



**PRO**  
**Green** EXPO  
**Colorado Convention Center**

Denver, CO | February 5 - 7, 2020

# **A Review of Insecticide Classes and Characteristics**

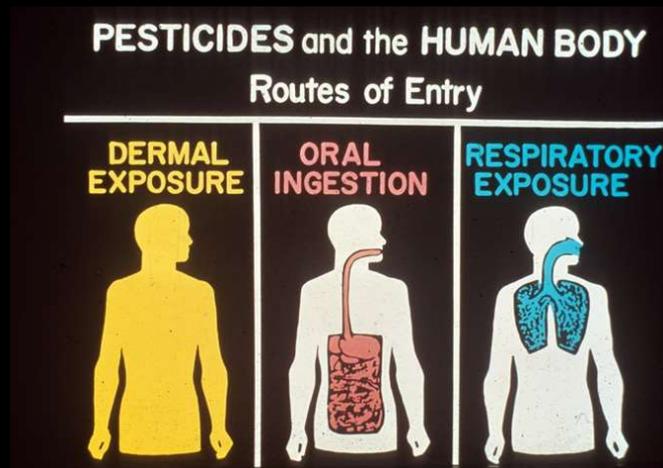
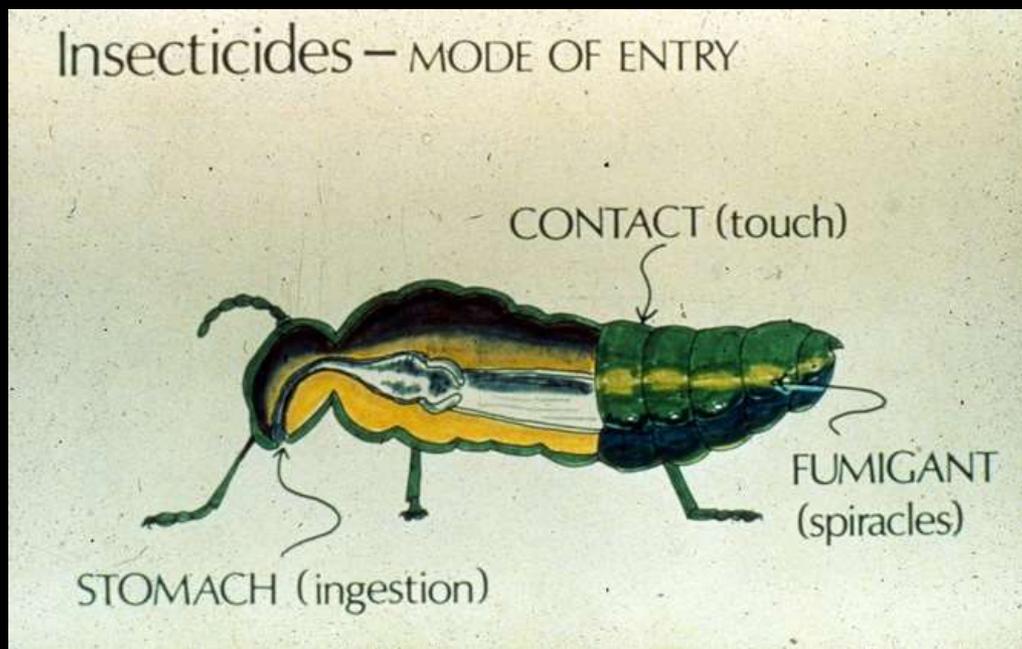
Whitney Cranshaw  
Colorado State University

# Common Types of Pesticides

## (Organisms Controlled)

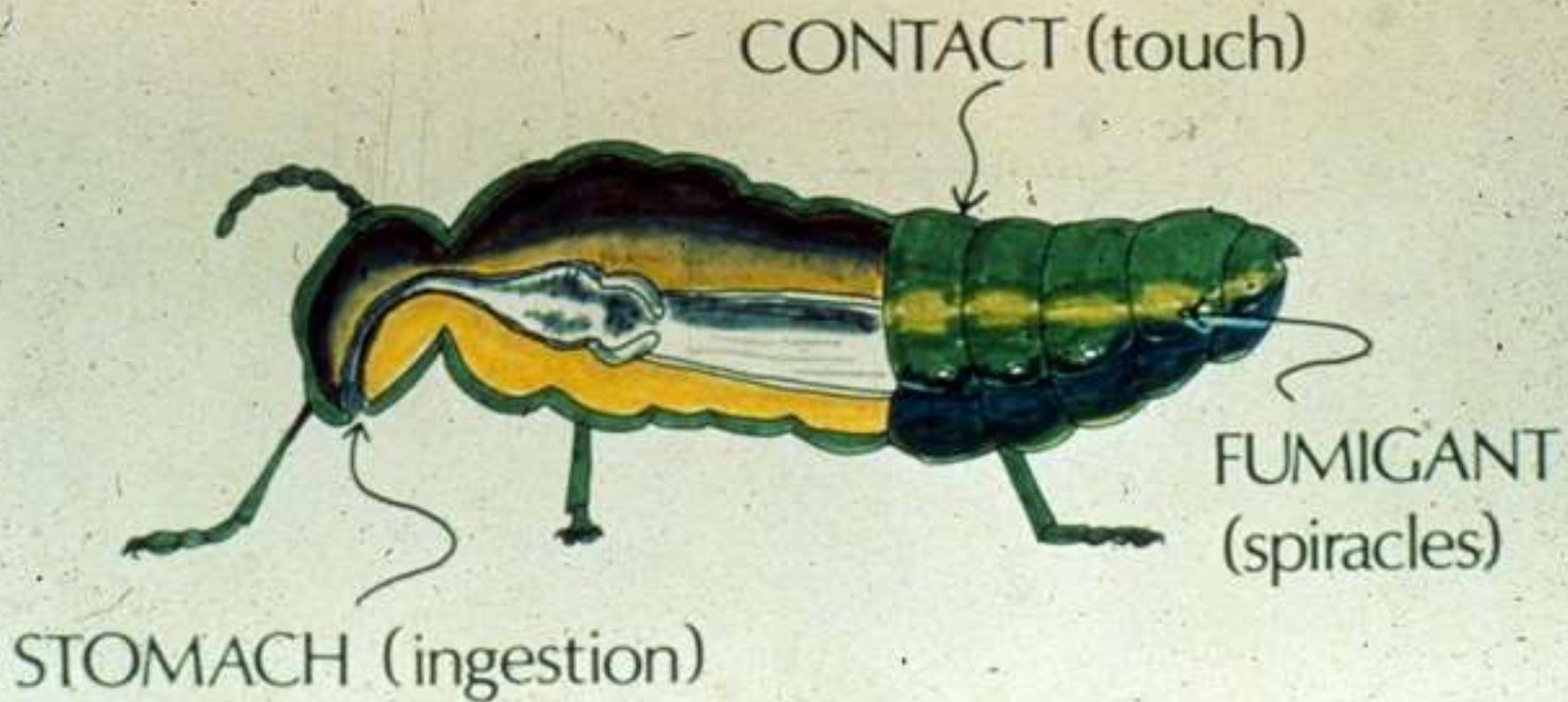
- **Herbicides**
  - *Higher Plants*
- **Algacides**
  - *Algae*
- **Fungicides**
  - *Fungi*
- **Bactericides**
  - *Bacteria*
- **Insecticides**
  - *Insects*
- **Acaricides/  
Miticides**
- **Molluscicides**

# Classification of Insecticides



# Mode of Entry

# Insecticides – MODE OF ENTRY



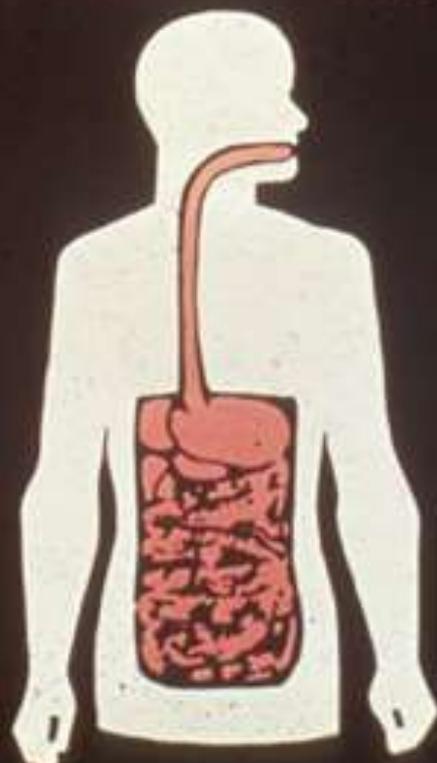
# PESTICIDES and the HUMAN BODY

## Routes of Entry

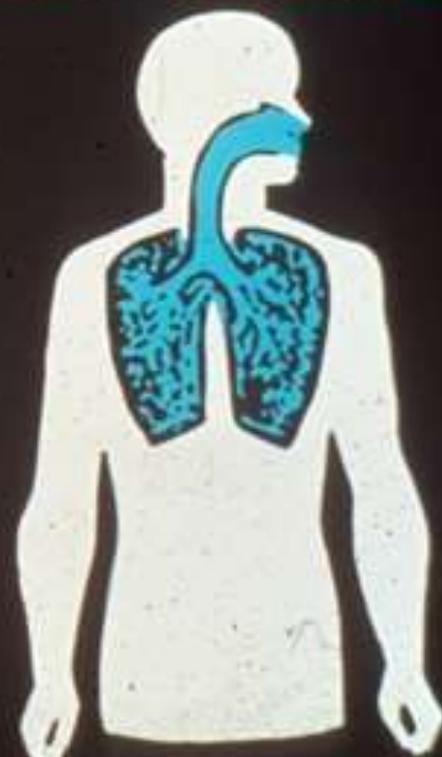
**DERMAL  
EXPOSURE**



**ORAL  
INGESTION**



**RESPIRATORY  
EXPOSURE**

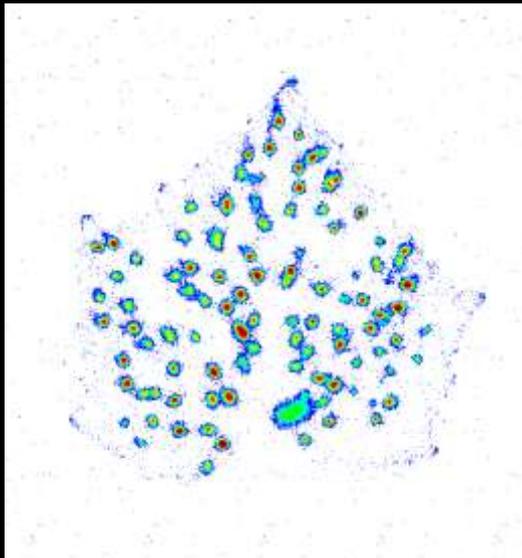


## *Classification of Insecticides*

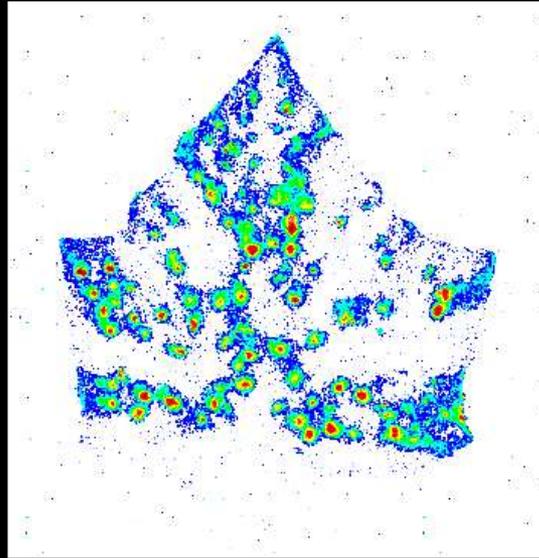
# Systemic or Not Systemic?

*Are they capable of moving within the plant?*

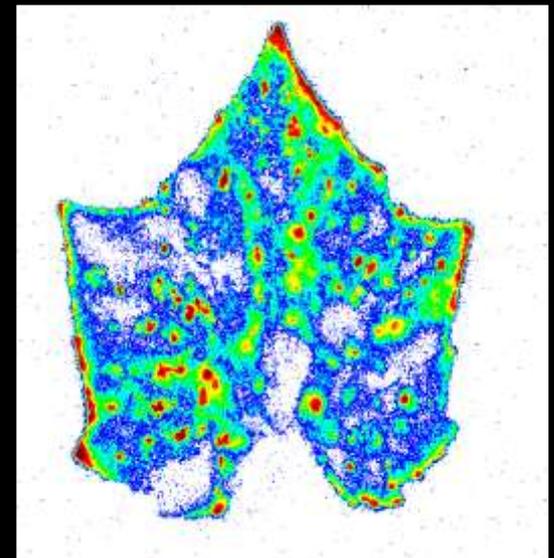
# Distribution of C<sup>14</sup> labeled Thiamethoxam™ 25WG after a foliar application to cucumber leaves



