grasshoppers, leafminers, spider mites, sap beetles, stink bugs, bill bugs and white grubs (2,4).

Lepidopteran complex. The fall armyworm is the most damaging lepidopteran pest of Florida sweet corn (4). Adults lay protected egg clusters under leaves, and young larvae feed on leaf tissue before moving to emerging tassels where severe damage can impact pollination and ear fill. All stages of larvae feed on ears, entering through the silk channel or directly through the husk, feeding on kernels and rendering the ears unsaleable. Damage in unmanaged sweet corn is extensive and can reach 100% in mid-to late season, which requires multiple applications of insecticides to attain the USDA standard of less than10% damage for U.S. Fancy designation and the generally accepted grower and industry standard of less than 2% damage.

A wide range of insecticide active ingredients spanning range of IRAC MoA groups are available to control lepidopteran adults and larvae in sweet corn (4). Materials are needed to provide fast knockdown and control of adults entering fields to hold egg laying to low levels, and materials with good efficacy and persistence on plant surfaces are needed to control feeding larvae to prevent ear damage. Persistence of insecticides varies from 3-10 days between active ingredients with the most being effective for only 5-7 days. Multiple applications are needed to produce clean ears. Spray programs vary with production region and seasonality, but an average of at least 10-12 applications are commonly used, and more may be needed when pest pressure is high. With multiple applications, resistance development is always a threat, and the availability of several MoA groups is essential to provide long-term lepidopteran control. The following active ingredients are available and provide good lepidopteran control (4):

1. **MoA Class 3A Pyrethroids:** Permethrin, esfenvalerate, beta-cyfluthrin, lambda-cyhalothrin, bifenthrin, zeta-cypermethrin, gamma cyhalothrin, deltamethrin.

2. **MoA Class 1A and 1B, organophosphates and carbamates:** methomyl, thiodicarb, chlorpyrifos, methyl-parathion, carbaryl.

3. **Other MoA groups:** indoxacarb (22), diamides (28), spinosad (5), spinetoram (5), novaluron (15), endosulfan (2) , methoxyfenozide (18) *Bacillus thuringiensis* various sub-species (11A)

Of the 23 active ingredients available to growers, the pyrethroids provide the most effective control with good persistence and are the foundation of most lepidopteran control programs used by growers. Active ingredients in other MoA groups are rotated with the pyrethroids to manage resistance.

The corn earworm, which also attacks tomatoes and cotton, is widely distributed in all sweet corn production areas of Florida and was the most damaging lepidopteran pest 20 years ago before it was largely replaced by the fall armyworm (4). Outbreaks continue to occur in southern Flor-

ida, however, and can cause 100% ear damage in areas south of Lake Okeechobee and in northern counties harvesting through July.

The adult moths are attracted to corn silks where they lay individual eggs. Larvae feed on the silks and quickly enter the ear tip where they feed on tip kernels and may continue feeding extensively in the ear. Since the time that larvae are exposed to insecticide residues on the silk before they enter the ear is short, management must combine effective adult control to reduce egg laying and fast knockdown of larvae on the silks. Pyrethroids provide excellent adult control and fast knockdown and are used extensively by growers in earworm control programs. Alternative active ingredients with different MoAs are used in rotation to avoid resistance, which has been reported in other southern production areas (Dr. Brian Flood, Del Monte, personal communication).

Lesser cornstalk borer can be a severe pest of sweet corn, particularly in warm and dry conditions (4). Larvae are found close to the soil surface and tunnel in the stem and brace roots causing severe wilting and stand loss in young plants. Insecticides applied to the soil at planting, emergence or cultivation are common preventative treatments for lesser cornstalk borers as there are no effective rescue treatments. Active ingredients in two MoA groups are pyrethroids (tefluthrin, beta-cyfluthrin and bifenthrin) or organophosphates (terbufos and chlorpyrifos). Sweet corn that is genetically modified to produce *Bt* endotoxins can provide effective resistance to fall armyworm, corn earworm and lesser cornstalk borer. These varieties are available, but their use is dependent on grower choice. Most Florida growers do not use GMO (genetically modified organism) sweet corn in response to consumer reluctance to accept this technology (Paul Allen, R. C. Hatton Farms, Pahokee Florida, personal communication).

Various species of cutworm are also serious but sporadic soil pests of sweet corn. Larvae cause stand reduction by clipping young seedlings off at the soil level. Rescue treatments are not effective, and soil treatments using pyrethroid or organophosphate active ingredients (listed for stalk borer) provide effective control.

Dipteran pests. Picture-winged flies are serious pests throughout Florida sweet corn and are the limiting factors in early season production close to Lake Okeechobee where the micro-climate is ideal. Picture-winged flies have a wide host range and are also saprophytic — feeding on damaged plants. Three distinct species are serious pests of sweet corn and are known collectively as corn silk flies, although the species differ in susceptibility to insecticidal active ingredients, and field scouts must distinguish between species to determine the most effective controls (Dr. Greg Nuessly, University of Florida, Everglades Research and Education Center, personal communication). These flies are year-round pests in southern production areas and are primarily spring pests in central areas. In northern plantings, damage is severe throughout the summer. Adult flies are attracted to sweet corn fields and lay eggs in ears, tassels and holes caused by other boring insects (4). Damage is most severe on the ears where larval feeding in the silks can disrupt pollination and ear fill; the associated decay and fermentation reduces grade at harvest. Decaying silks also attract sap beetles, which reduces

Insect Pests of Florida Fresh Market Sweet Corn

Pests	When controls are applied	Importance of pyrethroids	Resistance concerns	Alternative management strategies	**Potential impacts of pyrethroid loss**
Key Pests					
Lepidopteran complex: fall armyworm, corn earworm	Row tassel to harvest	Only options providing adult knockdown and persistence on plant to protect ears	Multiple sprays used –resistance anticipated, use pyrethroids in rotation with other MoAs to manage resistance	None	Increased ear damage, severe economic loss
Soil lepidopteran complex: lesser cornstalk borer, cutworms	Germination and early plant growth	Safe and effective as soil or banded applications	None	Organophosphate and carbamate soil applications	Reduced plant stand, lower yields, increased environmental risk
Corn silk fly	Silking	Continual re-infestation requires multiple applications. Pyrethroids are only option with adult knockdown and larval control and are primary tools	Resistance to pyrethroids documented, AIs with different MoAs needed in rotations to manage resistance, potential for synergists to extend efficacy	Carbamates,organophosphates and other AIs are available but less effective	Could not produce winter sweet corn in FL, increased worker safety and environmental risk
Sporadic Pests					
Rootworm and cucumber beetle adults	Row tassel through brown silk	Pyrethroids used for ear protection prevent silk pruning	Lepidopteran resistance management	None	Reduced ear fill, lower quality
Aphids	Tassel emergence	AIs used for silk worm also control aphids	None	None	Reduced pollination and ear fill

grade through contamination. Larvae also feed on ear kernels throughout the cob, leaving empty kernels that result in unmarketable product. Damage in unmanaged sweet corn often reaches 100%.

Silk fly management is targeted at controlling adults, which are active on plant surfaces prior to egg laying (4,6). This is complicated by the ubiquitous distribution of adults on vegetation and rotation crops, such as sugarcane surrounding fields that act as sources of continual re-infestation and require repeated applications to produce clean produce. Many of the active ingredients listed for lepidopteran control are also active on corn silk flies with pyrethroids, organophosphates and carbamates being the most commonly used by growers. Several organophosphate and carbamate active ingredients, such as methomyl, provide good adult kill but have essentially no persistence on leaf surfaces and are ineffective in situations where re-infestation occurs. The organophosphate chlorpyrifos provides excellent adult kill and some residual control, but an extended PHI of 21 days limits its use. Pyrethroids provide excellent knockdown of adults and have the best residual on leaf surfaces; thus, the pyrethroid active ingredients form the basis of most silk fly management programs. Pyrethroid toxicity on leaf surfaces is often reduced by up to 70% within three days of application, requiring frequent resprays. Sweet corn is frequently harvested by hand and must be scouted frequently. Worker safety during late season is a major concern, further prompting reliance on pyrethroids with demonstrated safety and short PHIs.

Other sporadic pests of sweet corn. Banded cucumber beetles and spotted corn rootworm beetles can be sporadic pests of sweet corn with most severe damage occurring when adults feed on ear silk (4). Silk pruning can disrupt pollination and prevent full ear fill. Since ear damage is primarily during silking, insecticides applied for lepidopteran or silkworm control provide effective beetle control.

Wireworm larvae have extended lifecycles and cause sporadic stand loss from root feeding on sweet corn. Damage is most severe in sweet corn rotated to follow crops with grassy weeds or sugar cane, and soil insecticides applied for stalk borers provide wireworm suppression.

Several species of aphids, including the bird cherry-oat aphid, the corn leaf aphid and the melon aphid, are widely distributed in Florida sweet corn acreage. Aphids feed on young leaves and tassels and can cause stunting and disrupt pollination or contaminate ears if uncontrolled. These aphid species are also vectors of several viruses that are damaging to other vegetable crops such as peppers, cucurbits and potatoes. Viral disease is not common in sweet corn, and aphid control is limited to severe infestations and to prevent migration to susceptible crops. Effective aphid control is provided by several active ingredients that are applied for lepidopteran management with pyrethroids being particularly effective (4).

There are estimates that more than 90% of the sweet corn ears would be damaged by worms in Florida without insecticide sprays

https://croplifefoundation.files.wordpress.com/2012/07/combined_document_sweet_corn.pdf

Chaetopsis massyla (corn silk fly) on corn leaf
Photo by Gregg Nuessly, University of Florida

4.2 Main insights from Florida fresh market sweet corn production

- The silk fly complex is the most economically important insect pest management challenge facing fresh sweet corn growers in south Florida. The biology of the silk fly with limited exposure to pesticide residues on leaf surfaces and continual re-infestation potential necessitates an adult control approach. Pyrethroids are the only effective alternatives and multiple applications are required to produce damage-free sweet corn.
- The ear-feeding lepidopteran pests (fall armyworm and corn earworm) cause severe economic damage in south Florida and all other sweet corn production areas. There are no biological controls that can hold populations below damaging levels, and multiple spray programs are needed to produce damage-free corn. A wide range of active ingredients is needed to provide fast knockdown of adults to suppress egg laying and provide residual control on leaf surfaces to control larvae. Pyrethroids are the most effective in both adult and larval control and form the basis of management programs for most growers. A range of alternative active ingredients with differing MoAs are rotated with the pyrethroids to manage resistance.
- Soil inhabiting lepidopteran pests (lesser cornstalk borer and cutworm complex) cause sporadic damage and must be managed with preventative soil-applied insecticides. The only effective active ingredients for this use are pyrethroids and organophosphates.
- Other sporadic pests of sweet corn are usually controlled effectively with management programs targeting other pests.

4.3 Impacts of pyrethroid insecticides at the farm level: A case study, R. C. Hatton Farms, Pahokee, Florida

In mid-January when most of Middle America is in the grips of winter, fresh vegetables would be a distant memory for most if not for the perseverance and pioneering spirit of growers like R. C. Hatton of Pahokee, Florida, located on the shores of Lake Okeechobee. Robert Hatton recognized the unique micro-climate created by the lake on its southeastern fringes and the value of the dark rich soil — Florida's 'black gold.' He founded R. C. Hatton Farms in 1932 on a few hundred acres during the Great Depression to grow sweet corn and green beans to supply winter vegetables to the Atlantic states. The farm has since grown to over 10,000 acres with 4,500 acres of sweet corn, 3,000 acres of green beans and 4,500 acres of sugar cane. Hatton Farms is now the largest grower and distributer of sweet corn and green beans in the United States. Vertically integrated, they plant, manage, harvest, pack, sell and distribute fresh vegetables to everywhere east of the Mississippi in the U.S. The farm has continued to thrive and grow based on a firm commitment to sustainability in protecting the fertility of the rich soil they depend on, pioneering new pest management technologies to produce safe food, providing rewarding opportunities for their employees and supporting their local communities.

Producing fresh sweet corn and green beans presents some unique pest management challenges that come with combining high levels of pest pressure and essentially zero tolerance for damage. To discuss Hatton Farms' approach to meeting these challenges, we sat down with Paul Allen, vice president and co-owner, in his busy headquarters office. Paul is also president of Sunshine Sweet Corn Farmers of Florida and active in the Florida Fruit and Vegetable Association, Fresh from Florida and the Florida Farm Bureau.

The basis of managing pests is to have accurate information on what pests are out there and to use that knowledge to make wise decisions. Paul shares that important task with one of Florida's long established independent crop advising services:

"We feel that Glades Crop Care is the best there is. They have a lot of experience and we have some unique challenges."

The key to producing good quality sweet corn is the micro-climate provided by Lake Okeechobee. Timing and the fortunes of unpredictable weather outside the lake play a big part Paul says:

"We try to harvest here through March because there can be a February freeze (away from the lake), and there may be no sweet corn except way out here."

The economic advantage of maintaining supply was seen this year when the homestead area to the south got 14 inches of rain in December that eliminated a good portion of the January sweet corn crop. While Hatton was harvesting in January:

"The only sweet corn there is right around here and one other place. The market's 20-22 bucks."

Hatton benefited this time around, but the lake effect benefit comes at a cost:

"Guess what comes along with this lake — a lot of pests! Even now some of the corn I'm harvesting (in January) has silk fly issues."

Silk flies are Paul's most threatening pest through most of his winter season, and he is already in an intensive management program using primarily pyrethroids to keep the corn clean and marketable. The silk fly challenge will get worse as the season progresses:

"When the temperatures start warming up in March and early April, the silk flies are really --- really a problem in here, but that's the importance of pyrethroids to me; the pyrethroids are what works on silk flies. It makes the whole process of having product all the way through December, January, February and March possible. I can't go out ten miles from the lake where there is less silk fly pressure because it's too cold. If we don't have pyrethroids, everything I just told you is out the window."

Besides silk flies, which he manages with multiple applications of pyrethroids, Paul also deals with the complex of lepidopteran pests that increase in his late harvested corn. He relies on continual scouting and uses a variety

Paul Allen, vice president and co-owner of R. C. Hatton Farms

of active ingredients to stay ahead of the populations and avoid resistance. He uses pyrethroids because they work, and they are inexpensive but rotates with active ingredients like methomyl, spinetoram, chlorantraniliprole and methoxyfenozide. These programs are expensive, but they are necessary in a crop where there is a large and destructive pest complex and a zero tolerance for damage. Scouting ensures that sprays are kept to a minimum, but in mid- to late season when pest pressure is at its highest, there may be as many as 26 applications. Hatton Farms does not use GMO sweet corn to control lepidoptera because of consumer concern over the technology and because they have developed and marketed their own varieties based on taste, appearance and adaptability to their conditions.

Green beans have a more limited pest complex that requires fewer pesticide applications, and yet, the pests are challenging. The most economically important pests are thrips, which transmit a devastating virus disease — red node virus. The only effective active ingredients in management of thrips are the pyrethroids. Research at the University of Florida, Everglades Research and Education Center demonstrates that 2-3 pyrethroid sprays, before bloom, during bloom and after bloom provide the only acceptable level of control.

When asked what the impacts of changes in pyrethroid availability would be for Hatton Farms, Paul's assessment was bleak:

"From a production standpoint, it's going to affect what we are able to do in the winter. What you have to remember is that in the winter time, south Florida is feeding your country with fresh vegetables east of the Mississippi. I mean, it's where it's coming from."

The inevitable conclusion from the largest and one of the most sustainable growers in Florida is that without pyrethroids, there will be no fresh, winter vegetables. The economic impacts in the Pahokee area would be far reaching. Applications of less effective and more expensive active ingredients would increase, and the quality of product would diminish, forcing a decline in vegetable acreage. Jobs provided on the farm and in the packing sheds and distribution centers would disappear, and the local economy and communities would suffer.

An outcome that is more difficult to predict is the impact on food safety across the eastern United States. The supply of fresh, winter vegetables coming from Florida is among the safest of any economy in the world — with certifications and inspections assuring that the food is safe. Without fresh winter vegetables from Florida, alternative sources of supply would emerge with no guarantee of pesticide residue levels, bacterial contamination or genetic origin.