1 hour after application

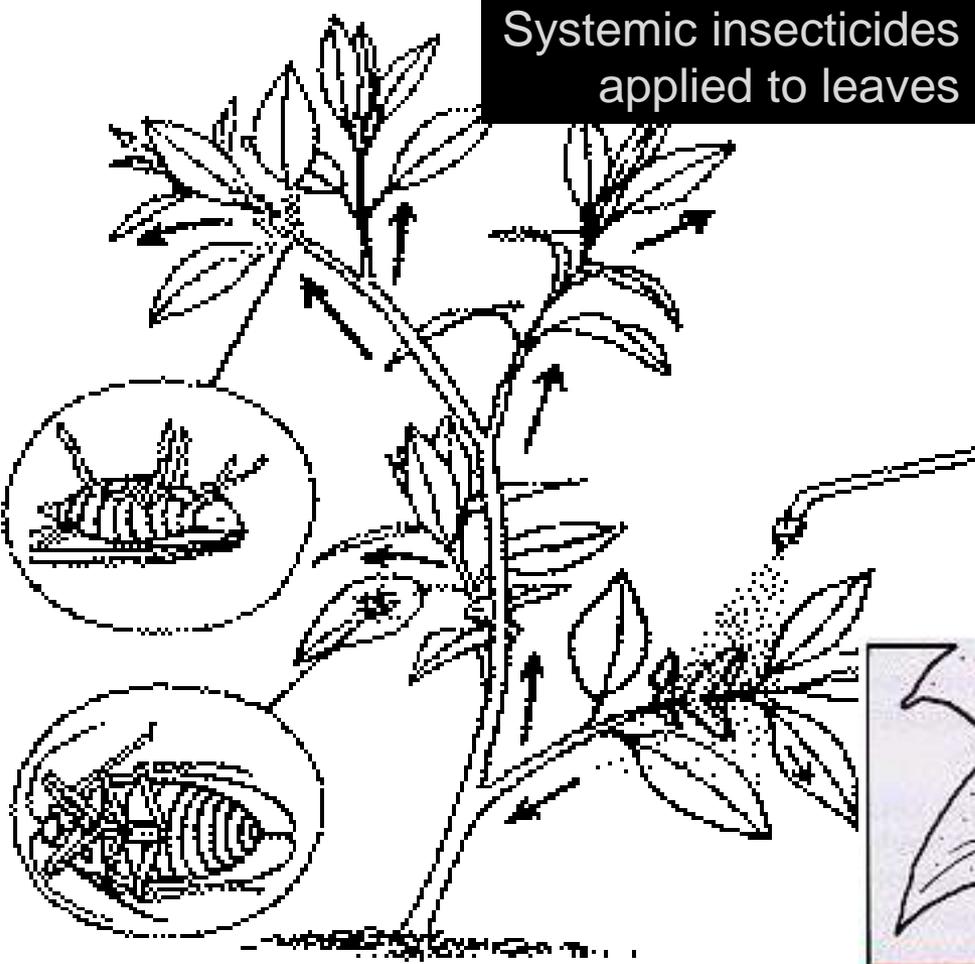


8 hour after application



24 hour after application

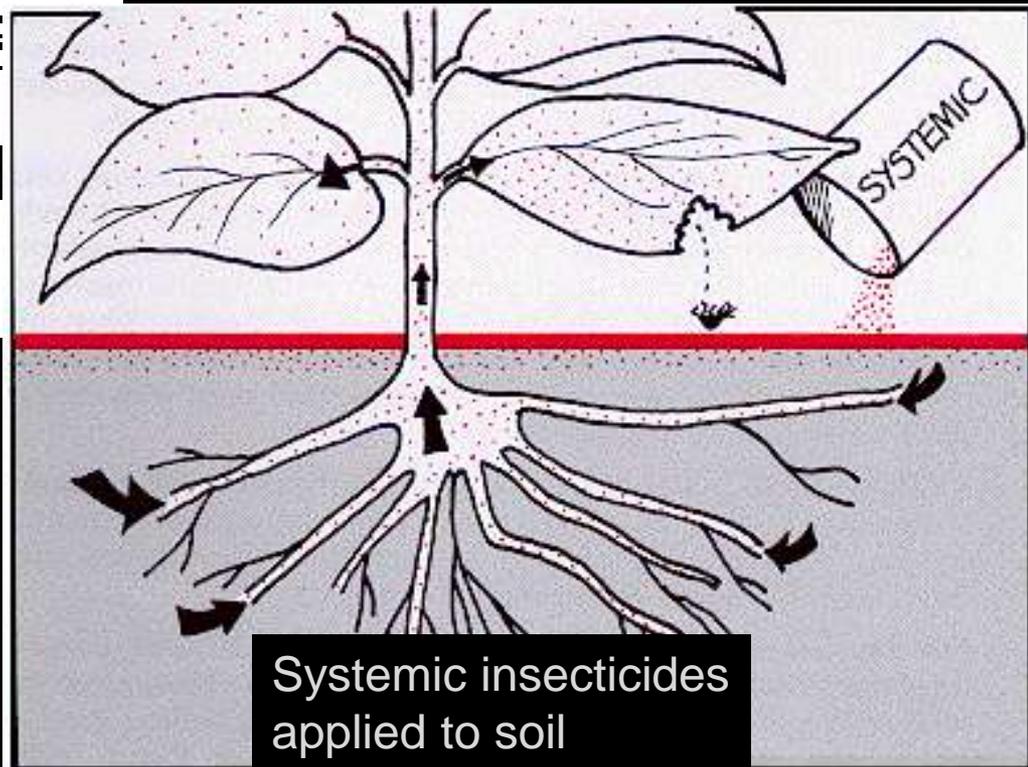
Systemic insecticides  
applied to leaves



Some systemic insecticide  
can move into plants when  
sprayed onto leaves.

Some systemic insecticides  
can move into plant when  
applied to the roots.

Most systemic  
insecticides will appear in  
highest concentration in  
the new growth



Systemic insecticides  
applied to soil

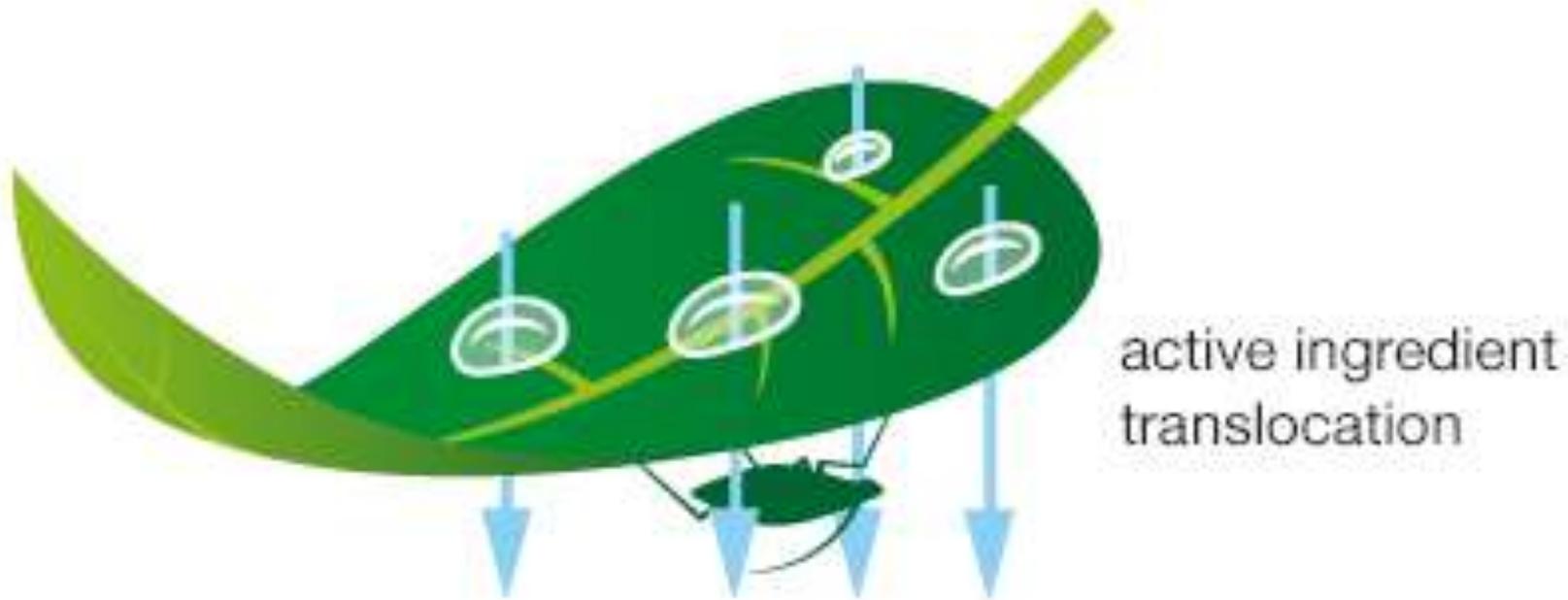
# Systemic Insecticides

- *Capable of some translocation in plant*
- *Range exists in ability to move in plant*
  - Some limited to translaminar movement
  - Some broadly distribute in plant (usually to newer growth)
- *Systemic activity is limited to a small number of insecticides*
  - Most neonicotinoids
  - Diamides (limited)
  - Abamectin (translaminar only)

# Systemic Insecticides

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- ***Systemic activity is limited to a small number of insecticides***
  - Some organophosphates
  - All neonicotinoids
  - Diamides (limited)
  - Avermectins (translaminar only)

**Translaminar movement** – Insecticide can move through a leaf (but not necessarily to another leaf)



**Example: Foliar applications of abamectin (Avid)**

**Essentially all systemic insecticide** move primarily in the xylem of the plant.

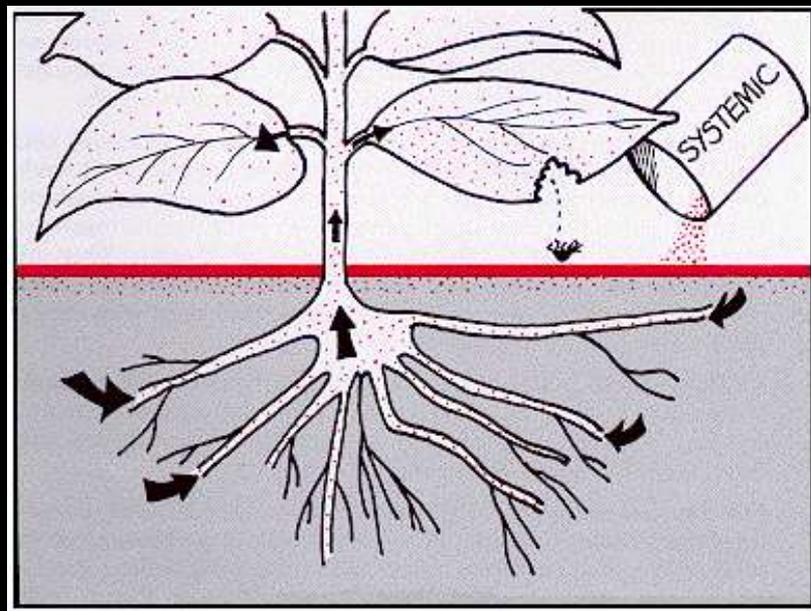
**Essentially all systemic insecticides** primarily move upward.

**Only one product moves both upwards and downwards - spirotetramat**

This is labeled for greenhouse/nursery crops as **Kontos** and for fruits and vegetables as **Movento**



# Common method of applying systemic insecticides – soil applications for root uptake



Soil injections



Soil drenches

**Foliar sprays are often used when soil active systemic insecticides are not available**



## *Classification of Insecticides*

**Broad Spectrum  
or Selective  
Activity?**

# **Selectivity of Insecticides Can Derive from.....**

- **Differences in inherent toxicity of the insecticide to different insects**
- **Persistence of the insecticide**
- **Formulation of the pesticide**
- **Time when the insecticide is applied**
- **Where the insecticide is applied**

# Pesticide that is Selective because it is *Inherent Toxicity of the Pesticide*

What this means

higher  $LD_{50}/LC_{50}$  = less toxic



lower  $LD_{50}/LC_{50}$  = more toxic



**LD50: Lethal dose that will kill 50% of the test population**

# Acute Toxicity of Neonicotinoids to Adult Honey Bees

(Oral LD50 – micrograms/bee)

|                 |        |
|-----------------|--------|
| • Acetamiprid   | 14.53  |
| • Imidacloprid  | 0.005  |
| • Dinotefuran   | 0.056  |
| • Thiamethoxam  | 0.005  |
| • Chlothianidin | 0.0003 |

**Pesticide that is Selective  
in the *Time it is Applied***



**Applications made during the dormant season**

# Insecticides and Pollinators: Bottom Line

Always avoid applications to plants *that bees are visiting* – ***It is the law!***



# Systemic Insecticides and Pollinators: Bottom Line?

Avoid applications to plants *that bees visit that are in bloom – or soon will be in bloom*



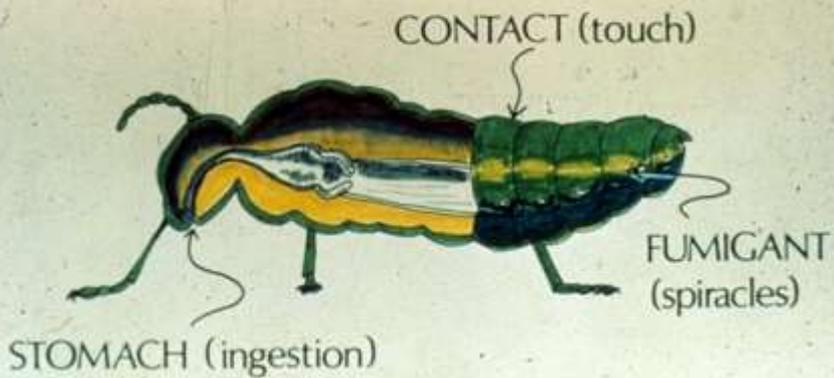
# Spider Mite Control Products

- *Least disruptive of natural enemies*
  - Floramite (bifenazate)
  - TetraSan (extoxazole)
  - Hexygon (hexythiazox)



# Pesticide that is Selective in the *Mode of Entry*

Insecticides – MODE OF ENTRY



**Treated Foliage Consumed**



*Bacillus thuringiensis*  
example

# Pesticide that is Selective because of its *Persistence of Activity*

Pyrethrins



Insecticidal Soap

# Insecticide Persistence

- **General measure – half life**
- **Factors affecting degradation**
  - Sunlight/UV
  - Moisture
  - pH
  - Microbial degradation

Examples of insecticides that are very rapidly degraded upon exposure to sunlight



Pyrethrins



*Bacillus thuringiensis*

# Pyrethrins

An example of an insecticide that *very rapidly breaks down upon exposure to light*



***Tanacetum*** (= *Chrysanthemum*)  
***cinerariifolium***  
***Pyrethrum daisy*** – source of  
*pyrethrum*

# Pyrethroid Insecticides (a.k.a., synthetic pyrethrins)



Pyrethroid insecticides are based on the chemistry of natural pyrethrins

**Many pyrethroid insecticides have ability to persist for weeks - months**



**Pesticide that is Selective  
because of *Where the  
Pesticide is Applied***



**Soil application of  
systemic insecticide**



**Spraying whole plant**

# Pesticide that is Selective because of the *Formulation* of the Pesticide



**Baits**

**VS.**



**Sprays**



**Dusts**



# **Selectivity of Insecticides Can Derive from.....**

- **Differences in inherent toxicity of the insecticide to different insects**
- **Persistence of the insecticide**
- **Time when the insecticide is applied**
- **Where the insecticide is applied**
- **Formulation of the pesticide**

# “Historical” Classes of Insecticides

Heavy metal/  
inorganic  
insecticides



Chlorinated hydrocarbon  
insecticides



Organophosphate Insecticides



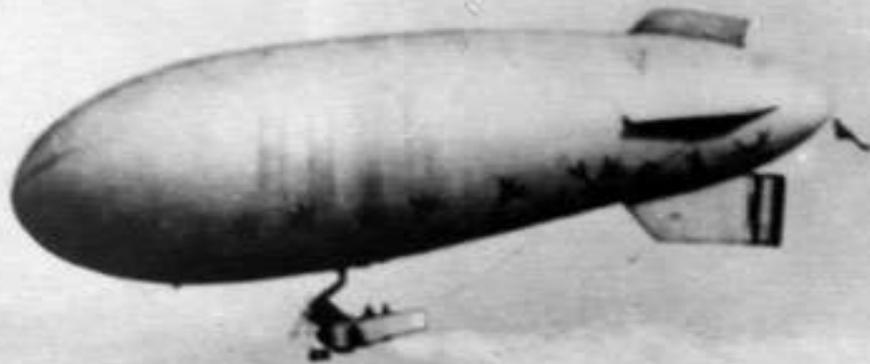
# **Insect Control Products Available a Century Ago**

- **Lead Arsenate/Calcium Arsenate**
- **Sulfur/Lime Sulfur**
- **Dormant Oils**
- **Nicotine Sulfate**
- **Rotenone**
- **Pyrethrins**
- **Ryania**

# Insect Control Products Available a Century Ago

- ~~Lead Arsenate/Calcium Arsenate~~
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**Aerial application of lead  
arsenate for gypsy moth control**



UGA1275079



## What we used 35 years ago

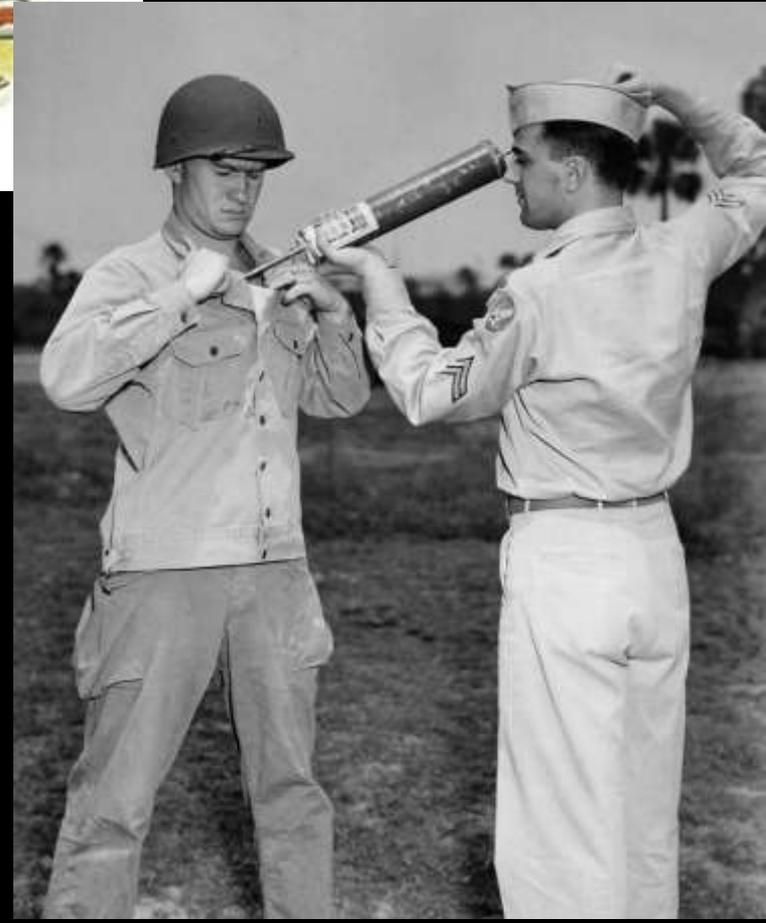
- Dursban
- Malathion
- Methoxychlor
- Diazinon
- Carbaryl
- Cygon
- Orthene
- MetaSystox-R
- Furadan

# Chlorinated Hydrocarbons

- **First widely used class of synthetically produced insecticides**
  - Post World War II
- **Generally broad spectrum of activity against insects**
- **Low to moderate acute toxicity to humans**
- **Very long persistence – weeks to months, sometimes longer**
  - Some soil applications lasting many years



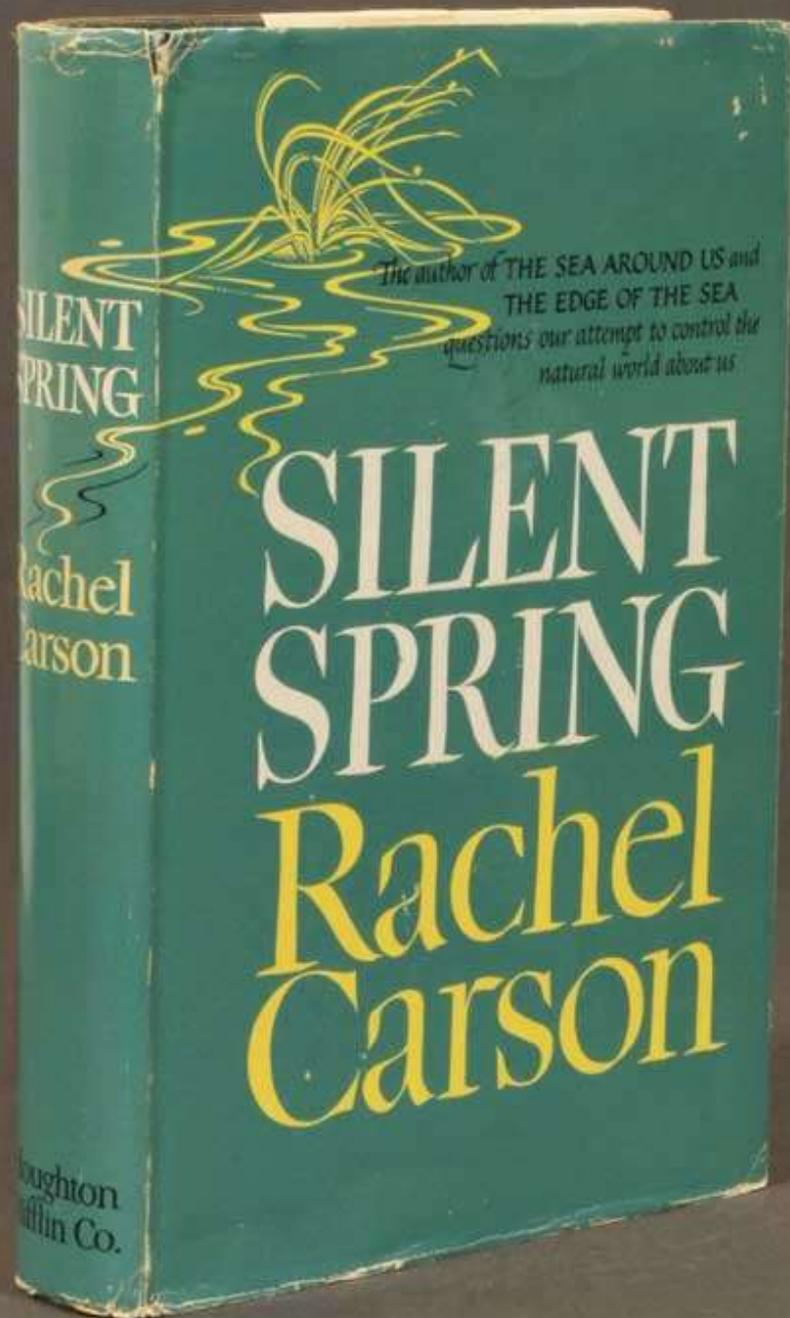
When first introduced, originally to stop epidemic typhus during World War II, DDT and the new chlorinated hydrocarbons were considered nearly miraculous



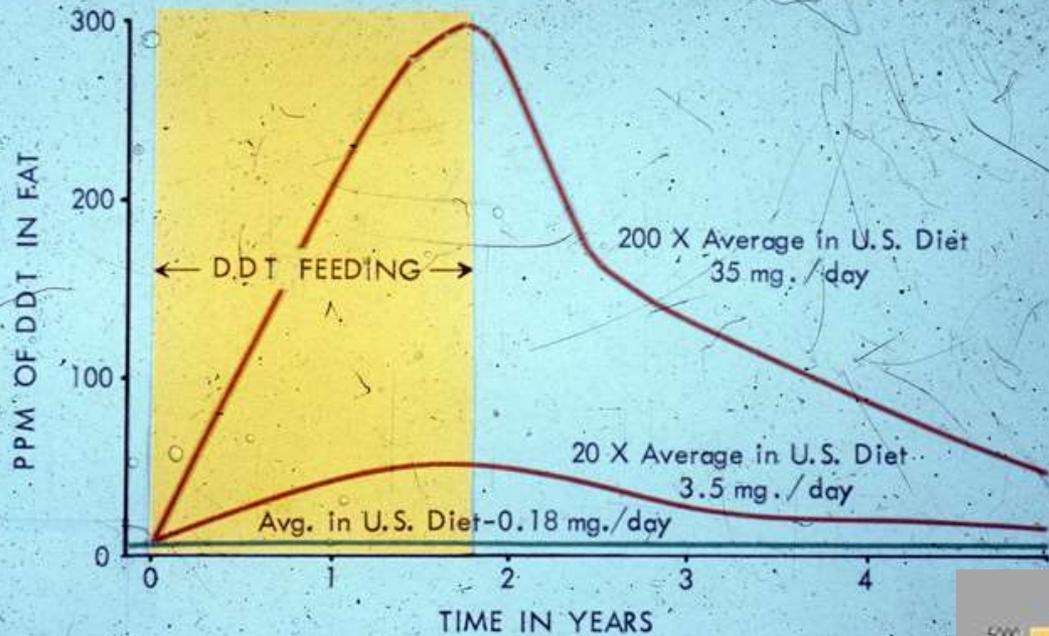
# Chlorinated Hydrocarbons

- **Fat soluble**
- **Persistent in the environment**
  - Concentrated in fat tissues
  - Biomagnification in ecosystems
  - Showed some hormonal effects at high concentrations (***estrogen mimics***)

The book that started a rethinking about insecticide use



## DDT STORAGE IN HUMAN FAT

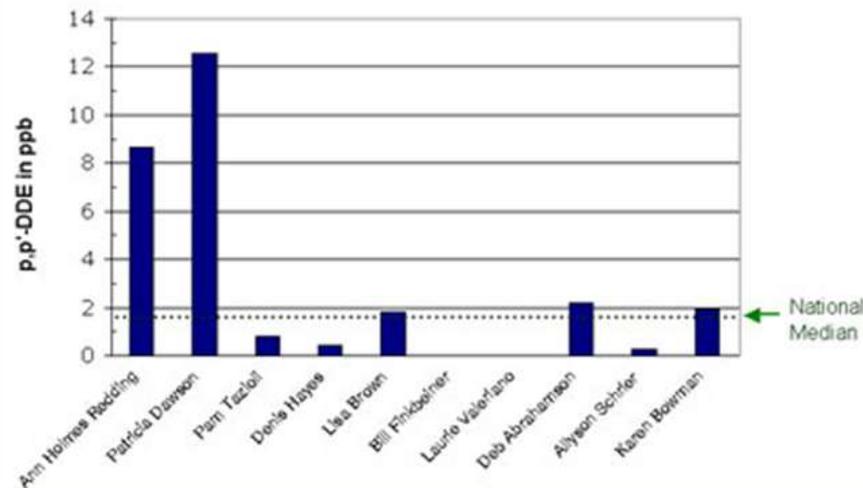


**Chlorinated hydrocarbons, such as DDT, are persistent and concentrate in fat**

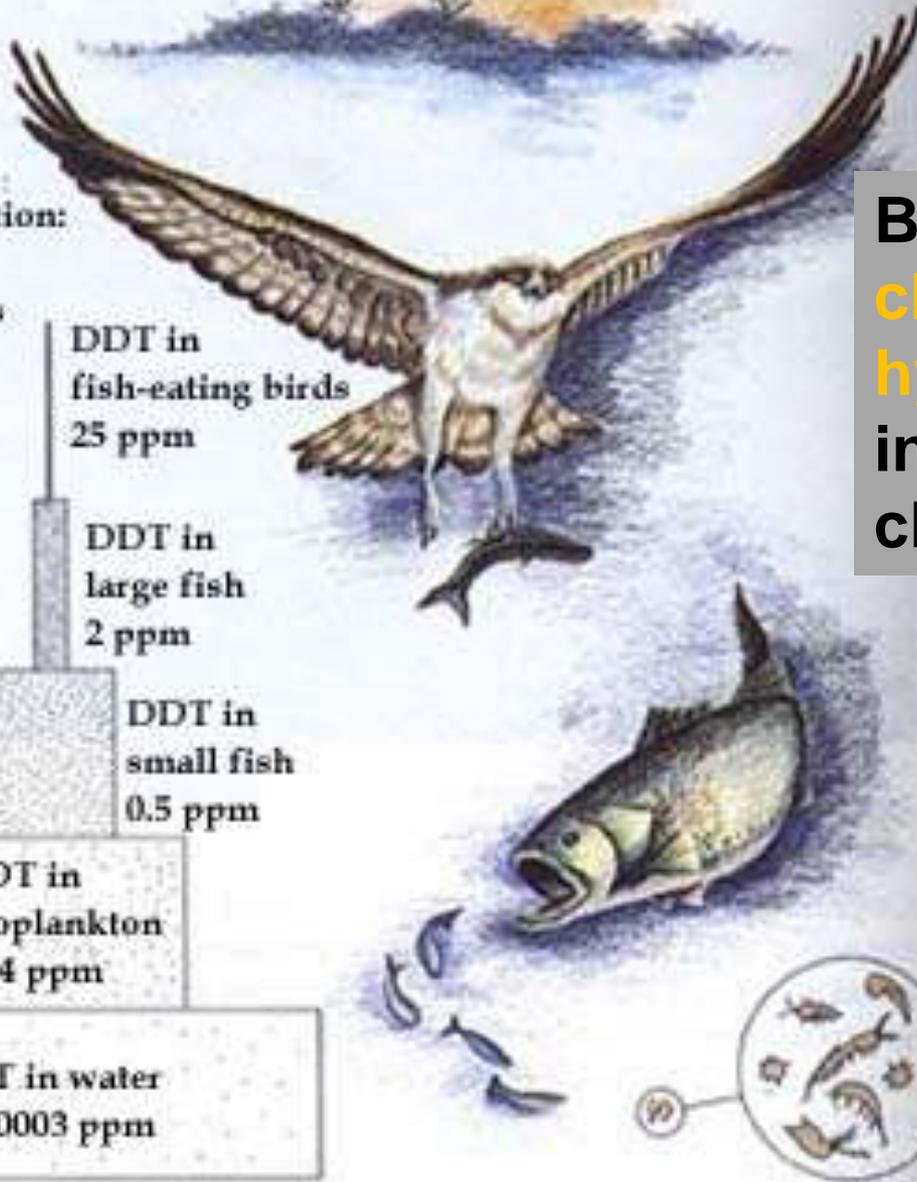
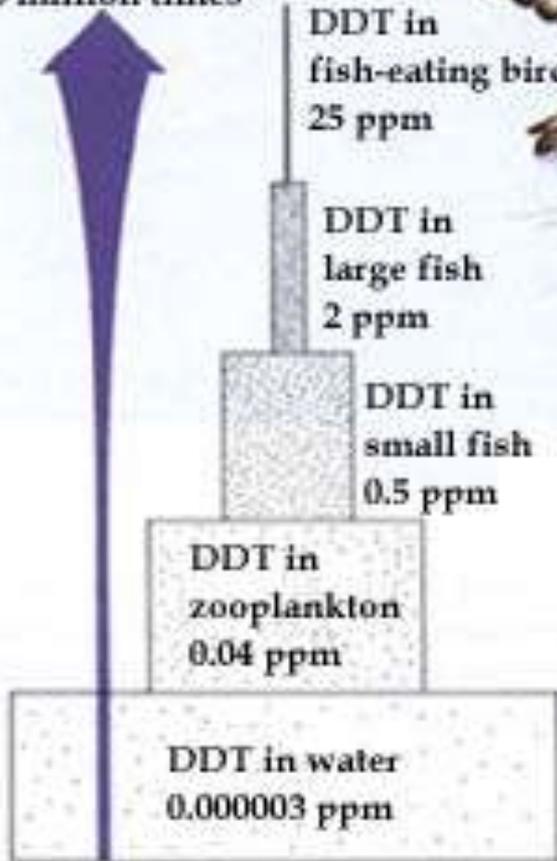
Figure 6  
DDT in Breast Milk, West Germany