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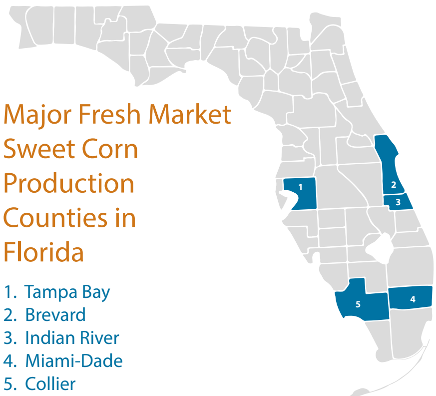
5.0 Florida fresh market tomatoes



Major Fresh Market Sweet Corn Production Counties in Florida

1. Tampa Bay
2. Brevard
3. Indian River
4. Miami-Dade
5. Collier

This study examines the use and value of pyrethroid insecticides in fresh market tomato production in Florida, which is ranked 1st in U.S. with a third of the national acreage and generates over 40% of production with an annual at over 40% of U.S. returns. The study is based on interviews with Gerry Odell of Lipman Produce in Immokalee, Florida — the largest fresh tomato grower in North America. Additional input was obtained from Charles Mellinger of Glades Crop Care, an independent crop consultant who has designed and implemented pest management strategies extensively with Lipman Produce and other major fresh tomato farmers in south Florida.

5.1 Florida fresh tomato production

Florida is the leading producer of fresh market tomatoes in the U.S. with 33% of national acreage producing 42% of national output (1.5 billion pounds) and valued at over $500 million (37% of national returns) in 2004 (1). Fresh tomatoes are the highest valued vegetable crop in Florida, generating 40% of revenue. Florida tomato acreage and production has been relatively consistent in recent years with close to 30,000 acres producing 9.0-9.5 million hundredweight annually. Crop value, however, is market driven and has been more volatile over the past five years — with a high of $620 million in 2010, decreasing to $435 million in 2011, followed by a low of $268 million in 2012 (a 38% reduction resulting from the lowest average prices in 20 years) and $378 in 2013 and $348 million 2014 (2,3).

The principal production areas are concentrated in south Florida and designated into four districts (1):

- The south Miami/Dade counties (8% of production)
- The eastern coastal area from Brevard to Indian River counties (10% of production)
- The southwest Immokalee area (34% of production)
- The Tampa Bay area (29% of production)
- The remaining 20% of production is in small pockets in the panhandle and northern counties.

Florida supplies most of the fresh tomatoes eaten in North America from October to June.

5.2 Pest management in fresh tomatoes in Florida — the arthropod pest complex, management approaches and the role of pyrethroid insecticides

The warm, humid Florida climate is ideally suited for the rapid development and movement of pest populations. Tomatoes, which have zero tolerance for damage, are particularly susceptible to injury that can be caused by an unusually broad range of arthropod pests. At least 27 pests have the potential of seriously reducing both yields and market value of tomato fruit. Insect/mite pests inflict a negative impact on yield and quality by directly

feeding on the plant and/or fruit and by vectoring destructive organisms — such as viruses that can reduce plant growth and vigor, resulting in death (2). The destructiveness of the arthropod pests on tomato can frequently lead to 100% crop loss if left uncontrolled, and as a result, pest management has traditionally relied on multiple insecticide applications that are targeted at different pest groups.

The most damaging insect pests of Florida fresh market tomatoes can be grouped into several groups (5):

Whiteflies. Several species of whitefly can infest tomato in both greenhouse and field situations, but the silverleaf whitefly is dominant and widely distributed in Florida. Heavy whitefly populations extract sap; the nymphs cause irregular ripening of fruit, which is a major quality defect. Adult whiteflies transmit geminiviruses that were introduced into Florida in the late '90s; Tomato Mottle Virus and the very severe Tomato Yellow Leaf Curl Virus are now common throughout all tomato production districts in Florida and can rapidly reach 100% infection with total crop loss if left uncontrolled.

Whitefly populations are highest in south, southwest and southcentral districts in the spring, although in west central region, the number of adults carrying virus is highest in the fall. Whitefly is less of a problem in northern Florida but may reach damaging numbers in the fall.

Whitefly control is essential throughout the season to keep virus spread to a minimum. Neonicotinoid active ingredients are essential components of all management programs in early season with two soil applications frequently used in greenhouse and field establishment. It is probable that without these early season applications of neonicotinoids, tomato production would not be economically feasible in Florida (Dr. C. Mellinger, Glades Crop Care, Jupiter, Florida, personal communication). The soil applications are complimented by selective active ingredients that target nymphs during the season, and broad spectrum insecticides (such as pyrethroids) are frequently used for adult control.

Lepidopteran complex. Several lepidopteran pests attack tomatoes and can cause damage by feeding on the foliage and tunneling into fruit, rendering them unsaleable. Species vary in their distribution and severity, but all cause serious economic damage if left uncontrolled. The most common species are the tomato fruitworm, the southern armyworm, the beet armyworm and the yellowstriped armyworm (4). Management of the lepidopteran complex is currently achieved with foliar sprays of selective active ingredients that are most effective on small larvae. Selective lepidopteran insecticides are expensive, vary in effectiveness between target species and do not control other pest species that may be present in the field. Thus, selective applications are frequently rotated with less expensive but equally effective broad spectrum pyrethroids.

The tomato pinworm. Tomato pinworm is a lepidopteran pest; larvae enter fruit under the calyx and are both hard to control and difficult to detect during grading. In the past, pinworm was a major economic threat; control was achieved with foliar sprays of pyrethroids and organophosphates until

Insect Pests of Florida Fresh Market Tomatoes

Pests	When controls are applied	Importance of pyrethroids	Resistance concerns	Alternative management strategies	**Potential impacts of pyrethroid loss**
Key Pests					
Whiteflies as vectors of geminiviruses	Neonicotinoids used in transplants and early field, supplemented with selective AIs for nymph control and pyrethroids for adult control	Needed for adult control in rotations of MoA groups	Resistance management critical to preserve efficacy of all MoAs, documented for essentially all classes, pyrethroid use increased as other classes are less effective	Plant resistance (partial)	Greater reliance on alternative MoAs, faster resistance, lack of control, decline of industry
Tomato pinworm and new lepidopteran threat, *Tuta absoluta*	Fruiting to harvest	Mating disruption replaced pyrethroids for tomato pinworm *T. absoluta* introduction imminent, pyrethroids will be essential	None current, AIs with different MoAs are available if *T. absoluta* established	Mating disruption (not developed)	Potentially serious fruit damage
Thrips as vectors of Tomato Spotted Wilt Virus	Fruiting to harvest	Bifenthrin and beta-cyfluthrin effective	Resistance is common, MoA class 5, AIs are recommended but should be rotated with effective pyrethroids	Plant resistance (partial)	Severe fruit quality loss
Colorado potato beetle	Planting to harvest	Used in conjunction with soil applications of neonicotinoids in early season	Managing resistance essential to preserve efficacy of all MoAs	Crop rotation (partial) Range of alternative AIs	More use of alternatives, faster resistance, more sprays
Sporadic Pests					
Hemipteran complex: leaf footed bugs, stink bugs	Fruiting	Pyrethroids only effective options	None	None	Increased fruit damage
Occasional 'worm' pests	All season when larvae or damage over threshold	Important for rapid clean-up of infestations, most effective and economical	Other alternative MoA available if resistance occurs	None	Reduced yield and quality

the pinworm pheromone was isolated and mating disruption techniques perfected. Mating disruption now provides effective pinworm suppression and sprays are rarely used to control them.

In the Mediterranean and both south and central America, a related lepidopteran pest, *Tuta absoluta,* is spreading rapidly throughout tomato production areas and causing major economic damage. There is a high probability that this pest will be introduced into Florida, and it will be essential to retain broad spectrum active ingredients such as the pyrethroids to provide adult control and prevent spread to other areas.

Thrips. Several species of thrips can be found in large numbers in Florida tomatoes, but western flower thrips are the primary species of concern that cause economic damage. Adults insert eggs into developing fruit, causing a dimple that is often surrounded by a white halo; this results in quality rejection. Adults also transmit Tomato Spotted Wilt Virus, a serious economic problem that is most severe in northern Florida. Thrips control is difficult with limited options available. Foliar sprays of spinosad and spinetoram are recommended; the pyrethroids bifenthrin and beta-cyfluthrin also provide effective control, but other pyrethroids are not recommended and may actually increase populations.

Plant bugs and stink bugs. Several species of stink bugs and leaf-footed bugs occur sporadically throughout Florida and can cause severe economic damage. Adults move into tomatoes from surrounding vegetation and feed on developing fruit by removing cell contents and leaving punctures, discoloration and fruit distortion. Pyrethroids provide effective stink bug and leaf-footed bug control and are essential pest management tools where these pests are present. A recent pest introduction into North America — the brown marmorated stink bug — has a wide host range and can be a more serious pest than native stink bugs on many crops, including tomato. This pest is already distributed from the Atlantic coast to the west coast, and although it is not yet reported as a pest in Florida, the potential for introduction is high, and the availability of pyrethroids to provide control and limit spread is essential.

Aphids. Several species of aphids can cause economic damage on tomato with the green peach aphid and the potato aphid being most common. Aphids do not attack the fruit but cause indirect damage by removing sap and reducing plant vigor. Aphids are also vectors of several plant viruses, although these are rarely seen in Florida; control is usually achieved with early season neonicotinoid applications. If populations persist into midseason, foliar sprays of specific materials (pymetrozine, flonicamid) may be needed. Foliar applications of broad spectrum pyrethroids (gamma-and lambda-cyhalothrin, beta-cyfluthrin) or organophosphate (dimethoate) are also effective.

Colorado potato beetle. Adult and larval Colorado potato beetles can cause severe defoliation and yield loss on tomato with most economic damage occurring in northern production areas. Soil-applied neonicotinoid active ingredients (also used for whitefly management) provide effective control of both adults and larvae. If populations persist, foliar applications

Geminivirus on tomato
Photo by Don Ferrin, Louisiana State University Agricultural Center, Bugwood.org

Whiteflies (vector of geminivirus)
Photo by Scott Bauer, USDA Agricultural Research Service, Bugwood.org

Tomatoes are a high-value, high input crop, which costs a lot to grow — more than $10,000 per acre to grow each year with a quarter of that cost coming from pest management needs

http://www.ipmcenters.org/cropprofiles/docs/FLtomatoes.pdf

of abamectin or pyrethroids are also effective. Resistance to these active ingredients has been documented in other states but not in Florida.

5.3 The changing nature of pest management strategies in Florida fresh market tomatoes

In tomatoes, the economic impact of individual pest groups within the broad pest complex has fluctuated over time. When combined with the development and registration of new pesticide active ingredients and the development of new integrated pest management (IPM) approaches to utilize them, the result is in an ever changing series of evolving pest management challenges.

5.3.1 The past

Prior to 1990, the dominant pest group was the lepidoptera, which included the fruit and foliage attacking tomato pinworm. IPM consisted of both scouting and multiple applications of broad spectrum insecticides at predetermined thresholds using primarily organophosphates, carbamates, organochlorines and pyrethroids (Gerry Odell, Lipman Produce, Immokalee Florida, personal communication).

In the early 1990s, new strains of whitefly were introduced together with the geminiviruses that they vector; the whitefly/virus threat became an equal concern for growers. Lepidopteran and whitefly control was initially achieved with even greater reliance on broad spectrum insecticides. In 2004, pyrethroids with efficacy against both whitefly and lepidoptera became the most widely used materials with three active ingredients — cyfluthrin, esfenvalerate and lambda-cyhalothrin — applied on an average of 42% of the tomato acreage six times per season (2, 4). Resistance problems emerged, particularly with whitefly; several new and more selective active ingredients entered pest management recommendations at this time and were adopted by growers. These new active ingredients were significantly more expensive but were used together with broad spectrum materials to manage an increasingly serious whitefly/virus threat. Of the new active ingredients, imidacloprid was applied twice as soil treatments to over 70% of acreage for whitefly control, and abamectin was applied three times to 34% of tomatoes for both whitefly and lepidopteran control. Use of *Bacillus thuringiensis* and spinosad for selective lepidopteran control in pest management programs also increased by 2004 with ten applications on 62% of acres and five applications on 37% of acres for these materials, respectively (2,4). Selective insecticides were applied at this stage in the development of tomato IPM more for their efficacy than their selectivity since they were frequently co-applied with broad spectrum materials that countered the advantages of selectivity.

5.3.2 The present

Over the next decade, the emphasis on selective insecticides as primary pest management options (based on the advantages of both selectivity and increasing efficacy) continued and reliance on broad spectrum insecticides

declined (5). Several significant new active ingredient introductions were important in this transition:

- The increasing availability of systemic neonicotinoid active ingredients, which provide effective control of whiteflies and geminivirus transmission in transplant greenhouses and during the early field season, have been largely credited with allowing the tomato industry to retain its preeminence in Florida. These active ingredients are also effective in controlling other key pests, including leafminers, aphids and Colorado potato beetles. Neonicotinoids are also registered as foliar applications but to avoid resistance, foliar sprays are not recommended following soil applications.
- New selective active ingredients (buprofezin, pyriproxyfen, spiromesifen, novaluron) targeting whitefly nymphs are highly effective and used widely.
- CheckMate® and NoMate® are tomato pinworm pheromones used in mating disruption programs that have been so successful that pinworm, (a major pest a decade ago) now rarely requires insecticidal control.
- Several new active ingredients from a range of different IRAC MoA groups with lepidopteran activity are now available to manage the broader lepidopteran complex that includes fruitworm, armyworm and cutworm. These include emamectin benzoate, spinetoram, spinosad, diamides, methoxyfenozide and tebufenozide.
- New selective active ingredients, including pymetrozine, acetamiprid and flonicamid, are now available for aphid and plant bug control.
- Chlorantraniliprole and other new diamides are now used extensively for control of lepidopteran, coleopteran and other pest groups. These materials are expensive but are justified based on their efficacy.

5.3.3 The future

Although more selective and extremely effective active ingredients currently dominate the pest management programs in tomato, growers have not been able to rely exclusively on them. Pests rarely occur alone, and it is often necessary to manage several pests simultaneously. Tank mixing selective active ingredients to target several pests can be prohibitively expensive and not economically sustainable. Growers are increasingly relying on the broad spectrum characteristics of older insecticides (such as the pyrethroids) to substitute for or to tank mix with selective insecticides. The increasing resistance of pest groups (including whiteflies, thrips, lepidoptera, aphids and beetles) to selective active ingredients that resulted from multiple applications of these materials is contributing to reduced efficacy and an increasing need to insert broad spectrum active ingredients into pest management programs. The future success of tomato pest management programs will hinge on preserving the efficacy of selective insecticides by using them less often. This can be achieved by retaining the availability of older but still effective broad spectrum active ingredients such as the pyrethroids and organophosphates and using them judiciously in conjunction with selective ingredients (Gerry Odell, Lipman Produce, Immokalee, Florida, personal communication).

5.4 Main insights from Florida fresh market tomato production

- Tomato IPM in south Florida presents volatile and dynamic challenges that continue to evolve as new pests are introduced, new IPM tools are registered and existing active ingredients lose efficacy through resistance programs.

- Three IPM phases have been manifested over the past 30 years:

  Pre-1990s. Lepidopteran pests dominated, and IPM was based on scouting and insecticidal treatments with pyrethroids, organophosphates and carbamates.

  Mid-1990s. A transition period when whiteflies and geminiviruses became the predominant pests, and IPM programs continued to use multiple broad spectrum sprays (largely pyrethroids) with a significant swing toward adoption of selective alternatives such as neonicotinoids, *Bt*s and spinosad.

  Present day. IPM concerns are dominated by whitefly and virus pressure, relying heavily on neonicotinoids and insect growth regulators, while lepidopteran control is achieved with selective materials and mating disruption. Resistance, however, is reducing the effectiveness of selective active ingredients, which is leading to increasing severity of renewed pest threats (leafminers, thrips) and increased need for broad spectrum pyrethroids.