Figure 7: DDT Levels in Ten Washingtonians



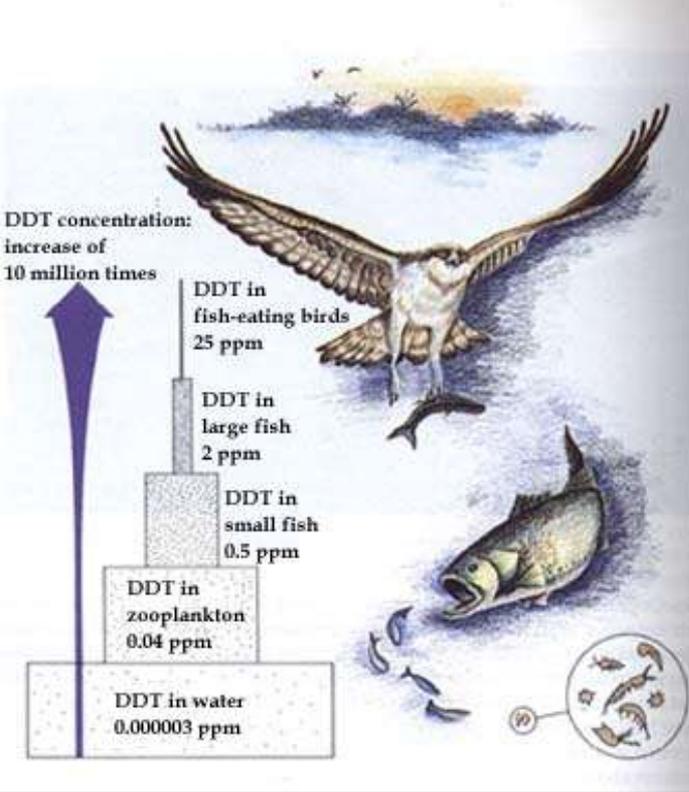
DDT concentration:  
increase of  
10 million times



Biomagnification of  
**chlorinated hydrocarbon**  
insecticides in food  
chains

## Biomagnification of **chlorinated hydrocarbon** insecticides in food chains

**In high levels chlorinated hydrocarbons act as estrogen mimics**



**Primary effect on top predators – egg shell thinning**





**Paul Muller –  
Received 1948 Nobel  
Prize for  
Medicine/Physiology  
for his discovery of  
the insecticidal  
activity of DDT**

Malaria mosquito



# Chlorinated Hydrocarbons

- **Fat soluble**
- **Persistent in the environment**
  - **Concentrated in fat tissues**
  - **Biomagnification** in ecosystems
  - Showed some hormonal effects at high concentrations (**estrogen mimics**)
- **Current Status**
  - DDT banned 1972
  - Termiticide uses eliminated in 1990s
  - Methoxychlor used for bark beetles into the 1990s; all uses ended in 2002

# Organophosphates

- Primary class used during 1960s through early 1990s
- Some have systemic activity
- Mode of Action: **Inhibition of cholinesterase**
  - Effects persist and can accumulate with repeated exposure
- Acute Toxicity (to humans): Moderate to very high

# Organophosphates were originally developed in Nazi Germany as Chemical Warfare (Nerve Gas) Agents

G Class (Sarin, Tabun), VCX series



## CHEMICAL WARFARE ☠ NERVE AGENTS

### PART ONE: THE G SERIES

THE G SERIES NERVE AGENTS ARE SO NAMED BECAUSE THEY WERE ALL FIRST SYNTHESISED IN GERMANY. THEY ARE ALL EXTREMELY TOXIC VOLATILE LIQUIDS, CLASSIFIED AS WEAPONS OF MASS DESTRUCTION BY THE U.N., AND THEIR PRODUCTION & STOCKPILING IS OUTLAWED.

| TABUN (GA)   | SARIN (GB)  | SOMAN (GD)   | CYCLOSARIN (GF)   |
|--|---|--|---|
| <chem>CCOP(=O)(CN)C#N</chem>   | <chem>CC(C)OP(=O)(O)C</chem>  | <chem>CC(C)OP(=O)(O)C(C)C</chem>   | <chem>C1CCN(C1)OP(=O)(O)C</chem>  |
| <b>SMELL &amp; APPEARANCE</b><br>Clear, colourless liquid though impurities can have a brown appearance. Pure Tabun is odourless, but it often has a strong "fishy" odour due to impurities. | <b>SMELL &amp; APPEARANCE</b><br>A clear, colourless liquid, odourless and tasteless in its pure form. It is a volatile liquid like other nerve gases and vapour generated is heavier than air. | <b>SMELL &amp; APPEARANCE</b><br>Soman is a clear, colourless, odourless liquid. It has a faint odour when pure, but when it reacts it has a yellow-brown odour and has a strong, long-persistent odour. | <b>SMELL &amp; APPEARANCE</b><br>Clear, colourless liquid with a weak, heavy, musty odourless, similar to peaches. It evaporates almost 50 times more than sarin, and is also longer-lasting. |
| <b>SYNTHESIS</b><br><b>1936</b> Discovered accidentally by Gerhard Schröder, a German chemist, while studying organophosphorus compounds.  | <b>SYNTHESIS</b><br><b>1938</b> Named after the town of sarin in the region of chemical warfare in the German-occupied Poland.  | <b>SYNTHESIS</b><br><b>1944</b> Discovered during research into the pharmacology of sarin & similar compounds by the German army.  | <b>SYNTHESIS</b><br><b>1949</b> The result of German research led to the first chemical agents to have manufactured cyclohexane groups.   |
| <b>LETHALITY</b><br>Lethal dose (LD50) 400 mg/kg (oral) 4000 mg/kg (inhalation)  | <b>LETHALITY</b><br>Lethal dose (LD50) 100 mg/kg (oral) 1700 mg/kg (inhalation)   | <b>LETHALITY</b><br>Lethal dose (LD50) 70 mg/kg (oral) 300 mg/kg (inhalation)  | <b>LETHALITY</b><br>Lethal dose (LD50) 50 mg/kg (oral) 350 mg/kg (inhalation)   |

### EFFECTS OF NERVE AGENTS

- Causes respiratory distress
- Causes loss of heart rhythm
- Causes loss of heart rate
- Causes paralysis of muscles
- Causes loss of consciousness
- Causes convulsions & loss of breathing
- Causes death

# Organophosphate Insecticides

## Historically Used for Landscape Pest Management

- Chlorpyrifos (Dursban)
- Diazinon
- Acephate (Orthene)
- Dimethoate (Cygon)
- Malathion
- Disulfoton (DiSyston)
- Oxydemetonmethyl (MetaSystox-R)



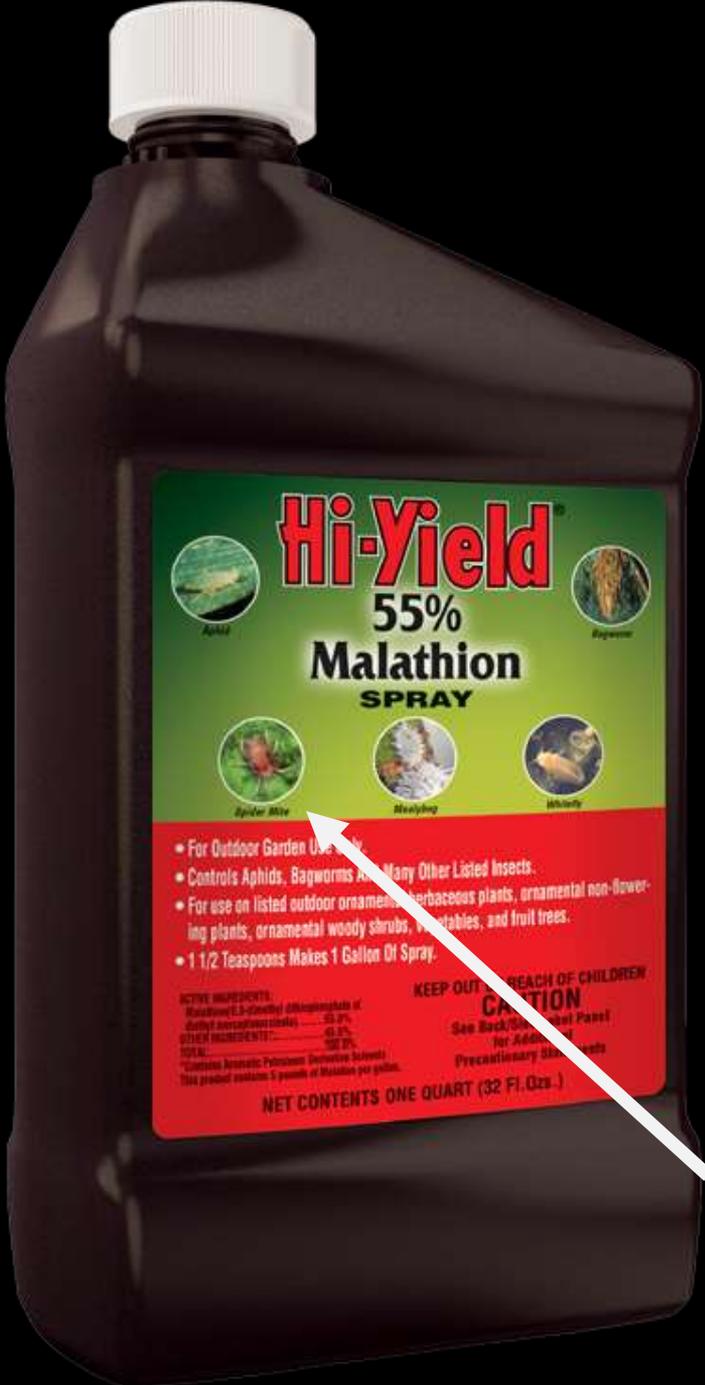
# Organophosphates

- **Non-target Effects:**
  - **Birds:** Moderate to **very high toxicity to birds**
  - **Fish:** Moderately toxic
- **Other:** **Many organophosphates have a strong associated odor**
- **Current Status**
  - **Steady reduction in registrations since late 1990s**

# Organophosphate Insecticides Presently Used in Landscape Care

- Acephate (Orthene, Lepitect)
- Malathion?





# Hi-Yield™

## 55%

### Malathion SPRAY



Aphid



Bagworm



Spider Mite



Weevil



Whitefly

- For Outdoor Garden Use
- Controls Aphids, Bagworms and Many Other Listed Insects.
- For use on listed outdoor ornamental herbaceous plants, ornamental non-flowering plants, ornamental woody shrubs, vegetables, and fruit trees.
- 1 1/2 Teaspoons Makes 1 Gallon Of Spray.

ACTIVE INGREDIENTS  
 Methyl 1,1-Dimethyl 4-thiohydantoinyl  
 methyl phosphorothioate ..... 55.0%  
 OTHER INGREDIENTS ..... 45.0%  
 TOTAL ..... 100.0%  
 \*Contains Insecticidal Pyrethroid Derivative Insect  
 This product contains 5 pounds of Malathion per gallon.

KEEP OUT OF REACH OF CHILDREN  
**CAUTION**  
 See Back/Other Label Panel  
 for Additional  
 Precautionary Statements

NET CONTENTS ONE QUART (32 FL. OZ.)



**Hi-Yield**

55%

**Malathion  
SPRAY**



Aphid



Bagworm



Spider Mite



Weevil



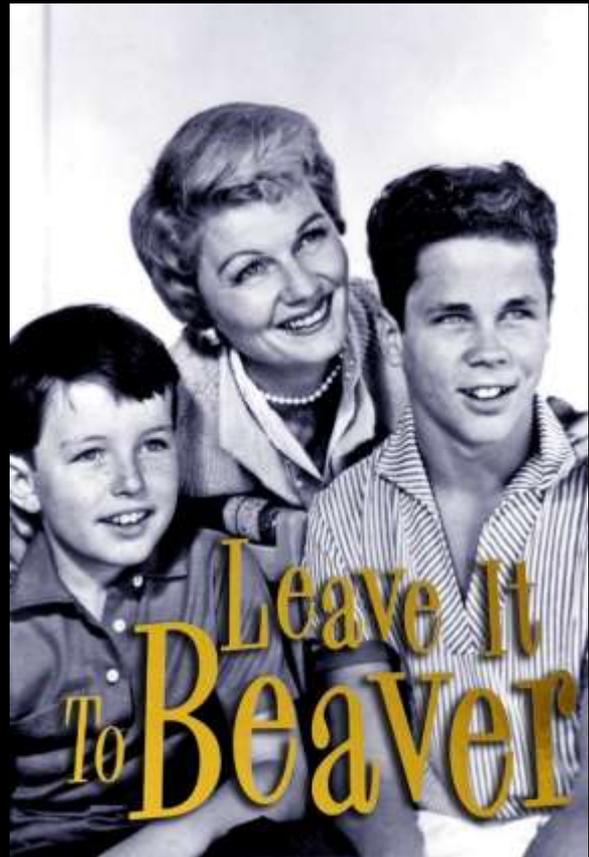
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NET CONTENTS ONE QUART (32 FL. OZS.)



Leave It  
 To  
**Beaver**

# There are over two dozen modes of action of insecticides and miticides



## IRAC - Insecticide Mode of Action Classification

Insecticide Resistance Action Committee [www.irac-online.org](http://www.irac-online.org)

### Introduction

Insecticide Resistance Action Committee [IRAC] promotes the use of a Mode of Action (MoA) classification of insecticides as the basis for effective and sustainable insecticide resistance management (IRM). Insecticides are allocated to specific groups based on their target site. Reviewed and re-issued periodically, the IRAC MoA classification list provides farmers, growers, advisors, extension staff, consultants and crop protection professionals with a guide to the selection of insecticides or acaricides in IRM programs. Effective IRM of this type preserves the utility and diversity of available insecticides and acaricides. Sample MoA groups are shown below.

### Effective IRM strategies: Sequences or alternations of MoA

All effective insecticide resistance management (IRM) strategies seek to minimise the selection of resistance to any one type of insecticide. In practice, alternations, sequences or rotations of compounds from different MoA groups provide sustainable and effective IRM for pest Lepidoptera. This ensures that selection from compounds in the same MoA group is minimised, and resistance is less likely to evolve.

Applications are often arranged into MoA spray windows or blocks that are defined by the stage of crop development and the biology of the pest species of concern. Local expert advice should always be followed with regard to spray windows and timings. Several sprays may be possible within each spray window but it is generally essential to ensure that successive generations of the pest are not treated with compounds from the same MoA group. Metabolic resistance mechanisms may give cross-resistance between MoA groups, and where this is known to occur, the above advice must be modified accordingly. IRAC also provides general recommendations for resistance management tactics regarding specific MoA groups, e.g. neonicotinoids (Group 4A).



### Growth & Development targets

- Group 7 Juvenile hormone mimics
- 7A Juvenile hormone analogues (e.g. Methoprene)
- 7B Fenoxycarb, 7C Pyriproxyfen
- Group 10 Mite growth inhibitors
- 10A Clofentazine, Hexythiazox, 10B Etoxazole
- Group 15 Inhibitors of Chitin biosynthesis, Type 0
- Benzoyleureas (e.g. Flufenoxuron, Novaluron)
- Group 16 Inhibitors of chitin biosynthesis, type 1
- Buprofezin
- Group 17 Moulting disruptor, Dipteran Cyromazine
- Group 18 Ecdysone agonists / moulting disruptors
- 18 Diacylhydrazines (e.g. Methoxyfenozide, Tebufenozide)

### Nerve & Muscle Targets

- Group 1 Acetylcholinesterase (AChE) inhibitors
- 1A Carbamates (e.g. Thiodicarb),
- 1B Organophosphates (e.g. Chlorpyrifos)
- Group 2 GABA-gated chloride channel antagonists
- 2A Cycloidiene Organochlorines (e.g. Endosulfan),
- 2B Phenylpyrazoles (e.g. Fipronil)
- Group 3 Sodium channel modulators
- 3A Pyrethrins, Pyrethroids (e.g. Cypermethrin,  $\lambda$ -Cyhalothrin)
- Group 4 Acetylcholine receptor (nAChR) agonists
- 4A Neonicotinoids e.g. Imidacloprid, Thiamethoxam)
- 4C Sulfoxaflor, 4D Flupyradifurone
- Group 5 Nicotinic acetylcholine receptor channel agonists (Allosteric)
- Spinosyns (e.g. Spinosad, Spinetoram)
- Group 6 Chloride channel activators Avermectins (e.g. Abamectin, Emamectin benzoate, Lepimectin)
- Group 9 Modulators of Chordotonal Organs
- 9B Pymetrozine, 9C Flonicamid
- Group 14 Nicotinic acetylcholine receptor channel blockers Nereistoxin analogs (e.g. Cartap hydrochloride)
- Group 19 Octopamine receptor agonists Amitraz
- Group 22 Voltage dependent sodium channel blockers
- 22A Indoxacarb, 22B Metaflumizone
- Group 28 Ryanodine receptor modulators
- Diamides (e.g. Flubendiamide, Chlorantraniliprole, Cyantraniliprole)



### Respiration targets

- Group 12 Inhibitors of mitochondrial ATP synthesis
- 12A Difenthiuron, 12B Organotin miticides (e.g. Cyhexatin), 12C Propargite, 12D Tetraifon
- Group 13 Uncouplers of oxidative phosphorylation via disruption of H proton gradient Chlorfenapyr
- Group 20 Mitochondrial complex III electron transport inhibitors
- 20A Hydramethylinon, 20B Acequinolyl,
- 20C Flucicrypyrim
- Group 21 Mitochondrial complex I electron transport inhibitors
- 21A METI acaricides (eg. Pyridaben, Tebufenpyrad)
- Group 23 Inhibitors of acetyl CoA carboxylase
- Tetronic & Tetramic acid derivatives (e.g. Spirodiclofen)
- Group 25 Mitochondrial complex II electron transport inhibitors Cyenopyrafen, Cyflumetofen

### Midgut Targets

- Group 11 Microbial disruptors of insect midgut membranes
- 11A *Bacillus thuringiensis*
- 11B *Bacillus sphaericus*

### Unknown

- UN Compounds of unknown or uncertain mode of action (e.g. Azadiractin, Bifenazate, Pyridatyl, Pyrifluquinazon),

# A great source of information on insecticide classes and their mode of action



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- Group 7 Juvenile hormone mimics
- 7A Juvenile hormone analogues (e.g. Methoprene)
- 7B Fenoxycarb, 7C Pyriproxyfen
- Group 10 Mitic growth inhibitors
- 10A Clofentezine, Hexythiazox, 10B Etoxazole
- Group 15 Inhibitors of Chitin biosynthesis, Type 0 Benzoylureas (e.g. Flufenoxuron, Novaluron)
- Group 16 Inhibitors of chitin biosynthesis, type 1 Buprofezin
- Group 17 Moulting disruptor, Dipteran Cyromazine
- Group 18 Ecdysone agonists / moulting disruptors
- 18a Disacyhydrazines (e.g. Methoxyfenozide, Tefufenozide)

### Nerve & Muscle Targets

- Group 1 Acetylcholinesterase (AChE) inhibitors
- 1A Carbamates (e.g. Thiodiazinon)
- 1B Organophosphates (e.g. Chlorpyrifos)
- Group 2 GABA-gated chloride channel antagonists
- 2A Cyclothiazide Organophosphates (e.g. Endosulfan)
- 2B Phenylpyrazoles (e.g. Fipronil)
- Group 3 Sodium channel modulators
- 3A Pyrethrins, Pyrethroids (e.g. Cypermethrin,  $\lambda$ -Cyhalothrin)
- Group 4 Acetylcholine receptor (nAChR) agonists
- 4A Neonicotinoids (e.g. Imidacloprid, Thiamethoxam)
- 4C Sulfoxalof, 4D Flupyradifurone
- Group 5 Nicotinic acetylcholine receptor channel agonists (Alfateric)
- 5A Spirooxins (e.g. Spirooxim, Spinetoram)
- Group 6 Chloride channel activators Avermectins (e.g. Abamectin, Emamectin benzoate, Lepidectin)
- Group 9 Modulators of Chordotonal Organs
- 9B Pyrimethozin, 9C Fluralaner
- Group 14 Nicotinic acetylcholine receptor channel blockers Nereistoin analogs (e.g. Cartap hydrochloride)
- Group 19 Octopamine receptor agonists Amirtaz
- Group 22 Voltage dependent sodium channel blockers
- 22A Indoxacarb, 22B Metflumizone
- Group 28 Ryanodine receptor modulators
- Diamides (e.g. Flubendiamide, Chlorantraniliprole, Cyantraniliprole)



### Respiration targets

- Group 12 Inhibitors of mitochondrial ATP synthesis
- 12A Diflufenican, 12B Organotin imides (e.g. Cyhexatin), 12C Preproprils, 12D Tetraflon
- Group 13 Uncouplers of oxidative phosphorylation via disruption of H<sup>+</sup> proton gradient Chlorfentypr
- Group 20 Mitochondrial complex III electron transport inhibitors
- 20A Hydramethylnon, 20B Acequinol, 20C Fluscyprim
- Group 21 Mitochondrial complex I electron transport inhibitors
- 21A METI acaricides (eg. Pyridaben, Tebufenpyrad)
- Group 23 Inhibitors of acetyl CoA carboxylase
- Tetronic & Tetramic acid derivatives (e.g. Spirodiclofen)
- Group 25 Mitochondrial complex II electron transport inhibitors Cyromazine, Cyflumetofen

### Midgut Targets

- Group 11 Microbial disruptors of insect midgut membranes
- 11A Bacillus thuringiensis
- 11B Bacillus sphaericus

### Unknown

UN Compounds of unknown or uncertain mode of action (e.g. Azadirachtin, Bifenazate, Pyridaty, Pyrifluquinazon)

This poster is for educational purposes only. Details are accurate to the best of our knowledge but IRAC and its member companies cannot accept responsibility for how this information is used or interpreted. Advice should always be sought from local experts or advisors and health and safety recommendations followed.

Designed & produced by the IRAC MoA Team, April 2014. Poster Ver 3.0. Based on MoA Classification Ver. 7.3. For further information visit the IRAC website: [www.irc-online.org](http://www.irc-online.org). © Photograph courtesy of Neil Armes. IRAC document protected by © Copyright.

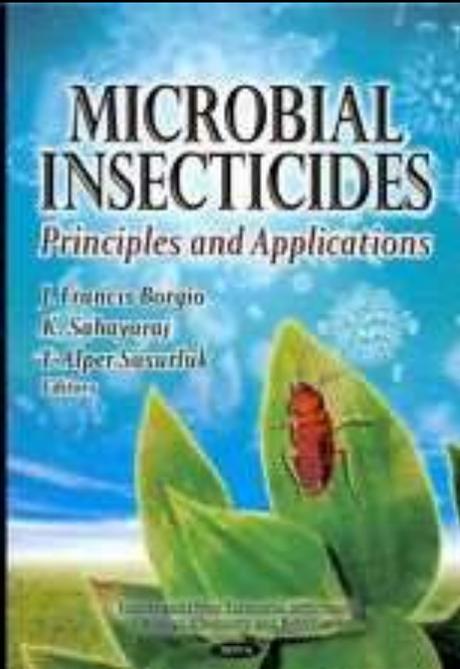
# IRAC – Insecticide Resistance Action Committee

# How were most presently used insecticides discovered?

## MICROBIAL INSECTICIDES

*Principles and Applications*

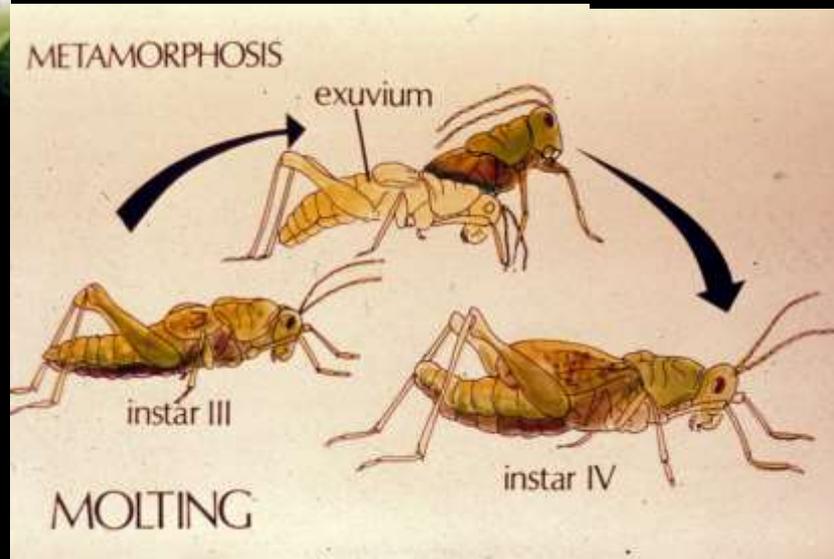
J. Francis Borgio  
K. Sahayraj  
T. Alper Sasurluk  
Editors



**Derived  
from  
microbes**



**Derived from active  
ingredients found in plants**

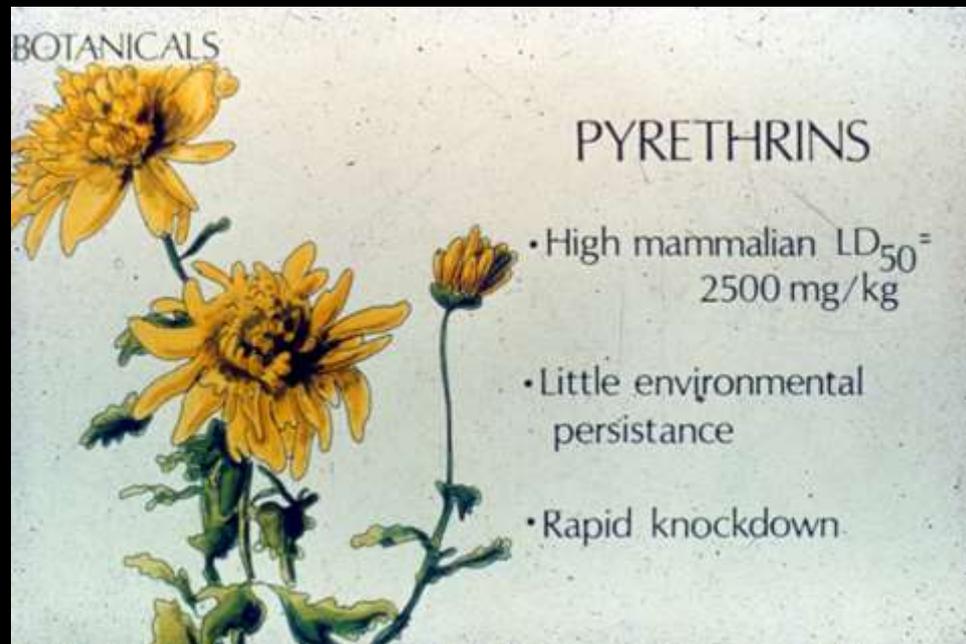


**Derived from  
hormones used  
in insect growth**

# Pyrethroid Insecticides (a.k.a., synthetic pyrethrins)



Pyrethrins are the active ingredient extracted from pyrethrum flowers



***Tanacetum (=Chrysanthemum)***  
***cinaerifolium***      **Pyrethrum Daisy**



Botanical source that lead to development of the pyrethroid insecticides



**Extracts of pyrethrum flowers contain active ingredients known as pyrethrins**

# Dalmatian (Pyrethrum) Daisy

*Tanacetum (=Chrysanthemum) cinaerifolium*



A Colorado *Plant*  
*Select Selection*

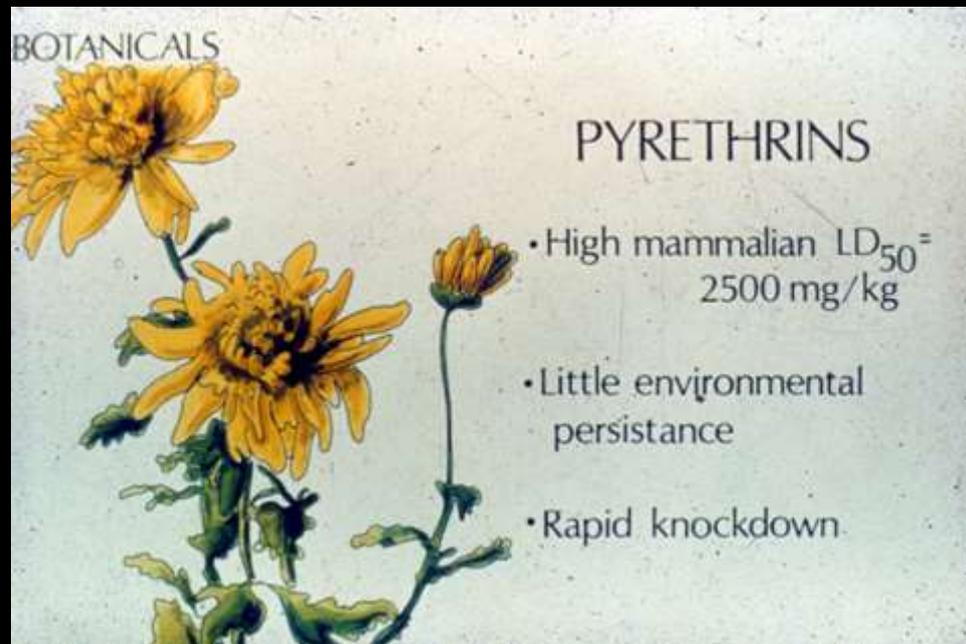


# Pyrethroid Insecticides

(a.k.a., synthetic pyrethrins)