Growers using IPM report 82% reduction in overall pesticide use

http://ipm.ifas.ufl.edu/Agricultural_IPM/Integrated_Pest_Management_and_Florida_Tomatoes.shtml

- Projected future. Multiple pest threats are addressed using new but expensive active ingredients that were introduced to offset declining efficacy of selective materials; these are used in conjunction with targeted use of broad spectrum pyrethroids and existing selective materials (such as the neonicotinoids) to combat a broad range of existing and potential new pest threats.

- The overall impact of potential changes in use patterns for pyrethroids or neonicotinoid active ingredients would likely be an increase in reliance on new and selective active ingredients, accelerated resistance to available tools, significant increases in pest management costs and ultimately, a scenario where tomato prices will increase; small farmers will be forced out of business; only large producers will survive through consolidation; and production and importation will increase from outside the U.S.

5.5 Impacts of pyrethroid insecticides at the farm level: A case study, Lipman Produce, Immokalee, Florida

It's the peak of the season in mid-January in the little town of Immokalee, Florida — the heart of the nation's largest center for winter vegetables in southwestern Florida. The town is bustling with activity, as numerous packing sheds unload tomatoes straight from the field, wash them, inspect them to ensure perfection and pack them onto semi-trailers that crowd the narrow streets as they head to every corner of the U.S. The big trucks (an assortment of new and old) are all competing for space and are always loaded to capacity! Pickup trucks also crowd into what must be the country's larg-

est farmers market, where hundreds of small scale growers gather daily to sell every kind of vegetable imaginable to wholesalers, retailers, restaurants and consumers who are just looking for a good deal on some fresh produce.

In the center of all this activity sits Lipman Produce — the largest fresh market tomato grower in the U.S. with close to 20,000 acres grown in Florida, South Carolina, Virginia, California and Mexico; they supply tomatoes year round! Fresh tomatoes cost over $10,000 an acre to produce, even before a fruit is picked, so this is no small investment.

Lipman is the largest now, but it all started small, not unlike the farmers market across the street. When Max Lipman started growing tomatoes on 40 acres in the 1930s, he teamed up with brothers and family to found 6-L Farms, which grew to its present size and expanded across four states before being renamed Lipman Produce in 2011. The company roots are firmly anchored in southwest Florida, and one of their farms south of Naples and close to the Gulf, growing 2,200 acres and producing 75 million transplants every year, still proudly bears the 6L- Farm name.

Lipman's is a key part of the Immokalee community on all levels from employment in their four packing sheds and in the field, to housing and education and as pioneers in tomato pest management. With over 80 years of experience in south Florida, they are a good choice for a case study.

Producing fresh tomatoes in south central Florida is a continuous challenge. The varying climate that can swing from unexpected killing frosts in spring to sweltering heat in summer — not to mention hurricanes, torrential rains and even extended periods of drought — can all make bringing in a crop that feeds America a challenge. But nothing quite compares with trying to manage what may well be the largest and most damaging arthropod pest complex attacking a single crop anywhere in the U.S. and having to do that so well that there is never even a blemish on that tomato you buy in the supermarket!

To discuss Lipman's approach to meeting these challenges, we sat down with Gerry Odell, the CFO (or Chief Farming Officer, as he likes his title to read), in the company's headquarters that is nestled among their four packing houses in Immokalee. Gerry has been in the tomato business for close to 30 years and has been in the trenches growing tomatoes in Florida, California, South Carolina, Virginia, Puerto Rico, Mexico and anywhere else needed to guarantee a year-round tomato supply to the marketplace. It's a big job, but no one is better qualified; Gerry works closely with his farm managers, Lipman's own extensive research group, Glades Crop Care (the agriculture consultants that he has worked with for most of his career) and the University of Florida research and Extension specialists, to stay on top of problems and new challenges as they develop. On his continuing interaction with the University of Florida, Gerry says:

"IFAS has been the backbone of Florida Agriculture, they have done a great job over the years…I think people are starting to see that we are going to need help to solve farming problems, and we are all going to starve to death if we don't solve them."

Gerry Odell, CFO, Lipman Produce

Pest management is a dynamic operation in Southern Florida tomatoes. There are lots of pests (27 are listed in the University of Florida's bulletins); the nature of the pest complex and the tools that are available to manage them are always evolving. When asked what the biggest threats are that he faces in today's production system, Gerry puts it in perspective:

"You can't name one pest that we don't have!"

But there are clear winners in the rogue's gallery, and it is clear that whiteflies are currently at the top of the list:

"Our biggest threat for years in Florida has been the whiteflies and the geminiviruses — that was the biggy, with the uneven ripening they cause."

But whiteflies are not alone, and the lepidopteran pests are still on the list along with other old favorites:

"You still have your lepidopteran pests, they are always a challenge, although they haven't been so hard to control since we have had Coragen®, which worked very well on armyworms and leafminers, but we are starting to see some resistance in leafminers and had to go back to abamectin."

The story continues — pests emerge, new and more effective tools become available, but then resistance reduces their effectiveness, and older tools are brought back.

Western flower thrips are a good example of this. Only a sporadic pest in south central Florida until Tomato Spotted Wilt Virus and more recently Chlorotic Spot Virus emerged as economic threats. Spray programs had to be ramped up with new materials (like spinosad), until resistance made them less effective, and the pyrethroids were needed again. As an alternative, more long-term approach, the Lipman breeding program is now focusing on developing virus resistance to address the thrips problem in Florida and other states (where it can be even more serious) and are only putting varieties into production that have Spotted Wilt Virus resistance. In 2015, even that added level of protection was not enough in California. Thrips populations were so high that they overwhelmed the resistance (which is not expressed strongly in the fruit) and significant losses to irregular ripening were suffered even with repeated pyrethroid and spinosad applications.

The tomato pinworm is another example of pests changing in status where a severe pest was brought under control with new technology, but a new pest is now threatening to take its place. The pinworm was a major pest a decade ago, requiring multiple pyrethroid and carbamate applications to produce saleable fruit. Then, the University of Florida perfected ways to use the insects own pheromone to disrupt mating so successfully that the need for insecticides faded. Now, the related pest *Tuta absoluta* that occupies a similar niche is causing severe economic damage in Central America and has a high potential for introduction into Florida. Gerry worries that when it arrives, we may no longer have tools like the pyrethroids to manage it until a new technological fix is found.

"Tuta absoluta, sure I am worried about Tuta absoluta, and what really worries me is that we are having our arsenal taken away; we have both hands tied behind our back — we are putting ourselves in a corner."

When asked about using pyrethroids in conjunction with the selective materials that are available for the pest complex today, Gerry indicates:

"You can't just spray IGRs [insect growth regulators] and make a crop — we're still using some pyrethroids and not necessarily because they are the best product, but it's the only product. It's not so much the pyrethroids themselves that I'm defending, it's the whole different classes of chemistry that we are losing."

Gerry is using all the selective alternatives and augmenting them with the newest, broad spectrum active ingredients like Coragen® or Verimark®, even when these are expensive, justifying the cost of Verimark by saying:

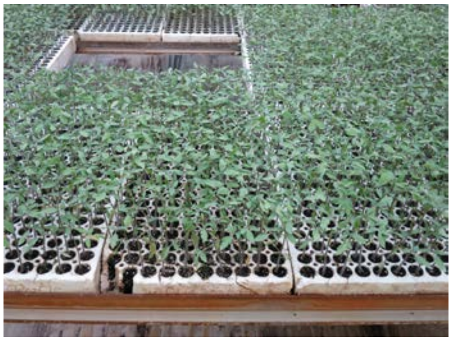
"It's pretty broad spectrum, so theoretically you could cover a lot of your specifics with a couple of applications a season… the overriding assumption seems to be, oh well, there's newer, sexier materials that are a lot greener and friendlier that you can use to take care of these problems — you just need to figure out how to do it."

Gerry has lived through the changing eras in insect pest management on tomatoes and has the benefit of hindsight. He argues strongly for retaining as many alternatives as is reasonable to be in a position to adapt to changing conditions, whether these are a new pest introduction, the development of resistance that renders a new insecticide less effective or the loss of active ingredients to regulation. He sums up his position by saying:

"I think the EPA understands. We need to have a mix of materials that we can use. It's not like we are going to use them all the time, but we need to have them in our toolbox so that when the time comes that we need a 5/8 inch wrench, we have one. There isn't some all purpose adjustable wrench out there that's going to get me the same result."

Gerry cited the neonicotinoids as a good example; when the new whitefly biotype and the geminiviruses came to Florida two decades ago, the industry was in trouble, and neonicotinoids saved the day. Now there are new systemics on the horizon that could potentially replace the neonicotinoids if their uses were curtailed, but we still need them in the IPM toolbox. In 2015, the California tomato crop was facing threats from three sides: Beet Curly Top Virus transmitted by the beet leafhopper, the Tomato Spotted Wilt Virus transmitted by thrips and geminiviruses transmitted by whitefly. Without the neonicotinoids and the ability to use them in combination with an aggressive spray program using multiple active ingredients that included pyrethroids, California fresh market and processed tomatoes (300,000 acres) would have suffered unprecedented losses.

Lipman Produce prides itself on its good stewardship and has an enviable record for protecting the land, conserving water, using the latest technologies to manage pests and reducing its carbon footprint, but as Gerry ruefully points out:



"At the end of the day, you have to be able to protect your crop, or you won't be in the stewardship business any longer because you will be out of business."

When asked how restrictions in the use patterns of active ingredients such as the pyrethroids and neonicotinoids would impact the tomato industry in Florida, Gerry was honest:

"The price of tomatoes is going to continue to go up because it's going to be more and more expensive and harder to produce and more and more people are going to drop out… if they start taking more and more products away, only the best guys who have the best resources and can figure out how to survive are going to survive. Anyone who has a hundred acres is going to take it on the chin. I mean, do you really want to get rid of all the small farmers in the U.S. when it seems like everyone is dying to buy products from their local farmer?"

Finally, Gerry is concerned over the impact such changes would have on the local community that is currently a healthy mix of a half dozen large producers and packers like Lipman and a host of small scale growers who together make up the fabric of the Immokalee community and its economy. The town is thriving at the peak of the winter vegetable season with a population of over 50,000. That normally goes down to 10,000 during the off-season but could be an indicator of what could happen if the south Florida tomato industry declined. Lipman employs a large workforce in the field and packing sheds, and these are good jobs that will probably survive, but if you take out all the small farmers, it would have far reaching negative impacts throughout the community.

5.6 References

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6.0 California almonds

This case study examines the use and value of pyrethroid insecticides in almond production in California, where 82% of the almonds produced worldwide are grown. Seventy two percent of California's almond crop is exported, and increasing global demand over the last decade has resulted in increasing value, expanded acreage and a resurgence in pesticide use to protect grower investment. As a result, naturally occurring biological control of pest populations in California nut crops has been disrupted and growers are now attempting to re-establish a balance between natural control and insecticide applications that are both needed to protect this valuable crop. This case study was conducted with Brad Higbee, Research Entomologist at Wonderful Orchards (formerly Paramount Farms) in Bakersfield, California; Wonderful Orchards is the largest almond grower in the world. We also received input from Dr. Frank Zalom, Department of Entomology, University of California, Davis.

6.1 California almond production

California is the leading producer of almonds worldwide with 82% of global production. In 2014, California produced 1.9 million kernel pounds on 870,000 bearing acres valued at $6.5 billion (1,2). An additional 150,000 non-bearing acres are expected to come into production over the next four to five years, and the prediction for acreage of bearing trees for 2015 was 890,000 acres. The almond industry has grown rapidly over the past 15 years with bearing acreage increasing 41% from 2000-2014. Yield per acre over the same time frame increased 31%, which when combined with increased acreage raised the total production from 703 million pounds to 1.9 billion pounds (62%). World demand for almonds grew steadily from 2000-2014 raising the price per pound from $0.97 to $3.5 (72%) and increasing the crop value close to 10-fold (90%) from $0.7 billion to $6.5 billion (1).

The almond industry is a large and dynamic part of California agriculture and makes major contributions to the state economy. Over 72% of the California crop is exported, making almonds the most valuable export crop with 25% of California farm exports (2.5 times more than wine, the second-most valuable agricultural export). The largest export markets are China and Europe (3). The total impact on the value of California agricultural output — including direct, indirect and induced economic output — is estimated at $21.5 billion, with $7.6 billion coming from almond farming, $11 billion is value-added, and $3.4 billion is contributed from the almond processing and manufacturing sectors (4). The whole almond industry, including processing and marketing, generates over 104,000 jobs statewide, with 68,000 generated by almond farming directly and 21,000 employed on the farm (4).

The almond crop is grown in the central part of the state with two distinct production areas in the San Joaquin and the Sacramento Valleys. Over 70% of the industry is located in the San Joaquin Valley with Kern County (157,500 acres) being the largest producer and Fresno, Stanislaus and Merced counties each growing over 100,000 acres (1).

Insect Pests of California Almonds

Pests	When controls are applied	Importance of pyrethroids	Resistance concerns	Alternative management strategies	**Potential impacts of pyrethroid loss**
Key Pests					
Navel orangeworm	Nut protection (May-August)	In rotation with other AIs needed to meet low damage requirements, need established MRLs for export	Some resistance to pyrethroids beginning, needed in MoA rotations to retain efficacy of selective alternatives	Nut sanitation (partial) not in pistachios, mating disruption (partial), not in pistachios	More sprays, increased resistance, higher costs, more damage,higher aflatoxin, reduced export and domestic sales
Hemipteran complex: leaf footed bugs, stink bugs, myrids (pistachios), brown marmorated stink bug (potential)	Early season movement into crop from outside (May-June)	Only alternative if chlorpyrifos restricted	None	None	Increased damage, less export, environmental damage, worker safety concerns with chlorpyrifos
Sporadic Pests					
Peach twig borer	Winter-spring dormant spray	Only pyrethroids effective at low temperatures	None	Pruning (partial), chlorpyrifos	Increased nut damage, environmental damage, worker safety with chlorpyrifos
Peach tree borer	Spring –summer hand trunk sprays near peaches	Pyrethroids only effective and safe alternative	None	Tree removal (partial)	Potential tree death

6.2 Pest management in California almonds — the arthropod pest complex, management approaches and the role of pyrethroid insecticides

The hot and dry climatic conditions in California's central valleys are ideally suited to arthropod reproduction and movement, and the University of California IPM recommendations list 18 insect and mite pests that can cause economic damage on almonds (5).

Although this case study is focused on almonds, pistachios are often grown in the same production areas and share a similar pest complex with the same key pests attacking both crops and requiring similar pest management approaches. Therefore, the following analysis of pest management on almonds and the role of pyrethroid insecticides, also references pest management on pistachios when appropriate.

Phytophagous mites and scales have long been listed as occasional pests of almonds (8). These pest groups have traditionally been managed by relying on natural biological regulation provided by predators and parasites. As the value of the almond crop has increased, however, growers have increased the application of insecticides to control other pests that damage the nut crop directly to protect their investment. This has resulted in frequent disruption of natural controls and necessitated applications of remedial treatments targeted specifically at resurgent mite populations (6). The two most frequently used broad spectrum insecticides were the organophosphate chlorpyrifos and the pyrethroid bifenthrin (7). Growers, PCAs and university specialists are now actively working to re-establish a balance between producing a clean, exportable crop and conserving natural controls. The key pests of almonds, which pest management programs must be built around and the approaches used, are discussed below.

Navel orangeworm. The navel orangeworm is the most destructive lepidopteran pest of almonds and other nut crops, such as pistachios and walnuts (9). Larvae overwinter in 'mummy' nuts on the ground or in trees, and there are three to four adult flights per year. Adults are attracted to developing nuts for oviposition; neonate larvae tunnel into the nut, and successive instars consume the nutmeat, leaving large amounts of frass and webbing and rendering the nuts unsalable. In addition to causing direct damage, larval feeding increases the likelihood of infection of both almond and pistachio nuts with *Aspergillus* spp. that produce aflatoxins, a carcinogenic crop contaminant that causes millions of dollars in losses annually (9,10). Aflatoxin contamination of nut crops is a major health concern in the U.S. and for many export countries, and consequently strict regulations have been applied to reduce aflatoxin levels and food safety risks (10).