Pyrethrins are the active ingredient extracted from pyrethrum flowers



# Some Presently Marketed Pyrethroid Insecticides

- Permethrin
- Cypermethrin
- Bifenthrin
- Resmethrin
- Sumithrin
- Tetramethrin
- Tralomethrin
- Deltamethrin
- Esfenvalerate
- Cyfluthrin
- Cyhalothrin
- Allethrin



# Some Pyrethroid Insecticides



Pyrethrins

# Pyrethroid Uses

- **Non-systemic, attaches well to organic matter (high Koc)**
- **Persistence ranges widely**
  - **Bifenthrin, cypermethrin** most persistent (days to a couple weeks)
  - **Permethrin, cyhalothrin, cyfluthrin** quite persistent (days)
  - **Resmethrin, sumithrin, pyrethrins** non-persistent (hours)

# **Pyrethroid Uses for Tree/Shrub Insect Control**

- **Generally broad spectrum**
  - **Standards for bark beetle and borer sprays**
  - **Strong on most beetles, caterpillars, sawflies, scale crawlers**
  - **OK on most Hemiptera (e.g., aphids, whiteflies, leafhoppers, bugs)**
  - **Fair to poor on spider mites**

# OTC Pyrethroids with Uses on Ornamental Plants

- **Bifenthrin/Cypermethrin (combination)**
  - Ortho Max Insect Killer for Lawns & Gardens
- **Cyfluthrin**
  - Bayer Advanced Rose & Flower Insect Killer, Bayer Advanced Vegetable & Garden Insect Spray
- **Gamma-cyhalothrin**
  - Spectracide Triazicide Insect Killer for Lawns & Landscapes
- **Permethrin**
  - Bonide Eight Insect Control Vegetable, Fruit & Flower; Bayer Advanced Complete Insect Dust for Gardens; Ace House & Garden Bug Killer<sup>2</sup>; probably many others

# Primary Pyrethroid Insecticide Found on Nursery Shelves – *That Can Be Used on Fruits/Vegetables*

- Permethrin



# A Pyrethroid Insecticide Found on Nursery Shelves – *That Can Be Used on Many Fruits/Vegetables*

**Active Ingredient:**  
**Gamma-cyhalothrin**



# Active Ingredients of Wood Borer Insecticides (Trunk Sprays)

- Permethrin (Astro, Permethrin, etc.)
- Bifenthrin (Onyx)





**Only One OTC product, containing permethrin, has a label and use rate that allows effective use against Borers and Bark Beetles!**

- Soil Insect And Termite Killer.
- Kills Home-Invading Pests (Outdoor).
- Controls Wood-Destroying Insects.

FOR OUTDOOR HOMEOWNER (RESIDENTIAL) USE ONLY.  
FOR OUTDOOR HOMEOWNER POST CONSTRUCTION USE ONLY.

|                     |        |
|---------------------|--------|
| ACTIVE INGREDIENT:  |        |
| Permethrin*         | 38.0%  |
| OTHER INGREDIENTS** | 62.0%  |
| TOTAL               | 100.0% |

KEEP OUT OF REACH  
OF CHILDREN  
**CAUTION**

\*Active ingredient: Max 52% (s) cis and min. 45% (s) trans  
\*\*Contains petroleum distillates.

See Back/Side Panel For Additional  
Precautionary Statements

**NET CONTENTS ONE PINT (16 FL. OZS.)**

# Pyrethroids are non-selective

...and can be rough on insect natural enemies





**Pyrethroids  
are highly  
toxic to  
bees**

**Treated flowers may  
kill flower visitors for  
a couple of days after  
application**



# How to Reduce Bee Poisoning from pesticides

L. Hooven  
R. Sagili  
E. Johansen



Photo: Ramesh Sagili

A PACIFIC NORTHWEST EXTENSION PUBLICATION • PNW 591  
Oregon State University ■ University of Idaho ■ Washington State University

## My favorite/”go to” publication on this subject

Table 4. Active ingredients of commonly used pesticides and their effect on bees in California, Idaho, Oregon, and Washington

| Active Ingredient   | Highly Toxic to Bees (RT)  | Toxic to Bees (RT) | No Bee Precautionary Statement (PS) on Label | Common Product Names  | Notes and Special Precautions  |
|---|--|--------------------|--|---|--|
| <b>Abamectin (Avermectin)</b><br><i>Fermentation products derived from soil bacterium, affects nerve and muscle action of insects and mites</i> | <b>X</b><br>0.025 lb ai/acre<br>1-3 days ERT,<br>≤ 0.025 lb ai/acre<br>8 hours RT [1]<br><i>Can vary with formulation and application rate</i> |                    |  | Abacide, Abacus, Abba, Agmectin, Agri-Mek, Ardent, Avert, Avicta, Avid, Epi-Mek, Reaper, Solera, Solero, Temprano, Timectin, Zoro | ERT to bumble bees [2], short RT to alfalfa leafcutting bees and alkali bees at 0.025 lb ai/acre [1].  |
| <b>Acephate</b><br><i>Organophosphate insecticide</i>   | <b>X</b><br>>3 days ERT [1]<br><i>Can vary with formulation and application rate</i>   |                    |  | Bracket, Orthene, Orthonex  | Incompatible with bumble bees [2], ERT to alfalfa leafcutting bees and alkali bees [1].  |
| <b>Acequinocyl</b><br><i>Quinolone insecticide/miticide, metabolic poison</i>   |  |                    | <b>X</b>                                     | Kanemite, Shuttle   |  |
| <b>Acetamiprid</b><br><i>Neonicotinoid insecticide (cyano group)</i>  |  | <b>X</b><br>Yes    |  | Assail, Tristar, Transport  | Length of residual toxicity to honey bees is unknown. ERT to alfalfa leafcutting bees and alkali bees [3], 2 day ERT to bumble bees [2].<br>Cyano group neonicotinoids exhibit lower toxicity to bees than nitro group neonicotinoids [4]. |

# Pyrethroids

- **Acute Toxicity to Humans:** Low to moderate
- **Non-target Effects:**
  - Birds: Low to very high acute toxicity
  - Fish: **Extremely toxic**
- **Current Status**
  - Broadly registered and available – *although under review*

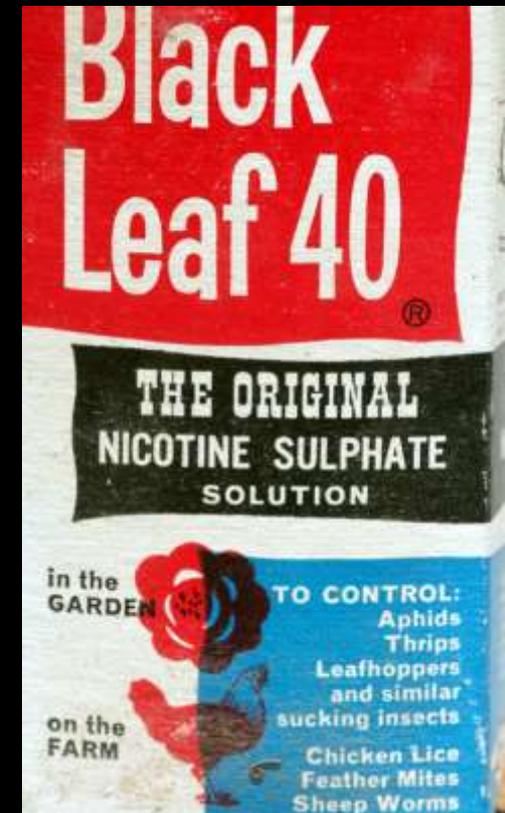


Botanical source that led to development of neonicotinoid insecticides

# Nicotine



Older nicotine sulfate insecticide



# Neonicotinoids

- **Insecticide class originally developed commercially in the late 1980s**
- **Mode of Action**
  - **Nicotinic acetylcholine receptor agonist**
  - **IRAC Mode of Action Group 7A**
  - **Nicotine mode of action similar**

# Neonicotinoids

- Insecticide class originally developed commercially in the late 1980s
- Mode of action - **Nicotinic acetylcholine receptor agonist**
  - **IRAC Mode of Action Group 7A**
  - **Nicotine mode of action similar**
- **Emerged in early 1990s**
  - **First new class of insecticide with systemic activity in plants in 30+ years**
- **Low toxicity to vertebrates accelerated registration as “reduced risk” products**

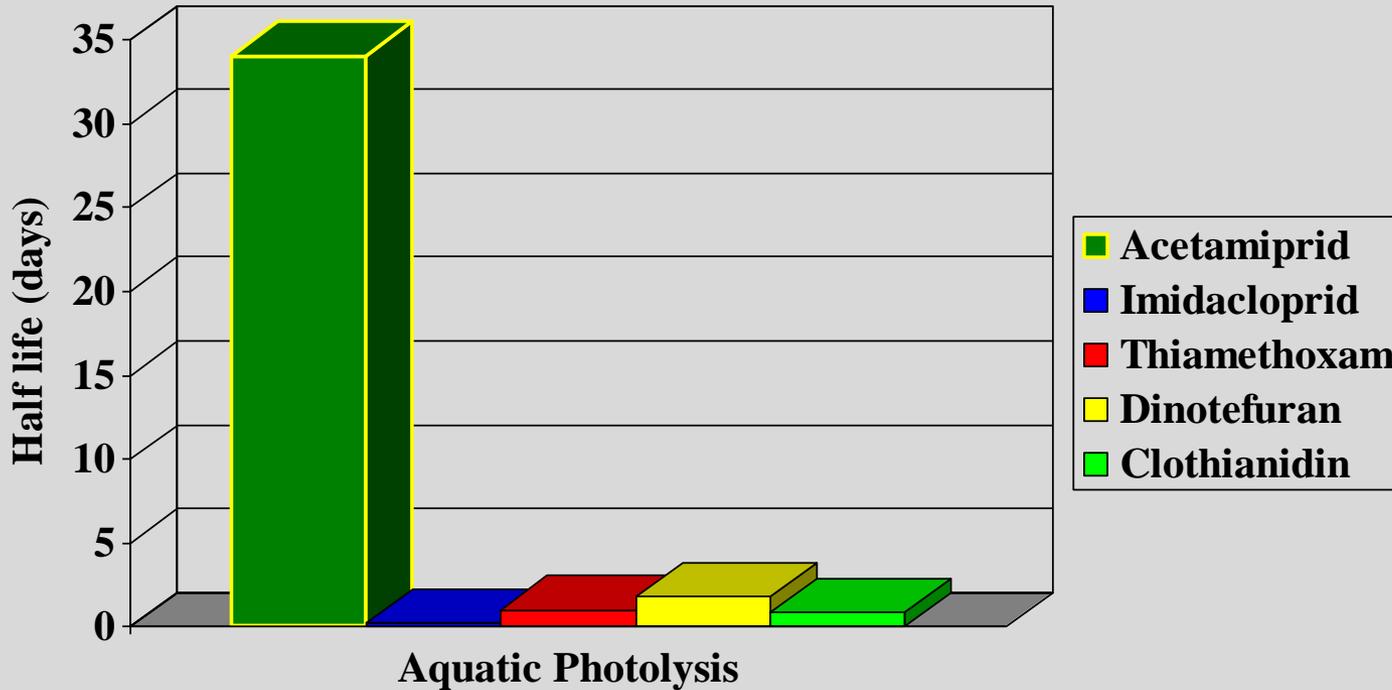
# Primary Neonicotinoid Insecticides Used in Landscape Plant Care

- **Imidacloprid** (Merit, Marathon, Zenith, Mallet, etc.)
- **Dinotefuran** (Safari, Zylam, Transtect)
- **Acetamiprid** (Tristar)

# **Not all Neonicotinoids are alike:**

- **UV stability**
- **Water solubility**
- **Rate of uptake by plants**
- **Mobilization within plants**
- **Host range of susceptible insects**

# Comparison of UV Stability



Data obtained from published EPA registration documents

# UV Stability

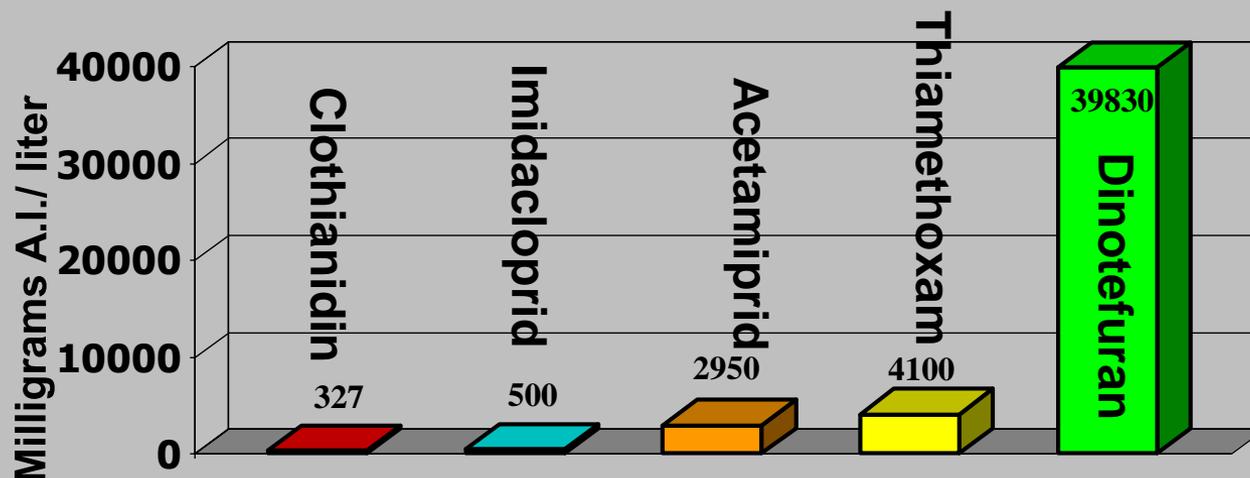
Neonicotinoids are generally not UV stable. Foliar persistence can be shortened by this feature.