Management of this insect has typically been achieved by a combination of cultural controls to remove mummy nuts (involving expensive removal of mummies from trees and the orchard floor) and reduce overwintering larvae and insecticides applied to developing nuts during the season (9). Management has been complicated by the rapid expansion of almond, pistachio and walnut plantings in central California, which has brought multiple hosts for navel orangeworm into close proximity and facilitat-

Almonds are California's top export crop!

http://cdpr.ca.gov/docs/pestmgt/cdpr_chlorpyrifos_critical_use_report.pdf

ed movement between crops that are treated at different times (12). To achieve sufficient levels of control to meet damage and food safety requirements, almonds and pistachios are treated with multiple applications of insecticides that frequently include both specific and broad spectrum active ingredients. The use of broad spectrum pyrethroid materials has increased substantially as the value of these nut crops has grown. Bifenthrin, one of the top five most frequently applied insecticides in almond orchards, increased 14.5-fold from 2007 to 2010 in almonds and 9.3-fold from 2008-2010 in pistachios (10).

Insecticides sprayed to control navel orangeworm in heavily infested orchards are usually applied using a rotation of IRAC MoA groups and bifenthrin to reduce the risk of resistance development. Active ingredients currently registered for control include organophosphates (group 1B), pyrethroids (group 3A), diamides (group 28), diacyl hydrazines (group18), avermectins (group 6) and spinosyns (group 5). The pyrethroids registered for use in almonds and pistachios include bifenthrin, beta-cyfluthrin, esfenvalerate, fenpropathrin, lambda-cyhalothrin and permethrin. These insecticides are selected by growers based on their low cost ($2-5/acre) and high effectiveness compared to other insecticides registered in almonds and pistachios (B. Higbee, unpublished data). From 2008-2012, bifenthrin and esfenvalerate were two of the five most intensively used insecticides on almond and lambda-cyhalothrin, bifenthrin, permethrin and beta-cyfluthrin constituted four of the five most intensively used insecticides used on pistachios (10). Insecticides applied in rotations that bracketed hull split and hull slip for efficacy, cost and resistance on almonds may thus involve broad spectrum pyrethroids and selective lepidopteran materials applied alone and in combination (11). The frequency of pyrethroid applications is greater in the southern San Joaquin Valley where navel orangeworm pressure is highest, and resistance in this area has been demonstrated (Brad Higbee, personal communication).

Adult naval orangeworm
Photo by Mark Dreiling, Bugwood.org

It is mandatory that every crop (including almonds) meet the MRLs established by the EPA for all pesticides registered on the crop when used for domestic consumption. Over 70% of almonds are exported, and MRLs are not well harmonized around the globe; some active ingredients registered in the U.S. (particularly recently registered pesticides) do not have established MRLs in some export markets and are prohibited for export to those countries. It is essential that any active ingredients used by almond growers have established MRLs in export destinations. Older broad spectrum insecticides have established MRLs, but newer active ingredients may not, which limits their availability as alternative materials.

Pyrethroid use in almonds increased since they are economically feasible and viable options to limit organophosphate applications

Mating disruption for navel orangeworm has been pioneered as a complimentary addition to insecticidal control by Paramount Farms (now Wonderful Orchards), and early trials demonstrated that this approach can be effective in holding populations at low levels, requiring fewer insecticide applications in almonds but was not effective in pistachios (13). In large-scale commercial trials, mating disruption was effective in almonds, reducing damage from 5% (damage above 3% is unacceptable) to 2% in 2013 (14). The cost of pheromone disruption ($100/acre) was higher than insecticidal control ($20-40/ acre), but the benefits gained from applying fewer

insecticides, reducing risk of resistance and disruption of natural control indicated that this approach was a viable management tool in commercial almonds (14). Mating disruption was more effective on large orchards (greater than 40 acres) where proximity to other almond or pistachio orchards that could serve as sources of re-infestation was less.

Hemipteran complex. Early in the season, leaf-footed bugs often enter almond orchards from surrounding vegetation (where they have overwintered) and cause serious damage by feeding on young nuts; this causes the embryo to abort, gumming on the shell and nut drop (2,13). This damage is most serious in the southern San Joaquin Valley. The only effective management option is to apply 1-2 sprays of the organophosphate chlorpyrifos or a pyrethroid in spring to prevent damage to developing nuts. Bifenthrin, lambda-cyhalothrin and esfenvalerate are listed as having the most IPM value in University of California recommendations (10).

Several species of stink bugs also move into almond orchards in spring when surrounding vegetation dries up, but the most economic damage results from the green stink bug, which overwinters on the orchard floor. Damage is similar to that caused by leaf-footed bugs, although feeding is later (June-July) and does not cause nut drop (16). Stink bug damage is most severe in the lower San Joaquin Valley, and incidence has increased in recent years following a decrease in dormant sprays of organophosphates and pyrethroids for other pests. Control of stink bugs can only be achieved using 1-2 applications of chlorpyrifos or pyrethroids. Bifenthrin and lambda-cyhalothrin are the materials listed in University of California recommendations (2,16).

The brown marmorated stink bug was introduced to the U.S. recently and is widely distributed. This stink bug has a broad host range and is more destructive than most native stink bugs. Recent reports of brown marmorated stink bug findings in the northern San Joaquin Valley indicate that this could be a new and significant pest in nut crops. As with other hemipteran pests, pyrethroids are the only management alternative should this pest become established.

Several species of small plant bugs (family Miridae) are commonly found on weeds and vegetation around and in orchards. When vegetation dries up, these pests move into orchards and feed on developing nuts. These pests include the tarnished plant bug, the California buckeye bug, the calocoris bug and the phytocoris bug; they are not economic pests of almond but can cause significant damage on pistachios — where they pierce developing nuts prior to hardening and cause discoloration, malformation and nut drop. When these pests are present, the only management options are to mow or destroy vegetation that may harbor adults and to spray trees to protect developing nuts. The pyrethroids (permethrin, bifenthrin, cyfluthrin, lambda-cyhalothrin and fenpropathrin) are the first six active ingredients listed in the University of California recommendations (17).

Occasional lepidopteran pests. Several lepidopteran pests can cause economic damage in almonds, and when present, controls are usually needed to avoid economic damage.

Maximum Residue Limit (MRL)

An MRL is the Maximum Residue Level of a pesticide that is allowed in or on a food. In the United States, these allowable residues are also called tolerances.

Only foods that meet MRLs may be placed on the market. As part of the pesticide registration process, the EPA sets the MRLs for foods in the United States.

However, MRLs are not well standardized around the globe. Customers in key export markets expect any residues present on produce to meet the MRLs set in the respective importing country.

The Almond Board of California works to try to reduce the number of MRL discrepancies in key export markets by providing data and background information to the USDA, EPA, individual countries and the Codex Alimentarius (Latin for 'Food Code') process when needed.

Codex sets international food safety and quality standards used by many countries. In addition, the Almond Board of California works with registrants to ensure they understand how exports are key to almond growers, and thus why working to establish international MRLs is critical to the success of the almond industry.

The EPA-USDA Maximum Residue Limit Database provides a list of MRLs by active ingredient and export market.

http://www.almonds.com/growers/growing-safe-product/pesticides#maximum-residue-limits

The peach twig borer can be a serious pest throughout the central valley, but damage is more serious in the northern growing areas in the Sacramento Valley. Larvae overwinter in tree bark crevasses, and adults lay eggs on developing shoots and fruit, which causes surface grooves. There are four generations per year and treatment regimes for navel orangeworm normally provide adequate nut protection. In areas where peach twig borer is prevalent, a dormant spray in spring is effective and easy to time. Pyrethroids are recommended for dormant sprays, if there is low potential for runoff and water contamination (18).

Tree borers, prune limb borer and American plum borer weaken young trees by boring into limb crotches, particularly in northern growing areas. Even if damage is not widespread and if boring is present, then directed trunk sprays are necessary to avoid progressive tree decline. Two to three trunk sprays are recommended every six weeks after April when adults emerge and other than carbaryl and chlorpyrifos, which present significant worker safety risks for hand applications, pyrethroids (bifenthrin, cyfluthrin, lambda-cyhalothrin and esfenvalerate) are the only recommended alternatives (19).

The peach tree borer is an occasional pest of almonds found mostly in the coastal and northern San Joaquin and Sacramento Valleys. Larvae bore into the trunk below the graft, attacking only the peach tree rootstock; if left uncontrolled, this can cause girdling and tree death. If a severe infestation is detected, insecticides must be applied to kill emerging adults and newly hatched larvae. Directed trunk sprays using the pyrethroid esfenvalerate are the only recommended alternatives for this pest (20).

The oriental fruit moth is an occasional pest of almonds, particularly in northern growing areas close to more susceptible peach trees that are harvested before almonds. Treatment regimes for navel orangeworms provide effective control.

6.4 Main insights from California almond production

- Increasing acreages of almonds, pistachios and citrus in the San Joaquin Valley over the past 20 years has led to a closer proximity of orchards and an increased population density and damage potential from navel orangeworm. These factors, combined with a dramatic increase in almond and pistachio prices over the past decade, have resulted in an upsurge in reliance on both broad spectrum pyrethroids and selective insecticides — both are needed to meet stringent standards for damage and aflatoxin contamination in both domestic and export markets.
- The predominance of the export market for both almonds and pistachios requires all active ingredients that are used for navel orangeworm control have established MRLs in export destination countries. Since newer, more selective active ingredients may not have established MRLs in all export markets, the availability of selective alternatives to broad spectrum materials is reduced.
- Pheromone-based mating disruption and cultural controls (based on stringent sanitation to reduce overwintering populations) used in com-

bination with timed applications of both broad spectrum pyrethroids and selective active ingredients (based on intensive monitoring) that are applied in rotation to reduce the potential for resistance provide a balanced and sustainable navel orangeworm management program.

- In the existing San Joaquin crop landscape, areas with a high potential for navel orangeworm damage are created that require adjustments in pest management approaches. In the western San Joaquin Valley, pistachios are the predominant orchards; sanitation is not as efficient, mating disruption is less effective; navel orangeworm damage potential is high; and almond orchards are at high risk. In the eastern and central San Joaquin Valley, almonds predominate and since sanitation and mating disruption are effective, damage potential is low with the exception of hot spots in close proximity to pistachios and citrus, which both serve as sources of navel orangeworm immigration. In these areas where damage potential is higher, pest management systems must be adjusted to include greater reliance on broad spectrum pyrethroids.
- In both almonds and pistachios, growers in the southern San Joaquin Valley must apply 2-3 early season applications of pyrethroids to prevent damage to developing nuts that are caused by a complex of hemipteran pests that move into orchards from surrounding vegetation as it dries. There are no alternative controls.

6.5 Impacts of pyrethroid insecticides at the farm level: A case study, Wonderful Orchards (formerly Paramount Farms), Bakersfield, California

Leave behind the urban expanse of Los Angeles County and head north on Interstate 5 (I5) over the Tejon Pass and suddenly you enter another world. Stretched out before you is the richest and most productive agricultural region in the world, the San Joaquin Valley. Aptly dubbed the 'food basket of the world,' the San Joaquin stretches 250 miles north and anywhere from 75-150 miles wide and is the home of remarkable agricultural diversity. California boasts nine of the top ten agricultural production counties in the nation and five of these are in the San Joaquin Valley. Its flat, fertile expanse is bounded on the east by the snow-capped Sierra Nevadas and on the west by the Sierra Madre and Coastal ranges providing the hot, dry summers and mild, damp winters that crops thrive on. And thrive they do, in great diversity with seemingly endless expanses of grapes, oranges, tangerines, peaches, almonds, pistachios, walnuts, cotton, alfalfa, tomatoes and every variety of vegetable imaginable.

For this case study, we are focusing on nuts and visiting with Wonderful Orchards, formerly known as Paramount farms, who are the world's largest producers of almonds and pistachios and located just north of Bakersfield in Kern County on the southern end of the San Joaquin Valley. With approximately 90,000 planted acres, Wonderful Orchards is the world's largest grower of almonds, pistachios and pomegranates.

Owners Steve and Lynda Resnick entered into agriculture in the early '80s with Paramount Citrus, quickly expanded to add nuts and pomegranates and became leading producers globally. The company became Wonderful Orchards in 2015, which is part of The Wonderful Company — a successful,

Research entomologist Brad Higbee out in the orchard

fast-growing privately held $4 billion company with worldwide distribution and agricultural enterprises that include wine grapes, wine, mandarin and navel oranges, snack foods, flavored water, juices and flower production. The Wonderful Company has a long-standing commitment to corporate social responsibility, including more than $100 million invested in environmental technologies and sustainability research; nearly $50 million in charitable giving and education initiatives in 2015; $30 million toward the construction of a new charter school campus in California's Central Valley; and innovative health and wellness programs for its employees.

The Resnick's core focus is on farming and doing it as well as it can be done. They are vertically integrated, with in-house expertise in every aspect of growing these crops — including all cultural aspects, pest control, irrigation technologies, specialized equipment use and all tied together with sophisticated information systems. Truly a planting-to-picking and tree-to table-operation on a scale that allows them to be on the cutting edge of progressive technologies and make significant contributions to the state's agriculture in areas such as water conservation and IPM.

To discuss the pest management philosophy at Wonderful Orchards, we sat down with Brad Higbee, the Director of Entomological Research in Shafter, California, literally in the center of thousands of acres of pristine almond and pistachio orchards that were ready to burst into flower and begin the new 2016 crop cycle. Brad is fully engaged with his staff of trained pest control specialists in developing, testing and implementing state-of-the-art approaches to managing the arthropod pest complex on almonds and pistachios. He often works jointly with University of California specialists and regularly publishes results of his research in scientific journals for all in the industry to share. Brad graduated from the University of California-Irvine and moved to Washington State where he worked with USDA Agriculture Research Service in developing pheromone disruption technologies to manage codling moth in apples (now the core practice in apple pest management) before coming to Paramount Farms 14 years ago. Brad's philosophy is to develop new approaches to managing the key pests of nut crops that will allow growers to protect their high value crops by balancing pesticide use with new approaches such as mating disruption and natural controls that regulate secondary pests.

We began with the industry's key pest — the navel orangeworm, which was not a major pest in the '70s and '80s. Most University of California research recommended sanitation to eliminate overwintering sites for larvae in nut mummies left on trees and on the orchard floor with few if any sprays required. This approach fit well with preserving natural enemies to biologically control secondary pests like mites. But this was when there were few pistachios grown, and almonds were a relatively new crop. In the '90s, the situation changed, and when he arrived in the southern San Joaquin, Brad recalls:

"We've got a moth pest that's costing us millions of dollars a year, and nobody is doing anything about it. It was clear that it was going to take more than that (sanitation) because by then you've got a lot of pistachios, figs and other hosts, citrus, and a rapidly increasing almond acreage that were contributing to your

populations. No matter how good a sanitation job you do; you've got immigration coming in so you have to deal with that."

The stage was set for a new approach, such as mating disruption, and Brad Higbee, an early pioneer in getting that approach accepted and implemented for apples and pears in Washington was ready to step in:

"I ran a couple of the original codling moth area-wide projects up there in Washington back in 1995-2000 and was working on it before that."

Establishing mating disruption for navel orangeworm was a slow process initially, but early results on almonds were encouraging:

"We published our first paper on mating disruption in 2005, showing that it clearly could be a benefit on almonds, and it's just now, almost ten years later, that the UC is finally putting it into their IPM program, so it takes a while."

In the early development of mating disruption, insecticide use to control navel orangeworm was already common and pyrethroids played a major role in limiting damage to acceptable levels and enabling growers to meet aflatoxin contamination standards. Early field trials, therefore, used a combination of insecticides to lower initial populations and mating disruption to hold populations at acceptable levels until monitoring traps indicated that additional sprays were needed. In an early area-wide trial on 2,500 acres of almonds that were averaging 5-10% damage, the whole acreage was treated with an aggressive insecticide program and half also received mating disruption. The results were impressive as Brad recalls:

"We took that damage down to 1.5% where it was insecticides alone and 0.5% where we included mating disruption."

These trials were conducted when a new pyrethroid (bifenthrin) was registered on almonds, which exhibited excellent adulticide activity and persistence.

"Bifenthrin was highly effective, and you could take a population down; you could literally smash populations for weeks with one application. That made the project possible."

The tricky part of using monitoring traps to make the 'no spray' follow-up decision. At that time, this was a big responsibility because a pyrethroid back-up spray was cheap insurance, but on the 2,500 acre trial site, only 300 acres were re-sprayed in 2007 and 2008. Brad recalls:

"Based on our monitoring system, it was traumatic — six weeks of time where I am saying no, we're looking good, we don't need to spray. People were very, very nervous, but it worked out fine and we were under 1%".

In 2009, only a few edges were resprayed where moths came from neighboring orchards, and in 2010 and 2012 no re-sprays were needed. At this time, economics began to play a major role as generic pyrethroid active ingredients came onto the market, and sprays became inexpensive:

"When generics hit,$5, $10 bucks/acre, mating disruption costs $100+/acre, so there wasn't much motivation. "

Multi-spray insecticide programs became commonplace once again. Contrary to earlier experiences where pyrethroid applications quickly disrupted natural controls and resulted in mite resurgence and increasing need for miticide applications, the new pyrethroid active ingredients (bifenthrin and lambda-cyhalothrin) did not flare mite populations, indicating that these active ingredients had some miticidal activity. After years of avoiding pyrethroids in almonds to preserve natural control, Brad included a permethrin treatment in an insecticidal trial to test the older active ingredient:

It is essential that any active ingredients used by almond growers have established MRLs in export destinations.

"I had to prove it to myself, so I put permethrin in an almond insecticidal trial and they did — boom! through the roof."

Location of orchards and crop patterns also play a major role in determining navel orangeworm pressure, the potential for success of mating disruption and the need for additional pyrethroid sprays. Mating disruption trials have been far less successful on pistachios than on almonds, and Brad has determined that this results from the inability to lower overwintering populations in pistachios. In almonds, sanitation involves re-shaking trees and even hand pulling to remove mummies from trees, followed by sweeping ground nuts into rows and destroying them by mowing that reduces mummies to less than10 per tree. On pistachios, the same sanitation practices work, but mowing does not destroy the mummies:

"It's like mowing marbles, we leave hundreds per tree, and if only half are infested, you have a huge resource."

In Kern County, soil conditions vary and east of I5, where soil is more fertile, almonds predominate. Since sanitation is effective, orangeworm damage is low (1%) and mating disruption is effective with occasional pyrethroid sprays — except in areas where hot spots are created close to pistachios and citrus, and more sprays are needed. To the west of I5, however, where soil is more alkaline, pistachios are the primary nut crop. Since sanitation is not effective, navel orangeworm pressure in almonds is higher (20-30% damage), and mating disruption is less effective, and consequently, more pyrethroid sprays are needed to get nuts to an acceptable 1% damage level.

Another major concern for both almond and pistachio growers, particularly in the southern San Joaquin Valley, is the hemipteran plant bug complex, which migrate into orchards from surrounding vegetation as it dries in spring and can cause serious economic damage feeding on developing fruit. There are no good monitoring or prediction tools, and pyrethroid sprays (2-3) are the only way to avoid severe economic loss, as Brad ruefully states:

"They don't live in the orchard most of the year, but they come in the spring. It's just kind of this flash, they are there, and if you are not there looking every day, they could do a lot of damage before you see them. Its [pyrethroids] the only effective products for these beasts."

When asked if he considers the newly introduced brown marmorated stink bug to be a threat, Brad indicates:

"Yeah, we are very, very concerned about it. I think we are about four or five years away. Pyrethroids are clearly going to be the number one option."

With low damage and aflatoxin contamination standards for export, the need to have MRLs established for all of the active ingredients used for navel orangeworm is a major concern for almond and pistachio growers that also restricts the number of selective materials that can be used. Wonderful Orchards relies on methoxyfenozide and chlorantraniliprole for specific orangeworm control and rotate these active ingredients with pyrethroids as needed to reduce the risk of resistance. As more pyrethroids are used for navel orangeworm to back up mating disruption in areas where pressure is high, and the same materials are used to control hemipteran pests at times when orangeworm can be exposed to sub-lethal doses, the development of resistance to pyrethroids is inevitable. Brad has been monitoring resistance since 2007, and the results are disturbing:

"We started seeing it in 2012 and by 2013 we saw, not full field failures, but performance was diminished. Now we still don't have full field failures, but where pyrethroids used to be up here [indicates high performance] and the others were down here [indicates medium performance], now they are all similar."

Resistance management using rotations of MoAs, reducing sprays by using intensive monitoring protocols and employing alternative strategies to regulate populations (such as mating disruption and sanitation) are key components of pest management for Wonderful Orchards. The prospect of losing effective tools through re-registration is a major concern, and Brad sums it up succinctly when he stated:

"Well, I tell you, if we lose the pyrethroids, and it's not so much the older ones, it's the new ones — the Warriors, the cyfluthrins and the bifenthrin based products — we would be in big trouble. The organophosphates, it remains to be seen. It will hurt some, but the pyrethroids would be a lot worse…if I had a choice, the pyrethroids, I wouldn't have to think a millisecond about that choice."

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Bee and Growing Almonds

Pollination is critical to growing almonds. Growers are extremely protective when using pesticides that could impact bee health; they use only bee safe materials during the short period of flowering almonds (April and May).

Wonderful Orchards is investigating breeding native pollinators (mainly, the blue orchard bee) and releasing them in their almond orchards!

The future may yet lie in plant breeding; a new self-pollinating almond variety 'Independence', which does not require bees was released in 2008 and is gaining traction with growers.

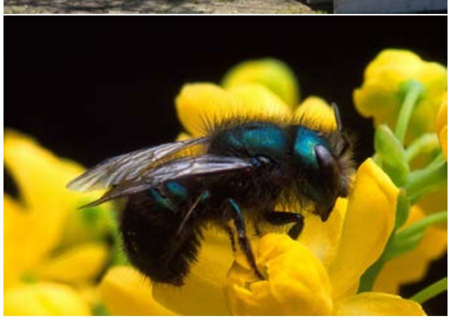

Photo by Jack Dykinga, USDA Agricultural Research Service, Bugwood.org

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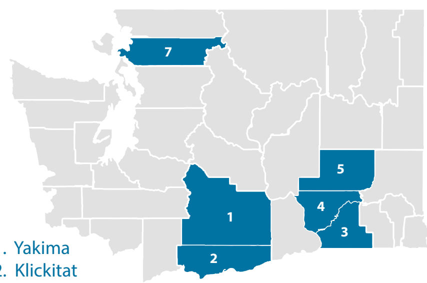
7.0 Washington potatoes and processed sweet corn contrasted with Wisconsin potatoes and processed sweet corn

Potatoes and processed sweet corn are important agricultural commodities in the U.S., and Washington and Wisconsin are key production states. This case study examines the use and value of pyrethroid insecticides in both potatoes and processing sweet corn in Washington, which typifies production in the Pacific Northwest, and contrasts this with Wisconsin, which typifies production and pest management the Midwestern and eastern United States. These production systems together are representative of 77% of the potatoes and 84% of the processed sweet corn grown in the U.S.

In Washington, the case study was conducted with Ron Reimann, co-owner of T and R Farms of Pasco, Washington, which grows 1,100 acres of potatoes and 700 acres of processed sweet corn. Additional input was provided by Rich Jaeger of R and K Agriculture LLC, an independent crop advisor for T and R farms; Jennifer Riebe of JFR Crop Services, an independent crop advisor from Boise, Idaho and board member of the Tri-State Potato Commission; Dr. Alan Schreiber of Agricultural Development Group Inc. in Eltopia, Washington; Dr. Carrie Wohleb, a vegetable specialist at Washington State University; Charles Grasham, manager of Crop Protectants, Simplot Grower Services in Boise, Idaho; Tom Salaiz, a regional agronomist for McCains Inc., in Burley, Idaho; Dr. Joe Guethner from University of Idaho, Moscow, Idaho; and Chuck Martin of Del Monte Foods in Kalamath Valley,Washington.

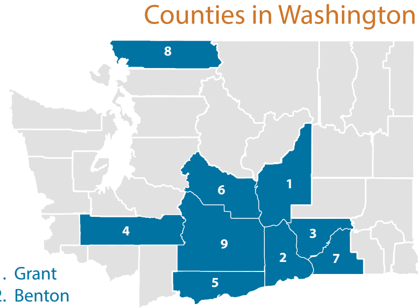
In Wisconsin, on-farm comparisons were drawn from Steve Diercks of Coloma Farms in Coloma, Wisconsin, which grows 900 acres of potatoes and 200-300 acres of processed sweet corn. Additional input was provided by Randy Van-Haren, an independent crop consultant of Pest Pros from Plainfield, Wisconsin; Dr. Russ Groves, a professor and vegetable extension specialist from the University of Wisconsin-Madison; and Dr. Brian Flood, a corporate fellow and research entomologist for Del Monte Foods in Plover, Wisconsin.

Major
Potato Production
Counties in Washington



1. Yakima
2. Klickitat
3. Walla Walla
4. Franklin
5. Adams
6. Skagit

Major
Sweet Corn Production
Counties in Washington



1. Grant
2. Benton
3. Franklin
4. Lewis
5. Klickitat
6. Kittitas
7. Walla Walla
8. Whatcom
9. Yakima

7.1 Washington and Pacific Northwest potato and processed sweet corn production

POTATOES. The Pacific Northwest is the leading potato production region in the U.S. with 533,000 harvested acres (56.3% of U.S.) yielding 253 million cwt (61.7% of U.S.) valued at $1.92 billion in 2015 (1,2). Idaho is the leading production state with 324,000 acres producing 130.3 million cwt; Washington is 2nd with 170,000 acres producing 100.3 million cwt, and Oregon with 38,900 acres producing 21.8 million cwt is ranked 6th nationally (1).

The Washington crop is grown primarily in the Columbia Basin in eastern Washington where fertile volcanic soil, excellent growing conditions, ample water from the Columbia and Snake River irrigation projects and a long growing season (120-140 days) combine to make Washington the most productive state in the region with 590 cwt/ acre compared with Oregon at 560 cwt/ acre and Idaho at 402 cwt/acre (1); the region leads the nation, which averages 397 cwt/acre in productivity. The Columbia basin is comprised of two primary regions: the northern (where long season russets

for processing predominate) and the southern (where a mix of both fresh and processed varieties are grown). The primary production counties are Yakima, Klickitat, Benton, Walla Walla, Franklin and Adams. The Skagit Valley in northwest Washington is also a primary production area where short season, fresh and specialty crops are grown.

Potatoes are the 3rd most valuable crop grown in Washington after apples and wheat, contribute $4.6 billion to state economy and create 23,500 jobs (3,4). Over 85% of the Washington potato crop is processed into frozen and dried products, with 40% exported internationally. Lamb Weston (Con Agra Foods) is the largest processor with seven plants operating year-round and generating 4,300 full time jobs.

PROCESSED SWEET CORN. The Pacific Northwest region (Washington and Oregon) ranks 2nd in U.S. processed sweet corn with 100,000 harvested acres (32.5% of U.S.) yielding 970,850 tons (39% of U.S.) valued at $104.1 million in 2015 (5). Washington is the leading production state in the nation with 78,800 acres producing 772,240 tons valued at $76.3 million, while Oregon ranks 4th with 21,200 acres producing 198,610 tons valued at $27.8 million (3). Productivity is the highest in the U.S. with an average yield of 8.7 tons/acre compared to 7.7 tons/acre in the Midwest. Price received/ton is also highest in the Pacific Northwest, averaging $123/ton compared to $92/ton in the Midwest (5).

The Washington sweet corn crop is grown primarily in the southern Columbia Basin in eastern Washington where fertile volcanic soil, excellent growing conditions, ample water from the Columbia and Snake River irrigation projects and a long growing season are ideal for sweet corn production; the relatively short maturity for sweet corn allows many growers to double-crop with peas. Processed sweet corn is grown in Grant, Benton, Franklin, Lewis, Klickitat, Kittitas, Walla Walla, Whatcom and Yakima counties with the majority in Grant County (6). The majority of processed sweet corn in Washington is frozen with eight freezing plants; Del Monte is the sole canning processor and contracts primarily with growers in Yakima County.

7.2 Wisconsin and the upper Midwest potato and processed sweet corn production

POTATOES. The upper Midwest and eastern U.S. states — which include Wisconsin (64,000 acres), Minnesota (44,000 acres), North Dakota (80,000 acres), Michigan (45,000 acres), Maine (51,000 acres) and New York (17,000 acres) together with several eastern states with minor production (1,500-3,500 acres) — comprise a contiguous potato production area with similar climate and production practices. Together, these states represent a significant potato production area with 232,000 acres (25% of U.S.) generating 117 million cwt (29% of U.S.) valued at $779 million (1).

Wisconsin potato production is ranked 3rd in the U.S. with 445.6 million cwt produced on 64,000 acres valued on-farm at $225 million. Wisconsin is also ranked 3rd nationally in productivity with average yields of 460 cwt/acre behind Washington (590 cwt/acre) and Oregon (560cwt/acre) (1).

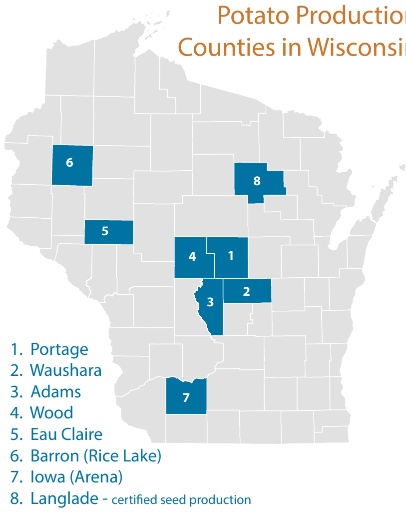
Insect Pests of Washington Potatoes

Pests	When controls are applied	Importance of pyrethroids	Resistance concerns	Alternative management strategies	**Potential impacts of pyrethroid loss**
Key Pests					
Potato psyllid, vector of zebra chip	Season long with pyrethroids early (June) and late (August) to avoid disruption of mites	Essential early and late to manage psyllids	Multiple psyllid controls used with rotation of MoA, AIs to manage resistance to all classes	Systemic neonicotinoid at planting	Greater use of alternatives, faster resistance, more zebra chip
Beet leafhopper, vector of BLTVA	Early season (May-June)	Only effective option to control adult leafhopper immigration and establishment of BLTVA	None	None	Increase in virescence, yield and quality loss
Thrips	Mid season (July-August)	Essential in thrip control	Resistance common and rotation of AIs with different MoAs essential to management	None	Faster resistance in alternative MoAs, reduced efficacy and yield
Potato tuberworm	Late season, close to harvest (September-October)	Only option to provide control with short PHIs and established MRLs for export	None if limited to late season	Cultural (partial)	Increased tuber damage, processing plant rejection, failure to meet MRLs for export
Colorado potato beetle	Early season (May-June)	Used in conjunction with neonicotinoids or where no systemic used	Resistance widespread in U.S. to all MoAs but not in WA,pyrethroids used in rotation with other MoAs	None	Increased resistance, more sprays, increased costs, declining efficacy
Sporadic Pests					
Foliage feeding lepidoptera	Mid-season (July-August)	Used for fast response to damage when over threshold	Resistance not an issue, alternative MoAs available	None	Slower response, increased damage, reduced yields
Hemipteran complex	Mid-season (June- August)	Only effective option to reduce damage	None	None	Reduced yields

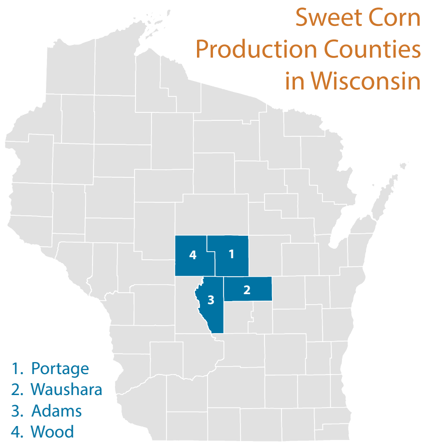
Insect Pests of Washington Sweet Corn

Key Pests					
Corn earworm	Row tassel to brown silk	A range of AIs with differing MoAs available, pyrethroids the only AIs that have sufficient adult knockdown and surface persistence to prevent ear damage	Not reported in earworm but alternative MoAs registered if needed	None	Substantial increase in sprays, increased resistance, crop rejection
Sporadic Pests					
Seed corn maggot	Seed	Neonicotinoid seed treatment	None	Cultural (partial), alternative AIs, organophosphates	Increased environmental risk if neonicotinoids restricted
Cutworms and armyworms	Emergence to early plant growth	Soil or banded applications	None	Alternative AIs, organophosphates, carbamates	Increased environmental risk
Corn rootworm adults	Silking	Pyrethroids for ear protection, control silk pruning	None	None	Reduced pollination and ear fill

Major Potato Production Counties in Wisconsin



Major Processed Sweet Corn Production Counties in Wisconsin



The Wisconsin crop is grown primarily on sandy glacial outwash soils in central, northwestern and southcentral areas of the state with production concentrated in Portage, Waushara, Adams, Wood, Eau Claire, Barron (Rice Lake) and Iowa (Arena) Counties. Approximately 45% of Wisconsin potatoes are processed, 45% are marketed fresh while 10% are grown as certified seed in Langlade County.