**Acetamiprid** is an exception.



# Relative Water Solubility of Neonicotinoids:

## *Water Solubility (Active Ingredient)*



### ***Information sources***

***Clothianidin (Celero), Acetamiprid (Tristar), Dinotefuran (Safari) – EPA Pesticide Fact Sheet  
Imidacloprid (Marathon), thiamethoxam (Flagship) – MSDS for Products***

Slide information courtesy J. Chamberlin



*Longwood  
Gardens*

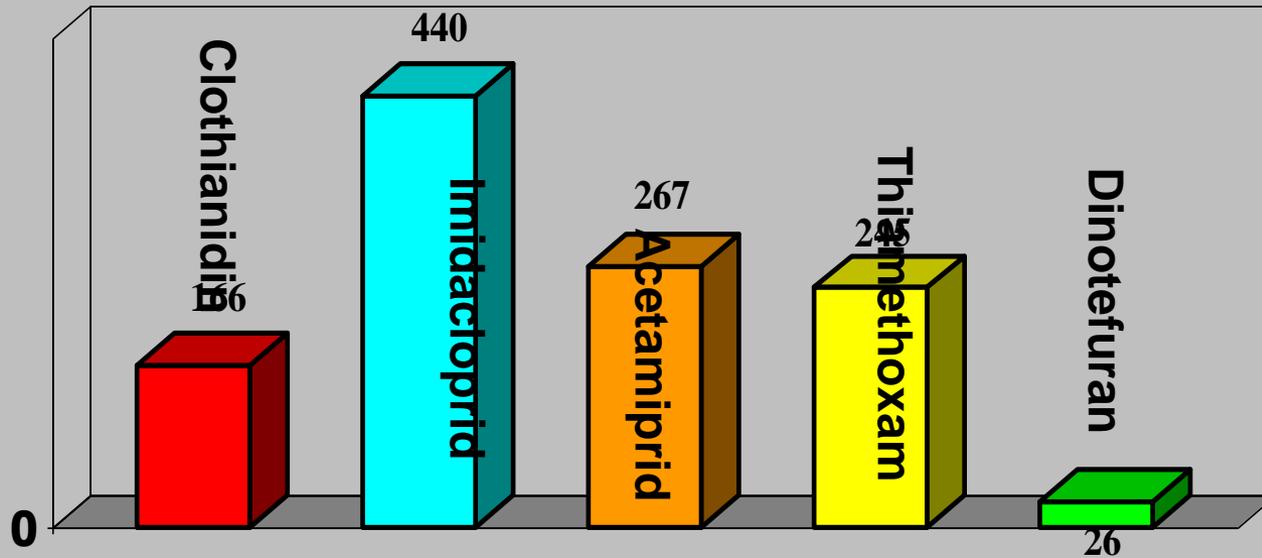
# Water Solubility

There is wide range of water solubility among the neonicotinoids.

**Dinotefuran** (Safari, Transtect, Zylam) *is highly water soluble.*



# $K_{oc}$ Values of Neonicotinoids:



Source Data: EPA Pesticide Fact Sheets



# Koc Value

There is wide range of Koc values (measure of adsorption to organic matter) among the neonicotinoids. This affects mobility within plants.

**Dinotefuran** (Safari, Transtect, Zylam) *has a much lower Koc value than do other neonicotinoids*





Dinotefuran (Safari, Zylam,  
Transtect)

# **Not all Neonicotinoids are alike:**

- **UV stability**
- **Water solubility**
- **Rate of uptake by plants**
- **Mobilization within plants**
- **Host range of susceptible insects**

# Acute Toxicity of Neonicotinoids to Adult Honey Bees

(Dermal LD50 in micrograms/bee)

|                 |       |
|-----------------|-------|
| • Acetamiprid   | 8.09  |
| • Imidacloprid  | 0.08  |
| • Dinotefuran   | 0.022 |
| • Thiamethoxam  | 0.024 |
| • Chlothianidin | 0.044 |

# Acute Toxicity of Neonicotinoids to Adult Honey Bees

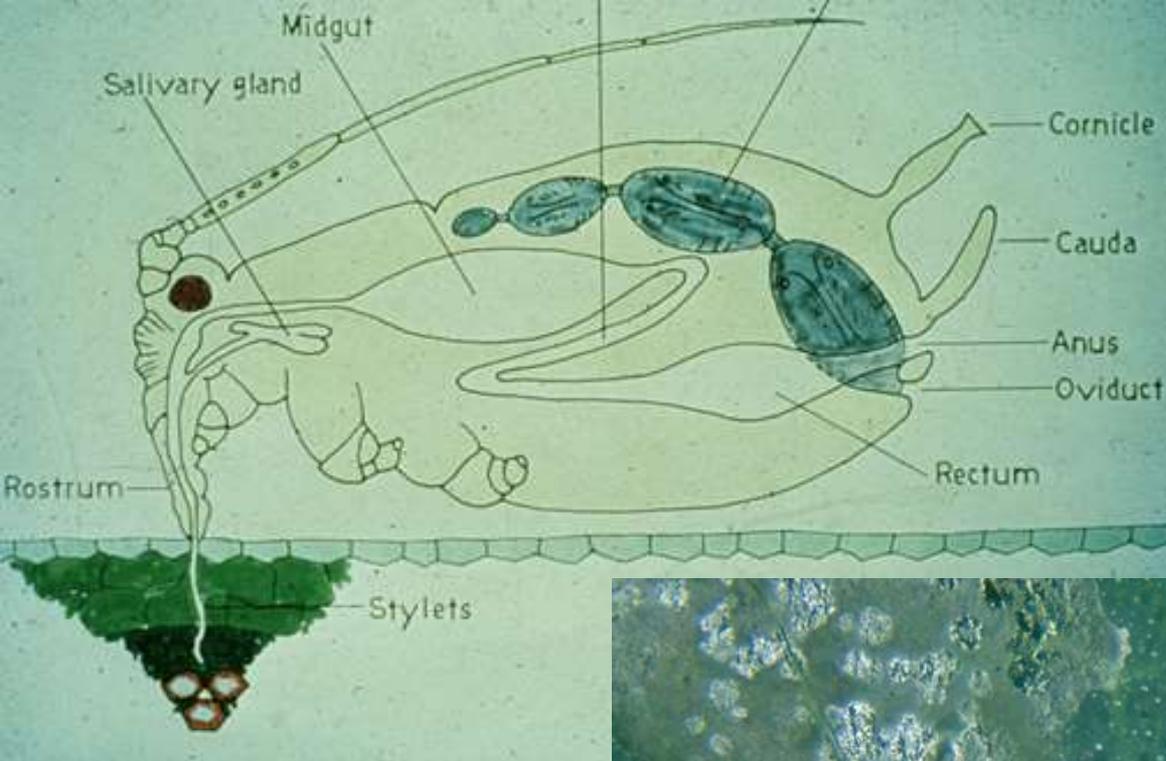
(Oral LD50 – micrograms/bee)

|                 |        |
|-----------------|--------|
| • Acetamiprid   | 14.53  |
| • Imidacloprid  | 0.005  |
| • Dinotefuran   | 0.056  |
| • Thiamethoxam  | 0.005  |
| • Chlothianidin | 0.0003 |



**Neonicotinoids  
are effective  
against most  
phloem-feeding  
insects**





**Aphids and soft scales suck sap from the phloem and excrete honeydew**



***If the insect excretes honeydew, neonicotinoids will almost always work well for its control***





**Most all  
neonictinoids  
have good activity  
against beetle  
larvae and sawfly  
larvae**





**Armored scales** – poor,  
with an exception



**Spider mites** – often  
terrible



**Neonicotinoid host  
range, continued**

**Caterpillars/Lepidoptera** –  
poor with some exceptions



Imidacloprid formulations

# Over-the-Counter Imidacloprid Formulations





# Imidacloprid Characteristics and Niche

- **Advantages**

- Good persistence with soil application
- Easy to apply soil treatment
- Inexpensive

# Imidacloprid Characteristics and Niche

- **Limitations**

- Poor on caterpillars
- Weak on armored scales
- Tends to make spider mite problems worse
- High risk for pollinators



**Imidacloprid  
Control Range**

**Yes – Soft Scale**



**No – Armored  
Scale**

Oak lecanium



European elm scale



## Soft Scales

## Families Coccidae, Eriococcidae

Pine tortoise scale



Cottony maple scale



# Soft Scales vs. Armored Scales



**Feeding Site: Phloem**

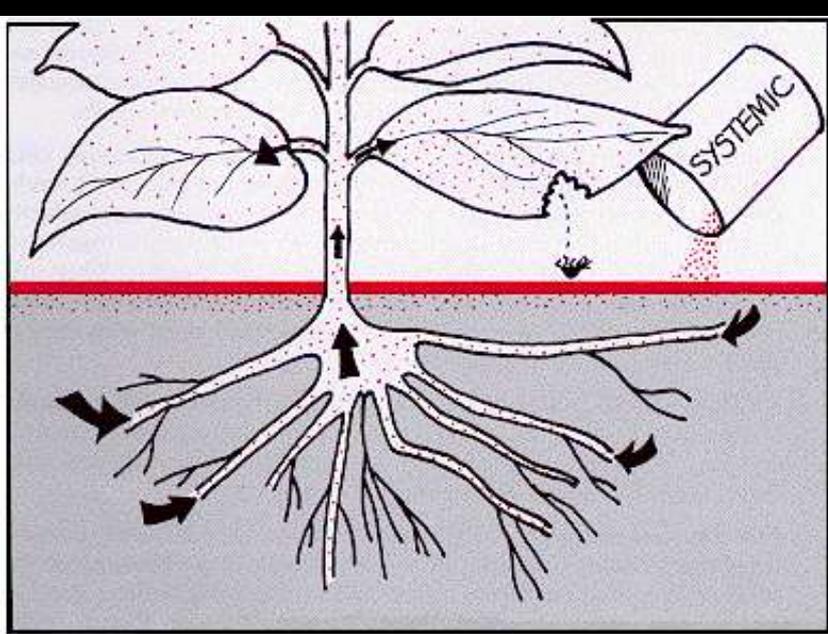
**Soft scales produce honeydew**



**Feeding Site: Cells, often of the cambium**

**Armored scales do not produce honeydew**

# Systemic insecticides for wood borers?



# Imidacloprid for Borers?



**Yes.....but**



**Imidacloprid will not work well on borers that are the larval stage of moths**





# Lilac/ash borer

Not effective



# Peach tree borer larval tunneling in base of plant

Not effective





## Zimmerman pine moth injury

Not effective



**Imidacloprid *will not* work well if the borer spends much of its life in the heartwood of the plant**



**Imidacloprid soil drenches *may work well* against flatheaded borer larvae (aka metallic wood borers)**





Bronze cane borer/  
Rose stem girdler



Twolined chestnut borer



**Four common *Agrilus* species  
metallic wood borers**

Bronze birch borer



Honeylocust borer





**Imidacloprid as a soil injection, soil drench**



**Neonicotinoids for emerald ash borer (and other flatheaded borers)**



**Dinotefuran as a bark spray**





Retail formulation

# Dinotefuran formulations

## Commercial formulations for ornamentals



DoMyOwnPestControl.com



# Dinotefuran Characteristics and Niche

- **Advantages**

- Rapid uptake

- Mobile in plant

- Capable of trunk spray use

- **Limitation**

- High risk for pollinators

# Soil Systemic Insecticides and Scale Insects?

- Imidacloprid (Merit, Mallet, Zenith, etc.)
  - ***Soft scales only***
- Dinotefuran (Safari, Zylam, Transtect)
  - ***Soft scales and armored scales***



**Dinotefuran  
Control Range**

**Yes – Soft Scale**



**Yes – Armored  
Scale**

Pine needle scale



Oystershell scale



## Armored Scales Family Diaspididae

Poplar/willow scale



Black pineleaf scale





**Basal trunk spray with  
dinotefuran (Safari, Zylam)**



**Whole tree sprays  
produce surface  
residues on all foliage.  
Natural enemies are  
killed. Natural  
controls are wasted.**



**Treatment area limited  
to bark of lower trunk.  
Impacts on natural  
enemies are minimized**



Commercial formulation for ornamentals



Retail formulations



# Acetamiprid products

Commercial formulation for fruits and vegetables



# Acetamiprid Characteristics and Niche

- **Advantages**

- Stable in UV
- Good on caterpillars
- Fairly mobile in plant
- Low toxicity to honey bees

- **Limitation**

- Not suitable for soil application



Acetamiprid can be used as a systemic insecticide to be sprayed





## ***Ryania speciosa***

Botanical source that lead to development of the anthranilic diamides

**Powdered stems are the source of the insecticide ryania.**

**Active ingredient: ryanodine**



# Anthranilic Diamides

- **Based on chemistry of active compounds in ryania (ryanodines)**
  - **Effects ryanodine receptors associated with insect muscle**
- **Some systemic activity in plants**
- **Extremely low toxicity to mammals (Category IV)**
- **Recently registered products:**
  - **chlorantraniliprole (Acelepryn)**
  - **cyantraniliprole (Ference – *turfgrass label only*)**

# Anthranilic Diamides

- Based on chemistry of active compounds in ryania (ryanodines)
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  - chlorantraniliprole (Acelepryn)
  - cyantraniliprole (Ference – *turfgrass label only*)

# Chlorantraniliprole

(Acelepryn, Grub-Ex)



## HAZARDS TO HUMANS AND DOMESTIC ANIMALS

When used as directed this product does not present a hazard to humans or domestic animals.

### Personal Protective Equipment

Applicators and other handlers must wear:

- Long-sleeved shirt and long pants.
- Shoes plus socks.