PROCESSED SWEET CORN. The upper Midwestern states of Wisconsin and Minnesota comprise the largest processed sweet corn production area in the U.S. with 163,900 acres producing 1.25 million tons valued at $116.3 million. While Washington is the lead production state, Minnesota ranks 2nd with 103,200 acres producing 761.3 tons valued at $73.2 million, and Wisconsin ranks 3rd with 60,700 acres producing 490.2 million tons valued at $43.1 million (5).

Wisconsin sweet corn is crop grown primarily on irrigated sandy soils in rotation with potatoes. Primary production is concentrated in Portage, Waushara, Adams and Wood counties in central Wisconsin. Before irrigation was widespread, sweet corn was grown throughout the state on non-irrigated land by dairy farmers and processed at dozens of regional canneries scattered throughout the state. While some of this non-irrigated production remains, processing companies have consolidated to five to six major companies, and processed sweet corn acreage is increasingly concentrated on irrigated land. The majority of the Wisconsin crop is canned with crops destined for freezing grown primarily in the eastern counties bordering Lake Michigan.

7.3 Pest management in Washington potatoes and processed sweet corn — the arthropod pest complex, management approaches and the role of pyrethroid insecticides

POTATOES. The Pacific Northwest potato production areas comprise a large ecoregion with similar growing conditions and the same broad arthropod pest complex that varies between states in intensity and economic damage. The pest management approach in all states is based on intense surveillance/monitoring of pest populations and chemical management when populations reach damaging levels. Since three of the key insects in these production systems cause economic damage — primarily through their transmission of destructive plant diseases that are incurable once the plant has been inoculated (potato psyllid/zebra chip, beet leafhopper/ virescence agent (BLTVA) phytoplasma and green peach aphid/leafroll virus) — insecticidal regimes frequently need to incorporate prophylactic systemic treatments in combination with foliar sprays to prevent transmission when the vectors arrive in fields.

Potatoes in the Pacific Northwest have a broad arthropod pest complex with nine to ten key pests that must be managed annually to avoid economic damage although individual pest populations vary in intensity by season and by region (7). Four of the key pests have been introduced into the region within the past decade, and management of these 'new arrivals' has dominated the choice of insecticidal control in recent years with

Insect Pests of Wisconsin Potatoes

Pests	When controls are applied	Importance of pyrethroids	Resistance concerns	Alternative management strategies	**Potential impacts of pyrethroid loss**
Key Pests					
Colorado potato beetle	Early season where no neonicotinoid was used (May-June)	No longer critical	Resistance common to all MoAs, pyrethroids needed in resistance management programs	Cultural (partial) , other AIs with various MoAs	Increased resistance to alternatives
Potato leafhopper	Mid-season (June- August)	Most effective and economical for rapid response to influxes that exceed thresholds	None	None	Increased use of alternatives, reduced worker safety
Sporadic Pests					
Foliage feeding lepidoptera	Mid-season (July-August)	Rapid response to damage over threshold	None and alternative MoAs available	None	Increased use of alternatives, reduced worker safety
Fleabeetles	Early season (June-July) where no systemic neonicotinoid used	No longer critical	None	Systemic neonicotinoids, other AIs (organophosphates)	Minor
Hemipteran complex	Early season-mid season (June-July)	Only effective option available	None	None	Reduced yield

Insect Pests of Wisconsin Sweet Corn

Key Pests					
Lepidopteran complex attacking ears: corn earworm, European corn borer, fall army worm, western bean cutworm	Row tassel through brown silk	Sole options to provide adult control and enough persistence to kill larvae prior to ear damage. Pyrethroids used extensively	None except earworm migrating from the south, alternative MoAs available if needed	None other than use of alternative AIs which are less effective	Severe yield loss, processor rejection Reversion to alternate AIs would result on more sprays, reduced efficacy, greater worker safety and environmental risk
Sporadic Pests					
Seed corn maggot	Seed	Neonicotinoid seed treatment	None	Cultural (partial), organophosphate soil applications	Increased worker and environmental risk
Cutworms, true armyworm	Seedling, early plant growth	Soil or banded pyrethroids	None	Organophosphates and carbamate soil treatments	Increased worker and environmental risk
Corn rootworm adults	Silking	Pyrethroids used for ear protection prevent silk pruning	None	None	Greater use of alternative AIs, more damage, less ear fill

price, efficacy and the spectrum of control serving as the primary drivers of insecticidal choice (Alan Schreiber, Agriculture Development Group, Eltopia, Washington, personal communication). These recent pest introductions include the following:

Potato Psyllid. The potato psyllid is a phloem-feeding homopteran pest that causes severe economic damage as the vector of zebra chip disease (a bacterial pathogen, *Candidatus* Liberibacter solanacearum that causes a dark, striped necrotic pattern in tubers that precludes processing). High populations in the absence of the pathogen can also cause plant yellowing and purpling that can reduce yields. The potato psyllid is a highly migratory species with host plants primarily in the nightshade family (Solanaceae) and morning glory family (Convolvulaceae), although other host plants have recently been reported; this species is known to have several distinct genetic haplotypes that vary in their ability to overwinter in northern regions, thus creating resident and migratory populations that complicate management options. The pest was first reported in the northwest in 2011 as a migrant from Texas and has caused sporadic and serious economic damage since that time (8). The Washington State Potato Commission funded a statewide psyllid and zebra chip monitoring network in 2012, and psyllid populations have increased rapidly with detections in 79% of sampled fields in 2015 (10). Since the proportion of psyllids carrying the disease varies by area and year, economic damage is hard to predict, and growers are advised to begin psyllid control programs early before populations are established and laying eggs (9).

Consequently, a combination of a planting time and systemic neonicotinoid application can provide control for 60-90 days, followed by a rotation of broad spectrum pyrethroids and more specific materials, such as abamectin and spinosad, for the remainder of the season is needed. Pyrethroids are usually not recommended in mid-season to avoid increasing mite populations but are essential early and late since they have superior efficacy against adult psyllids that move into fields early. Pyrethroids have established MRLs that are critical to meet export requirements in late season. Pyrethroid applications in early and late seasons also provide critically important control for other key pests that need to be managed at those times (e.g., beet leafhopper early and potato tuberworm late).

The alternatives to pyrethroids also have drawbacks that impact grower choice: spinosad is more expensive and abamectin should not be applied in combination with commonly used fungicides that are formulated with adjuvants that act as stickers or binders (e.g. Bravo-Weather Stik®, Dithane™-Rainshield™). Psyllid management is an important driver of insecticide use and in areas where zebra chip is prevalent, growers in Texas, Nebraska and Kansas spent $300-400/acre on psyllid control programs in 2009-2011(11).

Beet leafhopper. Planting time applications of neonicotinoid insecticides provide some leafhopper control when adults move into potatoes in spring, but foliar insecticide applications based on monitoring traps are the primary management approach. Pyrethroids are the most effective insecticides at this time, although repeated use can cause increases in mite populations and should be avoided. Older pyrethroids (such as permethrin and esfenval-

Adult potato psyllid
Photo by Oklahoma State University, Department of Entomology

Zebra chip crisps
Photo from Wikimedia Commons

Beet leafhopper
Photo by A.C. Magyarosy, Bugwood.org

Tuberworm damage on a potato
Photo by Silvia I. Rondon, Hermiston Agricultural Research and Extension Center, Oregon State University

erate) have been implicated in mite resurgence, but newer materials (such as bifenthrin) may have some miticidal activity and are less likely to increase mite populations.

Planting time applications of neonicotinoid insecticides provide some leafhopper control when adults move into potatoes in spring (particularly thiamethoxam), but foliar applications based on monitoring traps are the primary management approach. Pyrethroid active ingredients are the most effective materials at this time, although repeated use can cause increases in mite populations and should be avoided. Older pyrethroids (such as permethrin and esfenvalerate) have been implicated in mite resurgence, but newer materials (such as bifenthrin) may have some miticidal activity and are less likely to increase mites.

Thrips. Thrips are widely distributed in the Pacific Northwest with the highest populations in the southern half of the Columbia Basin and the western half of southern Idaho (7). It is estimated that 10-25% of potatoes are treated annually to avoid yield loss, although there is little definitive evidence that the leaf scarring and bronzing caused by thrips feeding causes economic yield loss. Two species — western flower thrips and onion thrips — have been implicated in damaging potato and both migrate into fields from surrounding vegetation, have multiple generations and can build up rapidly to high population levels.

Thrips have only emerged as a key pest of potatoes in the last 20 years, which has been attributed to the switch from broad spectrum systemic and foliar organophosphate and carbamate insecticides (used to control other pests but also controlled thrips) to neonicotinoids and selective foliar insecticides, which no longer control thrips and allowed them to emerge as key pests. Foliar insecticides are used to control thrips, and because of their cryptic lifestyle and ability to escape exposure, several consecutive applications are often needed. Resistance is a major concern, and rotation of active ingredients with different IRAC MoA groups is essential. The pyrethroids zeta-cypermethrin and bifenthrin (group 3), abamectin (group 6), spinetoram (group 5), dimethoate (group1B) and methomyl (group 1A) all have efficacy against thrips, and all are essential for rotations that delay resistance.

Potato tuberworm. The potato tuberworm is one of the most economically damaging pests of potatoes worldwide, but this pest was not seen in the Pacific Northwest until 2002-2003 when several fields were rejected by processors due to tuber damage (7). Since that time, the tuberworm has emerged as a key pest and an annual threat in many areas of the Columbia Basin. The insect overwinters as a pupa in the soil, and temperature is a major factor determining successful establishment. As of now, the tuberworm is established and causes economic damage in areas with high spring, summer or fall temperatures and is of less concern in areas with higher elevations and latitudes; counties in the southern Columbia Basin in Washington and in Oregon are at the greatest risk. Recent climatic changes bringing elevated temperatures and extended growing seasons are highly likely to extend the range of this pest in the Columbia Basin and lead to increasing economic damage.

Potato tuberworm is a lepidopteran pest with two to three generations per year, building high late season populations and causing tuber damage. Adults lay eggs on foliage and exposed tubers late in the season, and the crop must be protected through harvest to prevent tuber damage. University of Washington recommendations call for foliar insecticide control when adults are present from four weeks prior to desiccation through harvest. Fortunately, there is a range of insecticides with different modes of action that can be used to avoid resistance, which is common with this insect. Effective materials include pyrethroids, carbamates, organophosphates, spinosad and abamectin. In order to be effective applications must be made close to harvest and short PHIs and established MRLs are critical: abamectin (14 days), chlorantraniliprole (14 days), indoxacarb (7 days) and spinosad (7 days) are not viable alternatives close to harvest. The pyrethroids beta-cyfluthrin (0 day) and zeta-cypermethrin (1 day) have excellent tuberworm efficacy, short PHIs and established MRLs; they are important management tools.

The following insect and mite pests have been established and managed as key pests for many years in the Pacific Northwest; control programs directed at the introduced pests (above) also normally provide effective control of these pests:

Colorado potato beetle. The Colorado potato beetle is a serious economic threat to potato production worldwide and is widely distributed in the Pacific Northwest (7). Adults overwinter in or close to previous potato crops and migrate into new fields from the edges. Both adults and larvae defoliate plants and cause serious yield losses if left uncontrolled. This insect readily develops resistance to a wide range of MoAs, and resistance has been reported to organophosphates, carbamates, pyrethroids and neonicotinoids in other production regions.

In the Pacific Northwest, resistance is less common and the widespread use of neonicotinoid insecticides at planting provide effective control for 60-90 days; this has reduced the economic impact of the Colorado potato beetle in many areas. Where a neonicotinoid soil application has not been used or after the efficacy of the soil application declines, there is a wide range of effective foliar applied that can be used to manage populations during the season. These include multiple active ingredients in at least seven IRAC MoA groups (7). Used in rotation to avoid resistance, these materials should be selected based on efficacy, spectrum of control and price. Pyrethroids are effective, have a broad spectrum of control and are inexpensive, thus are good pest management alternatives but use should be restricted to early and late season applications to avoid increasing mite populations.

Lepidoptera as foliage feeding pests. Several lepidopteran pests, including cabbage looper, armyworms and cutworms, appear sporadically as defoliating larvae in potatoes, and although economic damage is infrequent, these infestations are often treated with foliar insecticides by growers. A range of active ingredients from at least five IRAC MoA groups provide good control, and pyrethroids, which are inexpensive, effective and also control other pests, are often used by growers (7).

Emerging and potential pest threats. For the past two decades, the Pacific Northwest has experienced a series of new or re-emerging pest threats that have required significant adjustments in approaches to pest management. Growers, PCAs and university specialists are therefore vigilant in detecting and developing plans to manage new potential threats to potatoes.

Lygus bugs represent a potential new pest threat that is increasing in many areas (12). Lygus bugs feed as both adults and larvae by extracting plant sap and in doing so, inject saliva that causes wilting of plant terminals, chlorosis and potentially yield loss. Lygus bugs move into potatoes from surrounding vegetation (often in large numbers) and can quickly cause economic damage if left uncontrolled. It is likely that lygus bugs have emerged as a pest threat following the widespread adoption of systemic neonicotinoid insecticides (do not provide effective lygus control) in place of organophosphate and carbamate systemics (in the past, did control lygus). Pyrethroids provide effective lygus control, and if lygus continues to emerge as a consistent economic threat, pyrethroids will be an essential management tool.

The brown marmorated stink bug, which was introduced in the early 2000s, is already widely distributed across the U.S. and represents a serious potential threat to potatoes. This stink bug has a broad host range and is more destructive than most native hemipteran stink bugs (13). As with other hemipteran pests, pyrethroids will be an essential management tool should this pest become established.

PROCESSED SWEET CORN. Sweet corn for processing in the Pacific Northwest is grown extensively in the central and southern Columbia Basin of Washington and in Oregon where it is an important rotation crop for potatoes. In the southern Columbia Basin, the relatively short maturity of early sweet corn (60-70 days) allows double cropping with peas. The arthropod pest complex attacking sweet corn is relatively narrow when compared with potatoes; a single dominant key pest, the corn earworm, causes most of the economic damage.

Corn earworm larvae
Photo by University of Minnesota, Department of Entomology

Corn earworm. The corn earworm is a damaging pest of sweet corn throughout the U.S., and the timing and extent of damage is dependent on the ability of the pupae to overwinter. In areas where pupae can overwinter, adults emerge in the spring and are a major problem on early varieties; whereas in areas with colder winters, pupae cannot overwinter and damage occurs later when second generation adults migrate to northern growing areas from the south (14). Adult earworm moths are attracted to silking sweet corn fields, and eggs are laid directly on fresh silks. Small larvae feed on silks; at the 3rd instar, they become cannibalistic and usually only one to two surviving larvae continue to feed in developing kernels and cause severe damage and contamination. Improved post-harvest cleanup technology in processing plants can remove minor tip damage and larval contamination, but foliar sprays are the only management approach that can produce the damage-free end product required by consumers. In-field control technology has evolved dramatically over the past two decades and has switched from multiple application regimes using 10-15 sprays of organophosphate and carbamate insecticides to a carefully targeted approach combining host susceptibility and earworm adult abundance in

a 'treatment window' approach (pioneered by Dr Brian Flood, Del Monte Foods) that normally limits applications to 1-3 based strictly on need. The importance of adult control to limit egg laying and persistence to control larvae before they enter the ear has limited insecticide selection largely to pyrethroids, which are used almost exclusively. Corn earworm is a migratory insect and has been slow to develop resistance to pyrethroids; however, in situations where pupae overwinter and successive generations are exposed in the same area, resistance is likely to occur. This has been reported in the southern U.S. and led to resistant populations migrating north in late season into the Midwest (Brain Flood, Corporate Researcher Del Monte, personal communication). Resistance has not been reported in the Pacific Northwest, but active ingredients in five different MoA groups are registered that could be rotated with pyrethroids to delay the onset of resistance and maintain the level of control needed to meet processing standards. Exports to the Pacific Rim are an important market for Washington processed sweet corn, and established MRLs in export destinations are of critical importance in selecting alternative active ingredients.

In Washington and Oregon, there are distinct regional differences in earworm populations and activity. In the southern Columbia Basin in Grant county (the Mattawa area), a warm micro-climate allows a high overwintering survival and early emergence of earworm adults that leads to high pressure on early sweet corn hybrids from the 1st generation (requiring 3-4 pyrethroid applications) and even higher populations of 2nd generation adults in August/September that attack later sweet corn double-cropped after peas (requiring 4-6 pyrethroid applications). In the Yakima valley, poor soils and lower overwintering survival require only three applications on early corn and 4-5 applications on late season varieties. In the Patterson area, winter survival is low and only 1-3 applications are needed on early varieties, while late varieties that receive immigration of 2nd generation adults from southern production areas often need 3-4 applications (Charles Martin, Field Agronomy Supervisor, Del Monte Foods, Toppenish, WA, personal communication).

Sweet corn varieties that have been genetically modified to express *Bt* endotoxins provide excellent control of corn earworm with no insecticide applications, but this technology cannot be used by processors since export to countries that do not accept GMO technology. Processing companies must also take stringent precautions to make sure that sweet corn fields are isolated from potential contamination from GMO field corn.

Other sweet corn pests include:

Cutworms and armyworms are occasional pests in the Pacific Northwest, causing stand loss and whorl damage on early growth stage corn. When damage is significant, an additional early season pyrethroid spray provides effective control.

Corn rootworm is emerging as a pest threat in sweet corn in Washington, primarily in the adult stage when it feeds on pollen and silks in mid-season (6). Corn earworm control programs using primarily pyrethroids also control corn rootworms and their associated damage.

Washington State producers may double crop in sweet corn years providing more options for resistance management and IPM practices in rotation crops

Other emerging pests. The High Plain Virus, which is spread by the wheat curl mite, has emerged as a new pest in sweet corn grown in proximity to wheat (6). Management is focused on cultural practices that remove potential 'green bridges' between crops. The brown marmorated stink bug that was introduced into the U.S. in the early 2000s is potentially a serious threat to sweet corn, however, pyrethroids used in earworm management programs are also the most effective tools for managing stink bugs and should prevent ear damage (13).

7.4 Pest management in Wisconsin potatoes and processed sweet corn — the arthropod pest complex, management approaches and the role of pyrethroid insecticides

POTATOES. The Midwest (Wisconsin, Minnesota, North Dakota and Michigan), together with the eastern U.S. (Maine and New York) comprise a large, temperate ecoregion with similar growing conditions and the same broad arthropod pest complex that may vary between states in intensity and economic damage but generally has the same pest species. The pest management approach in all states is based on intense surveillance/monitoring of pest populations and chemical management when populations reach damaging levels. In contrast with the Pacific Northwest where many serious pests are present annually, and the key pests driving pest management decisions are newly introduced species, there are relatively few key pests in Wisconsin, and they have been established for many years.

In Wisconsin and the Midwestern ecoregion, the insect pest complex is broad with15 species, but only three species occur annually as key pests that cause economic damage and drive pest management decisions (16).

Resistance is a concern for sweet corn and potato insect pests — chemical options must be maintained to prevent resistance development

Colorado potato beetle. The Colorado potato beetle is a serious economic threat to potato production throughout the region, and commercial production is seldom possible without the use of insecticides (15). This insect is known for its extraordinary capacity to develop resistance, and in some parts of the region, beetle populations are now resistant to most major classes of insecticides (Russ Groves, University of Wisconsin Entomologist, personal communication). Management programs must be designed to incorporate all potential cultural practices to reduce populations, and insecticidal inputs should be carefully targeted at specific development stages and follow strict rotation of MoA groups to manage resistance (15). Management programs rely heavily on soil applications of neonicotinoids to reduce early season beetle populations and are used in combination with rotations of foliar insecticides with differing MoAs that are still effective.

In Wisconsin, resistance to organophosphates, carbamates and pyrethroids is widespread and their effectiveness in beetle management is minimal (Russ Groves, University of Wisconsin Entomologist, personal communication). Managing crop rotations to reduce the intensity of potato production in specific areas has been successful in slowing resistance to soil applied neonicotinoids and preserving their efficacy on many farms, and neonicotinoids continue to be an important component of early season control (16). The anticipated availability of new systemic active ingredients (anthranilic

diamides) will provide an additional tool to control beetles in early season and when used in rotation with neonicotinoids, will prolong this component of beetle management programs.

Foliar insecticides will continue to be a key management approach, and there is a wide range of effective foliar sprays that can be used to manage populations during the season (17). These include multiple active ingredients in at least seven IRAC MoA groups, which should carefully targeted at susceptible life stages and rotated between MoAs to preserve their effectiveness. A typical spray regime in Wisconsin for Colorado potato uses 2-4 foliar sprays, and pyrethroids are rarely needed.

Potato leafhopper. The potato leafhopper migrates annually into Wisconsin and other states in this ecoregion in early summer (15). If not controlled, phloem feeding causes severe economic loss through leaf curling, chlorosis, necrosis and plant death. The only management options for managing potato leafhopper are to hold populations below damaging levels by using insecticides. Soil-applied systemic insecticides suppress populations early in the season, and foliar insecticides are used when populations exceed thresholds during the season. Many insecticides from multiple MoA groups provide effective leafhopper control, but growers frequently use pyrethroids based on efficacy and cost (17). The potato leafhopper is not a pest in the Pacific Northwest.

In addition to the three key pests, the Midwest ecoregion has a range of occasional and sporadic pests that may require management if they reach damaging levels (15):

Lepidoptera as foliage feeding pests. Several lepidopteran pests, including cabbage looper, armyworms and cutworms, appear sporadically as defoliating larvae in potatoes in Wisconsin, and although economic damage is infrequent, these infestations are often treated with foliar insecticides by growers (15). A range of active ingredients from at least five IRAC MoA groups provide good larval control but pyrethroids, which are inexpensive, effective and also control other pests, are often used by growers (17). The European corn borer is not a pest in the Pacific Northwest, but in Wisconsin, larval tunneling in stems can cause yield loss in certain varieties. Foliar sprays for lepidopteran activity are recommended on susceptible varieties following egg laying to prevent tunneling; pyrethroids are used most frequently (15).

Occasional pests found in both the Midwest and Pacific Northwest. Potato flea beetles and tarnished plant bugs are occasional pests in both ecoregions. Flea beetles are held at low levels by systemic insecticides, but pyrethroids are the only effective material for tarnished plant bug control.

Occasional pests in the Midwest that are key pests in the Pacific Northwest. Potato psyllids, beet leafhopper and spider mites are key pests in the Pacific Northwest that drive pest management decisions, but these pests are rarely seen in Wisconsin. The aster leafhopper, which transmits a phytoplasma similar to BLTVA and causes purple top on potatoes in Wisconsin, is rarely an economic concern.

Potato leafhopper adults
Photo by University of Wisconsin

PROCESSED SWEET CORN. Sweet corn for processing in the Midwest is grown in Wisconsin, Minnesota and Illinois and uses both irrigated and non-irrigated production systems. In sharp contrast to the Pacific Northwest that has a narrow pest complex with only one key pest, Midwest sweet corn has an extensive pest complex with at least four key pests that drive pest management decision making. The key pests are all lepidopterans ('worms') that directly attack ears, and in a processing crop with essentially zero tolerance for damage and contamination, control practices have relied heavily on insecticides.

Over the past 20 years, many new insecticides have been registered, and processors have developed new approaches to predict, monitor and track pest populations and time applications using treatment windows that combine pest intensity with likelihood of crop damage. This has resulted in remarkable advances in Midwestern pest management for sweet corn that have significantly improved the effectiveness of control while markedly reducing insecticide inputs and improving both food and worker safety (18). These advances, which incorporate over 30 years of biological, ecological and behavioral research conducted by university specialists and processing industry researchers, have been assimilated into practical and effective pest management strategies by Dr. Brian Flood (Corporate Research Fellow, Del Monte Foods) and have been widely adopted by processors across the Midwest. The key lepidopteran pests in Midwestern sweet corn production are:

For Midwest states, corn earworm, European corn borer, and the fall armyworm would become serious problems if pyrethroids were lost

http://www.ipmcenters.org/pmsp/pdf/ncsweetcorn.pdf

Corn earworm. The corn earworm is a damaging pest of sweet corn throughout the U.S., and the timing and extent of damage is dependent on the ability of the pupae to survive the winter. In Wisconsin and other Midwestern states, cold soil temperatures prevent successful overwintering and migration flights of 2nd generation moths from southern production areas that arrive in Wisconsin fields in July and August and cause severe damage (18). Adult earworm moths are attracted into tasseling sweet corn fields and eggs are laid directly on fresh silks. Small larvae feed on silks; the 3rd instar become cannibalistic and usually only one to two surviving larvae continue to feed in developing kernels and cause severe damage and contamination. Improved post-harvest cleanup technology in processing plants can remove minor tip damage and larval contamination, but foliar sprays are the only management approach that can produce the damage-free end product required by consumers.

Corn earworm larvae
Photo by University of Minnesota, Department of Entomology

In-field control technology has evolved dramatically over the past two decades and has switched from multiple application regimes using 5-8 sprays of organophosphate and carbamate insecticides to a carefully targeted 'treatment window' approach (combining host susceptibility to ear damage and earworm adult abundance) that normally limits applications to 1-3 based strictly on need (18). In a current day Del Monte management regime, a single application of bifenthrin at early silking (using a higher application rate that increases persistence through the silking period) is sufficient to prevent ear damage in 80% of early to mid-season fields. In late plantings, cool temperatures can extend silk susceptibility and fields may be re-infested from earlier crops, requiring an additional 1-3 'tail-end' sprays. This approach has enabled Del Monte to reduce spray programs from 4-6

per season to an average of 1-3 per season across four states (Brian Flood, Del Monte Foods, personal communication).

The importance of combining adult control to limit egg laying and persistence to control larvae before they enter the ear has restricted insecticide selection largely to pyrethroid active ingredients that are used almost exclusively. Corn earworm is a migratory insect that has not developed resistance to pyrethroids as a result of exposure on sweetcorn in the Midwest. Repeated exposure to earlier generations in southern crops can lead to resistance in populations that migrate to the Midwest, the Midwest Food Processors Association is developing resistance assessment protocols to maintain the effectiveness of pyrethroid-based earworm control programs. If resistance is detected in migrants, several active ingredients in five different MoA groups are registered that could be rotated with pyrethroids to delay the onset of resistance, but these alternatives do not provide sufficient persistence to maintain the level of control needed to meet processing standards (17).

European corn borer. In Midwestern sweet corn, the European corn borer has perennially been a serious ear attacking pest that overwinters in corn stalks and normally has two generations per year (14,18). First generation moths lay eggs on young sweet corn in June, and larvae feed externally on leaves before boring into stems. Second generation adults reach peak flight in August when sweet corn is tasseling, and larvae feed on stalks and ears. Depending on stage of plant development relative to egg laying, control of both stalk and ear feeding requires insecticidal applications targeted at adults prior to egg laying and surface feeding larvae prior to boring. To avoid ear damage treatments should begin at late-whorl to early-row tassel to exploit the surface feeding vulnerability of the larvae. Efficacy in adult knockdown and persistence on leaf surfaces is essential to prevent ear damage, and although there are several insecticidal alternatives registered on sweet corn, only the newer pyrethroid active ingredients provide sufficient persistence on leaf surfaces to protect ears and these materials (e.g. bifenthrin and lambda-cyhalothrin) are used extensively. Applications are again based on a 'treatment window' approach using thermal unit predictions, adult trapping, mating site surveys and egg counts to determine abundance that has cut applications to 1-3 per season (18).

Sweet corn fields are surrounded by extensive acreages of field corn, which serve as a large refuge for European corn borer with no exposure to pyrethroid insecticides, and consequently, resistance in sweet corn is not an issue. In recent years, the presence of a large alternate host crop in field corn has benefited sweet corn processors in another way, beyond serving as a refuge for susceptible corn borers. In the early 2000s, field corn was genetically modified to express *Bt,* which confers plant resistance to lepidoptera. By 2010, over 60% of field corn acreage in the Midwest was genetically modified, and European corn borer populations that normally move into sweet corn were effectively suppressed across the region, significantly reducing the need for insecticidal control in areas adjacent to field corn (19). Corn borer monitoring is strictly observed to confirm abundance in local areas that may continue to experience high populations. In northern parts of the region and recently in Wisconsin, a univoltine strain of European corn borer with a single generation and an adult flight peak that falls between the June and August peaks of the traditional bivoltine strain has emerged that generates a continual adult presence throughout the season and requires vigilant monitoring.

Western bean cutworm: In the last decade, the western bean cutworm has emerged as an annual pest that attacks ears in mid-summer (15,18). Normally a Western Plains insect, the western bean cutworm now migrates annually into the Midwestern sweet corn production areas and is established in isolated areas. Adults lay eggs on foliage, and larvae feed on both leaves and ears; unlike corn earworm, they are not cannibalistic, and multiple larvae attack ears causing severe damage. Treatment for western bean cutworm runs from row tassel to brown silk, and pyrethroids are the only active ingredients that provide adult control and sufficient persistence to kill surface feeding larvae before they enter the ear.

Fall armyworm. The fall armyworm overwinters as a pupae in the soil and cannot survive freezing temperatures. Consequently, adult populations originate in Florida and south Texas and migrate up the Atlantic seaboard to eastern production areas and from Texas and Florida into the more southerly areas of the Midwest (15,18). Adults lay eggs on foliage, and larvae feed on all plant parts with a preference for ears. Larvae are most susceptible to insecticides when feeding externally on whorls and leaves, and as with European corn borer, treatments should begin during the late whorl, early row tassel stage to ensure ear protection; catch-up treatments are ineffective (18). Similar to other lepidopteran pests, pyrethroids provide the most effective control

GMO sweet corn. Sweet corn varieties that have been genetically modified to express *Bt* endotoxins provide excellent control of corn earworm, European corn borer and moderate control of fall armyworm and western bean cutworm with no insecticide applications. This technology cannot be used by processors because export to countries that do not accept GMO technology is an important part of the sweet corn processing industry. Processing companies must also take stringent precautions to make sure that sweet corn fields are isolated from potential contamination from GMO field corn.

Other Wisconsin and Midwestern sweet corn pests:

Cutworms and true armyworms are occasional pests in the Midwest causing stand loss and whorl damage on early growth corn (18). Damage is sporadic and hard to predict; if damage exceeds thresholds, rescue treatments are effective. Pyrethroids are frequently used for rescue treatments based on efficacy, spectrum of control and cost.

Western and northern corn rootworm. Corn rootworms are typically associated with field corn in the Midwest but annually cause economic damage on sweet corn as both larvae attacking the roots and adults feeding on ear silks (18). If sweet corn is grown in rotation with field corn and previous monitoring indicates that root worm pressure is probable, a soil insecticide should be applied at planting to avoid root pruning and yield loss (18). Pyrethroids (bifenthrin, lambda cyhalothrin, and tefluthrin) make up a significant portion of the soil insecticide applications options available. Root-

worm adults emerging in mid-summer are attracted into silking sweet corn and often disrupt pollination and impact ear fill by pruning silks. Pyrethroid insecticides, which are normally applied at this time to protect ears from worm damage, provide excellent adult rootworm control.

Corn flea beetle. The corn flea beetle is an economic pest of sweet corn on the southern Midwest where it transmits Stewart's wilt to seedling plants (18). Seed treatments with neonicotinoid insecticides provide effective control.

Aphids. The corn leaf aphid is a sporadic pest of tasseling sweet corn, where high populations may interfere with pollination and reduce ear fill (18). Pyrethroid insecticides applied for worm control normally provide effective control.

Hemipteran plant bugs. The tarnished plant bug is a sporadic pest on field edges and in weedy fields when adults move to sweet corn and feed on exposed ear tips (18). Varieties with protected tips prevent damage, and pyrethroid treatments for worm management also provide control. The brown marmorated stink bug, which was introduced into the U.S. in the early 2000s, is potentially a serious threat to sweet corn (13). Pyrethroids used in worm management programs are also the most effective tools for managing stink bugs and should prevent ear damage.

7.5 Main insights from the Washington (Pacific Northwest) potato and processed sweet corn study contrasted with Wisconsin (Midwest) potatoes and processed sweet corn

POTATOES IN WASHINGTON AND THE PACIFIC NORTHWEST

- Pyrethroids are essential in early season potato pest management. At this time, pyrethroids provide control of beet leafhopper, which are not controlled effectively by systemic neonicotinoids, and prevent early establishment of BLTVA. There are limited alternatives for early beet leafhopper control. These applications also control psyllids moving into fields and transmitting zebra chip when planting time neonicotinoids are declining in efficacy and before more selective psyllid materials are used.
- Pyrethroids are also essential pest management tools in late season potatoes to manage potato tuberworm close to harvest. These treatments are frequently the only effective alternatives with short PHIs and established MRLs that can be used close to harvest and are essential in processed potatoes (80% of crop) to meet export requirements. Pyrethroids can be applied at this time without disrupting mite predators. Late season pyrethroids also provide control of psyllids/zebra chip when many of the alternatives cannot be used close to harvest due to PHI or MRL concerns (e.g. abamectin, 14-day PHI).
- Up to 25% of the crop is treated to manage thrips in mid-season, and targeted pyrethroid applications are needed for use in rotation with active ingredients with different MoAs to manage resistance that occurs often

in thrips populations. The retention of pyrethroids is essential for thrips management since it is recommended that abamectin (a key alternative) not be applied in tank mixes with fungicides formulated with stickers or binders, which is common practice.

- Pyrethroids are an essential component of Colorado potato beetle pest and resistance management programs in the Pacific Northwest. Currently, no resistance to neonicotinoid or pyrethroid insecticides in Colorado potato beetles has been detected, and systemic neonicotinoids are the primary management tool. Strong resistance to neonicotinoids is present in all other production areas where Colorado potato beetles are pests, it is inevitable that resistant populations will be selected in the Pacific Northwest where most acres receive at planting applications of neonicotinoids. When this occurs (and in fields where systemic neonicotinoids are not used, as recommended for 20% pf potato acreage in Washington), pyrethroids will be essential components in foliar regimes based on rotations of active ingredients with differing MoAs that will be needed to manage beetle populations and manage resistance

- Pyrethroids will be a effective tool to manage an emerging pest threat from lygus bugs and to combat a potential new pest threat, the brown marmorated stink bug.

POTATOES IN WISCONSIN AND THE MIDWEST

- In Wisconsin and the Midwest ecoregion, the pest complex is not dominated by newly introduced pest species that transmit destructive potato diseases (beet leafhopper, potato psyllid) or present new damage potential (potato tuberworm) but consists of a relatively stable group of pest species where pyrethroid insecticides are of lesser importance than in the Pacific Northwest. The primary need for pyrethroids is in the management of the potato leafhopper, which annually migrates into the Midwest from the southeast. One to three applications, when leafhoppers exceed thresholds, provide excellent control. As in the Pacific Northwest, pyrethroids are also used occasionally to manage lepidopteran pests and are the only alternatives to manage existing hemipteran pests and potential pests, such as the brown marmorated stink bug.

SWEET CORN IN WASHINGTON AND THE PACIFIC NORTHWEST

- The sweet corn pest complex is relatively narrow with one key lepidopteran pest — the corn earworm — driving pest management decisions. A range of alternative (to pyrethroids) active ingredients with several different MoAs that have lepidopteran efficacy are registered on sweet corn. However, to meet the zero tolerance requirements for damage and contamination in processed sweet corn, an insecticide used for earworm control must have strong activity against adult moths entering fields to reduce egg laying and good persistence on plant surfaces to kill small larvae on ear silk before they enter ears. The pyrethroids, particularly the 3rd generation pyrethroids such as bifenthrin and lambda-cyhalothrin, are the only active ingredients with these characteristics and are widely relied on by the industry. Carefully targeted regimes of 2-4

applications provide excellent control and meet the need for established MRLs in the export market.

- A new potential pest — the brown marmorated stink bug — has been introduced into the Pacific Northwest and represents a potentially serious new damage threat. Pyrethroids are effective alternatives to manage this pest.

SWEET CORN IN WISCONSIN AND THE MIDWEST

- In contrast to the Pacific Northwest, sweet corn in the Midwest is attacked annually by up to four key lepidopteran pests that each cause severe damage to ears if left uncontrolled. In Wisconsin and the Midwest, the corn earworm, the fall armyworm and the western bean cutworm, (which all migrate into the region) and the European corn borer (which overwinters locally) represent a severe damage potential that requires multiple insecticidal applications to meet the stringent requirements of the processing industry. As with earworm management in the Pacific Northwest, successful control of this complex requires a strong efficacy against adult moths to reduce egg laying and good persistence on plant surfaces to kill externally feeding larvae before they bore into the plant or the ear. After extended research involving active ingredients from many MoA groups, pyrethroids (particularly the 3rd generation pyrethroids) are the only materials that can provide sufficient adult and larval control to meet the zero tolerance for damage required by the industry. Using a pest management approach that limits application to periods when plants are susceptible to damage and when key pests are in sufficient abundance to cause damage has enabled processors to reduce treatment regimes from 4-6 applications a decade ago to 1-3 applications currently.
- In Wisconsin and the Midwest, pyrethroids are also essential in the management of other pests in the complex that include corn rootworm adults, corn leaf aphid and potential new threats, such as the brown marmorated stink bug. These pests are currently controlled effectively by pyrethroid regimes targeting lepidopteran pests.

7.6 Impacts of pyrethroid insecticides at the farm level: A case study, T and R Farms, Pasco, Washington

It's February in the Washington's Columbia Basin, and the land is just beginning to wake up to begin another crop cycle. This is one of the world's great agricultural creations — where the Grand Coulee Dam and its sister impoundments on the Columbia River transformed vast stretches of desert into 600,000 acres of irrigated cropland that is valued at over $630 million annually. This is potato country; growers produce the biggest yields in the nation by taking full advantage of fertile soils, ideal climates and the plentiful water for irrigation. The basin is bordered by the meandering Columbia River to the north and west and by the Snake River to the south and east.

Our case study, T and R Farms, is nestled in the southeast corner of the basin on the banks of the Snake River from which it draws its irrigation water. The farm is a gently rolling landscape with close to 3,600 acres devoted to crop

The T and R Farms' family and crew

production; the primary crop is potatoes with 1,100 acres of long season russets grown for Lamb Weston for processing into fries. The potatoes are rotated with wheat (1,400 acres), sweet corn (700 acres) for processing into frozen whole kernel corn, field corn (460 acres) and even apples (100 acres grown in the mild micro-climate bordering the river). The farm owners Ron and Rella Reimann are keen environmentalists, and they have transformed over 1,000 acres of the least productive land on the farm that borders a natural juniper forest into a conservation reserve; they plant and maintain hundreds of acres with native plants and trees to harbor the wildlife that abounds there. White tail and mule deer, elk and even cougars are commonly seen, but Ron's love are the hundreds of bird species that live there. Particular favorites are his pheasants that are nurtured year-round and protected from predators by 'Caliente' mustard; this cover crop grows in a knee-high tangle on every potato acre and serves the dual purpose of being an excellent soil amendment and bio-fumigant prior to potatoes and as a cover that protects the pheasants.

T and R Farms is a true family farm; Ron, Rella and Reid (their son) have been in business with her brother 'Porky' Thomsen (the *T* in T and R) since they took over the potato farming tradition from Rella's father (Hank) and grandfather, who was a homesteader in Quincy WA. They started small in 1973 by renting and dry-land farming 320 acres east of Pasco where the farm now sits. After a year or so of hard scrabble or as Ron describes it:

"We looked at it for what it could be, not what it was."

They were able to secure water rights from the Snake River, and it grew from there. Ron was instrumental in forming the Columbia-Snake River Irrigators Association and serves as its president to work with growers and communities in preserving and conserving the water resources in the southern Columbia Basin.

In addition to their exemplary role in environmental conservation, T and R could serve as a demonstration site to showcase the latest technologies in potato and vegetable production. Every acre is carefully sampled before a crop is planted and seeding rates, fertility and even irrigation are closely matched to the needs and potential of the soils in each sector of the field. During the season, the crop is closely monitored to determine and supply the changing fertility and irrigation needs of the crop as it develops.

Crop protection is a major part of being a 'pure potato grower' in the tradition followed at T and R, and predictably, our meeting in the farm office was well attended with Ron, Rella, Porky and Reid front and center backed by Rich Jaeger of R and K Agriculture (their long time PCA) and Jennifer Riebe of JFR Crop Services (a former advisor who now operates in eastern Idaho but continues to keep tabs on the Washington scene).

"You can never know too much about what is going on in your crop."

This is the credo at T and R and is borne out in how they keep tabs on the pests in their fields and how to best manage them. As Ron describes it:

"We have Chris scouting one day, Randy two to three days (farm employees), then Rich scouting one or two days a week, then we schedule a weekly meeting, and we all get together, often with the Lamb Weston guy, and we'll go over what each guy sees because one guy will see something that the other guy hasn't, and then that's where we come up with our recommendations."

This approach serves them well and avoids the trap of spraying because there is a fear of damage based on what has happened in previous years. Psyllids/zebra chip, which was a major problem three years ago, led to use of materials that were expensive and not necessarily effective. Sometimes the processors may even strongly suggest using treatments that may not be justified. It's difficult to diagnose the need for psyllid control, and Rich follows the Washington State University trap reports closely but admits that he doesn't use them to decide, preferring to go in the field and see what's there.

The crop protection season begins at planting when a systemic neonicotinoid is applied to provide control of the Colorado potato beetle, a perennial pest in the south basin. Beetle control usually lasts for 90 days, but the crew is alert and in the fields to catch the arrival of the beet leafhopper — a serious threat that is not controlled by neonicotinoids, and before it can become established and cause virescence, Rich will call for a pyrethroid application. He does this at row closure, concentrating of varieties with purple flowers first, as he knows these are preferred by beet leafhoppers:

"Just prior to row closure, you can see them then as they start migrating in, and virescence is more of a problem on younger stuff anyway, right. Early in the season, you got to get on top of it. We use that (pyrethroid) because it's not persistent."

The scouts continue to watch the performance of the neonicotinoid against beetles over the next few weeks. They are ever mindful that resistance is around the corner, and Rich has already noted a falloff in beetle control in certain fields.

"They are starting to break a little earlier in some years than others."

This is a sure sign that neonicotinoid resistance is close. When that time comes, Rich will be ready to use the pyrethroids, which are already needed for early season beet leafhopper, in rotation with other materials like abamectin (used later for psyllids) and the growth regulator novaluron (used mid-season for young worm control).

"Worms are a huge problem here, so if you don't get them early, you are going to have a hell of a mess later."

Rich prefers to use these more selective materials in mid-season, in preference to more broad spectrum pyrethroids, to avoid flaring mite populations.

"Not after the middle of June — I won't use pyrethroids."

Thrips are a major problem in the south Columbia Basin, and several treatments are usually applied in mid-season to provide control. Again, they

avoid pyrethroids here to avoid mite problems later, and instead, use a variety of materials that include methomyl and abamectin applied 1-2 times. These materials are also registered for psyllid control and help provide control and reduce the potential for zebra chip. Safety and environmental impact are always key concerns for T and R, and Ron is thankful that methamidophos was canceled in recent years, even though it provided excellent control of most major pests; it was not compatible with the ducks, pheasants and wild birds he cherishes. Rich feels the same way about methomyl, which is toxic to mammals, and although he uses because it works, he looks forward to its withdrawal as a carbamate:

"The first thing I look for is it registered and will it kill what I am after; the second thing is what's it going to do to the environment — and that, for me, includes my customers, them and their people who are out there in the field all the time."

The Snake River

Another major concern for T and R farms is making sure that the insecticides they use have established MRLs in the countries where potatoes are exported. This is a critical concern and factors heavily into insecticide choices, as Ron adamantly states:

"Unless we figure out the proper MRLs, we won't use it!"

'Caliente' mustard cover crop in potato field

Pyrethroids have been registered for extended periods, and most have established MRLs and short PHIs, which are of critical importance to potato growers in the Columbia Basin; particularly in late season, when another recently introduced pest, the potato tuberworm must be controlled to avoid tuber damage and rejection at the processing plant. The most effective materials for tuberworm control are the pyrethroids, and with no threat of mite flares late in the season, they are essential for tuberworm control since they are the only alternatives with short PHIs and established MRLs. T and R farms typically use 1-2 pyrethroid applications in late season and as Ron points out:

"This is really important with our potatoes, as you are never sure when the processor will take them. You may get delayed two to three weeks at the last minute, and that crop has to be protected an extra three weeks, pyrethroids are all you have."

T and R Farms apple orchard

Sweet corn pest management is conducted by the processing company who use a trapping network for corn earworm and field scouts to monitor eggs. T and R does not get involved in material selection but keeps track of what is used on their farm. Ron consulted his records and reported that a neonicotinoid seed treatment is used to manage stand loss caused by seed corn maggot, and pyrethroids are the only insecticides used as foliar sprays to protect the ears:

"They use one spray minimum on our fields, usually bifenthrin or Mustang® or Warrior® at silking, and that may be it. There are some blocks where it's up to 2-3 times and even some where it's 3-4."

Ron Reimann and Jennifer Riebe

When asked what the impacts would be if they did not have pyrethroids, Ron and Rich were concerned but not overwhelmed; they have been forced

to adapt in the past and will do what is necessary in the future. The critical periods would be in early and late season. In early season, there would be no good alternatives for effective beet leafhopper control without pyrethroids and management of early establishment of BLTVA would require increased use of organophosphates and carbamates. If the neonicotinoids were not available for Colorado potato beetle control or resistance reduced their effectiveness, pyrethroids would be important rotational insecticides to control beetles without resistance.

In late season, pyrethroids are the only materials that combine effective control with short PHIs that can be used close to harvest and established MRLs that would allow access to important export markets. If pyrethroids were not available, the processing industry would face significant logistical challenges in tracking and separating incoming potatoes from multiple growers with differing pesticide histories to avoid failing to meet MRL requirements for specific export destinations.

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