**Applicator caution with chlorantraniliprole/Acelepryn**

**Class IV Toxicity – No Caution Label**

**No cautionary language for protection of bees**

**TABLE 3: Foliar Ornamental Application Rates**

| Acelepryn Ornamental Foliar Application Rates   |                                 |                       |      |                     |                                   |
|---|---------------------------------|-----------------------|------|---------------------|-----------------------------------|
| Target Pests  | Product (fl oz) per 100 Gallons | Lb AI per 100 Gallons | PPM  | Percent AI (wt/vol) | Maximum Gallons per Acre per Year |
| Leaf-feeding caterpillars (such as bagworms and tussock moth caterpillars [including whitemarked tussock moth]) | 1                               | 0.013                 | 15.6 | 0.00156             | 3840                              |
|   | 2                               | 0.026                 | 31.3 | 0.00313             | 1920                              |
|   | 4                               | 0.052                 | 62.5 | 0.0625              | 960                               |
|   | 8                               | 0.104                 | 125  | 0.0125              | 480                               |
| For maximum residual control of the pests listed above  | 16                              | 0.208                 | 250  | 0.025               | 240                               |

**Soil Applications:**

Acelepryn is a systemic product and will be translocated upward into the plant from root uptake. Soil treatment application rates are listed in Table 4. To assure optimum effectiveness, the product

The original federal label just includes certain caterpillars as target pests

Section 2(ee) recommendation indicates uses for control of many other insects – including Japanese beetle adults

**Section 2(ee) Recommendation**

**Effective:** 07/10/2015      **Expires:** 11/19/2018

AK1489002BC0715 Additional Pests of Ornamental Plants (Exterior Landscapes and Interior Plantscapes) in AK, AL, AR, AZ, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, OH, OK, PA, RI, SC, SD, TN, UT, VA, VT, WA, WI, WV and WY

**For Use**                      Banded ash clearwing, Fall webworm, Gypsy moth caterpillars, Hemlock Woolly Adelgid, Japanese beetle (adult), Lesser peachtree borer, Magnolia scale, Rhododendron borer, Rhododendron lace bug, Sawfly, Viburnum borer, Zimmerman pine moth

**Against:**

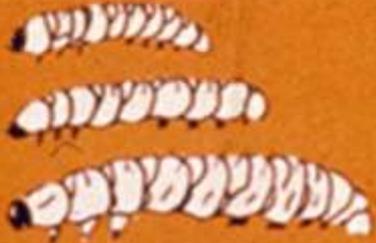
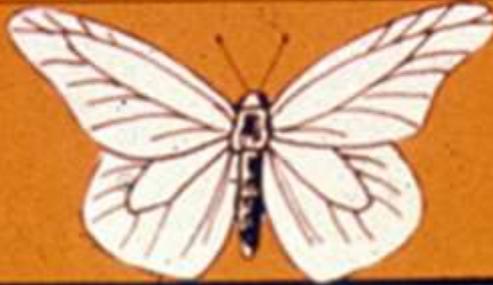
# Chlorantraniliprole Niche

- **Very low hazard to vertebrates**
- **Very low hazard to bees**
- **Target pests include:**
  - All leaf chewing caterpillars
  - Wood borers that are caterpillars
  - Leaf chewing beetles, including Japanese beetle
  - White grubs in lawns

# Insect Growth Regulators (IGRs)

- Affect growth processes of arthropods/disrupt hormones
- Diverse chemistry, mode of action
  - *Mimic/disrupt molting hormone (ecdysone)*
  - *Mimic/disrupt juvenile hormone*
  - *Prevent normal chitin synthesis*

# INTERACTION OF ECDYSONE - JH IN REGULATING GROWTH AND METAMORPHOSIS

| ecdysone  | JH  | Development  |
|---|---|--|
|    |    |  <p data-bbox="1130 442 1787 678">immature characters maintained during larval stages</p> |
|    |    |  <p data-bbox="1130 721 1787 892">tissue differentiation during pupal stage</p>          |
|  |  |  <p data-bbox="1130 1021 1787 1178">tissue differentiation completed</p>                |



# Colorado Potato Beetle

Larva



Pupa



**Potato beetles (top row) killed by IGR insecticide that prevented successful molting to pupal stage**



# **Insect Growth Regulators (IGRs)**

- **Acute Toxicity to Humans: Low**
- **Non-target Effects:**
  - **Birds: Low toxicity**
  - **Fish: Low toxicity**
- **Most are highly selective in effects on beneficial insects**

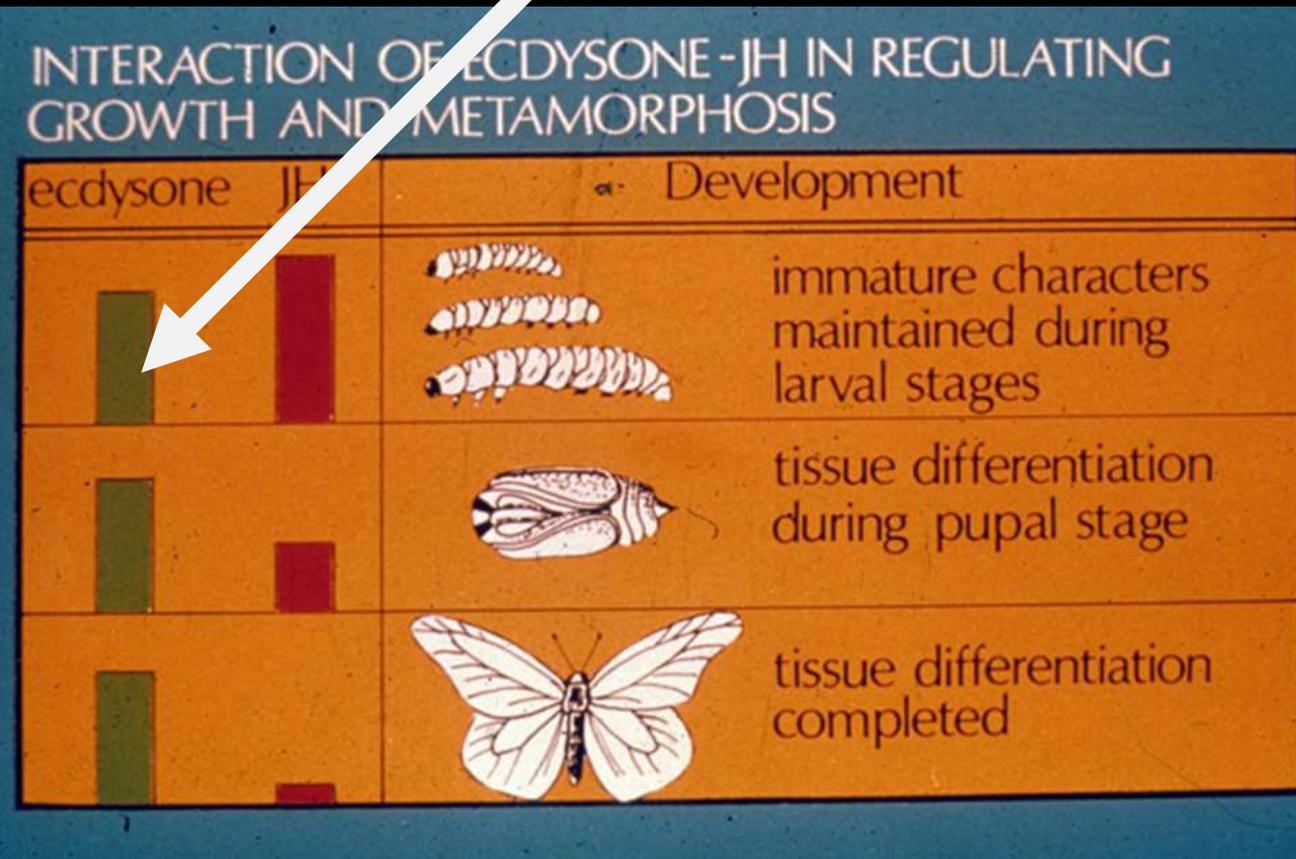


# *Azadirachtin indica (Neem)*

Neem seed extracts  
contain the active  
ingredient azadirachtin



# Azadirachtin affects the molting hormone ecdysone



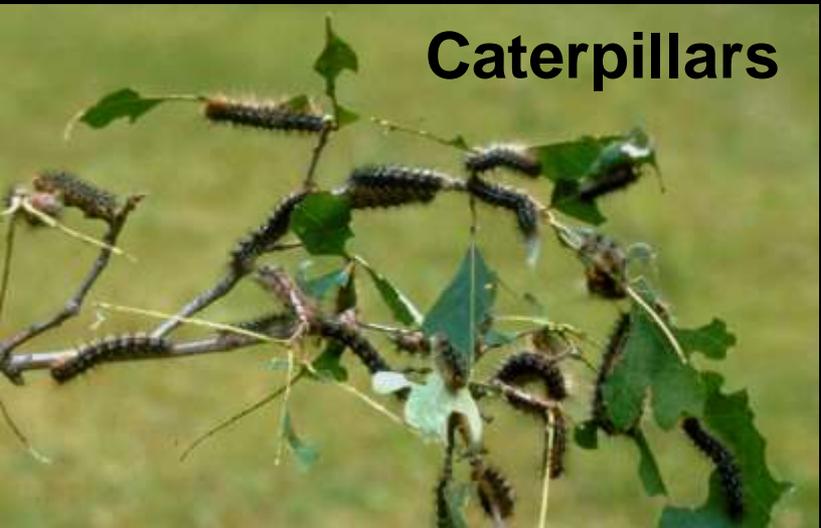
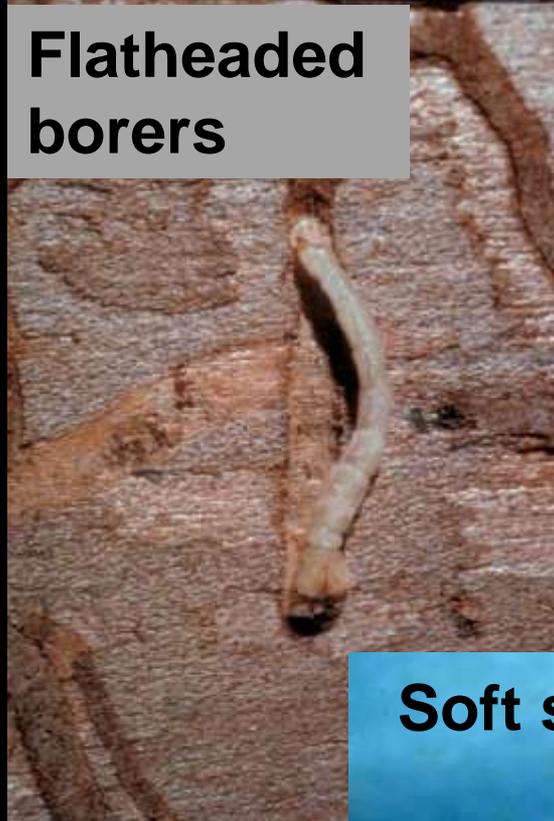
This disrupts many things including ability to molt and to reproduce successfully.

# Some target pests of azadirachtin



Leaf beetles

Flatheaded borers



Caterpillars

Soft scales



# Neem

- Active Ingredients: **Azadirachtin** primarily, oil fractions have some uses.
- Disrupts the molting hormone (ecdysone) of susceptible insects

Whole  
neem seed  
extract



Neem oil -  
Oil fraction  
only



**Examples of products that contain azadirachtin – but no neem oil**



Examples of products that contain the oil fraction from neem seed extracts, but has had the azadirachtin removed



# Horticultural Oils



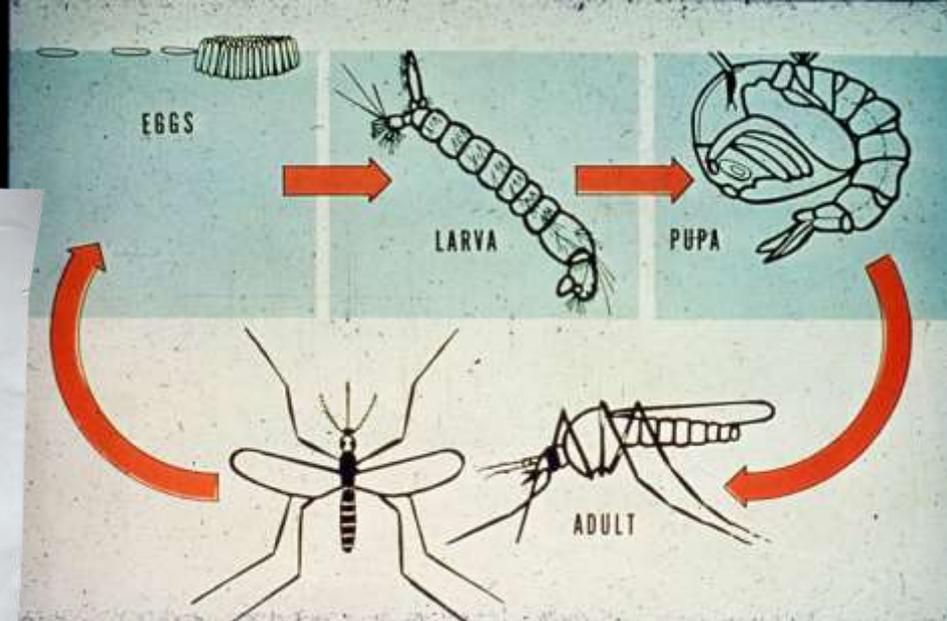
## Mineral oils

Horticultural oils may also be derived from **cottonseed**, **soybean**, **neem seed**, **sesame**, **fish**, and many other sources



## Neem seed oils

# Methoprene



## A juvenile hormone-derived insecticide





# Mosquito Life Cycle

Adult (left)

Larvae/wrigglers (lower left)

Pupae/tumblers (below)





# Pyriproxifen

**Mimics juvenile hormone.**

**Target pests: Scale insects, whiteflies, aphids (suppression)**

**Special Colorado Niche: *A selective insecticide for use on scale insects***

**Excellent against neonicotinoid-resistant European elm scale**

# Microbial Insecticides

- **Microbes Used as Insecticides**
  - **Bacteria**
  - **Viruses**
  - **Fungi**
    - **Microsporidia**
- **Insecticides Derived from Microbes**

# *Bacillus thuringiensis*

- Derived from a widely distributed soil bacterium
- Active ingredient a toxic protein crystal that destroys cells of the midgut
- Used as a stomach poison



# Treated Foliage Consumed



## Feeding Inhibition ( 1 Hour )

- **Toxin Crystals Dissolve in Gut.**
- **Larvae Stop Feeding.**
- **Growth Stops.**

**Insect Gut**



# Death (2-5 Days)



- Starvation
- Gut Disruption



# *Bacillus thuringiensis* var. *kurstaki* and *B.t.* var. *aizawai*



Used to control leaf feeding caterpillars

# *Bacillus thuringiensis* *var. israelensis*



Used to control larvae of certain kinds of flies (e.g., mosquitoes, fungus gnats, black flies)



**beetle GONE!** Target the pest!  
BIOLOGICAL INSECT CONTROL WATER DISPERSIBLE FORMULA

**Natural & Safer**  
Will Not Harm Pets or Wildlife



Controls Various Beetles, Weevils & Borers  
To Prevent Damage to Your Garden & Trees

FOR ORGANIC GARDENING

KEEP OUT OF REACH OF CHILDREN  
CAUTION

See back panel for additional precautionary statements,  
directions for use and storage and disposal.



Manufactured By:  
**PhylloM BioProducts**

ACTIVE INGREDIENT: *Bacillus thuringiensis* subsp. *galleriae*, Strain SDS-502 fermentation solids, spores and insecticidal toxin\*.....78.5% w/w  
OTHER INGREDIENTS:.....23.5% w/w  
TOTAL.....100.0% w/w

\*Contains a minimum of  $0.85 \times 10^{10}$  CFU per gram.

***Bacillus thuringiensis***  
**var. *galleriae***

A newly developed strain of Bt that can control adult Japanese beetles - and can be used on plants in flower!

# Key problem with control of Japanese beetle adults on many plants

Overlap of adult feeding on flowers – *and use of those flowers by pollinators*



***Never apply persistent insecticides to plants that are in flower and attractive to pollinators!!***





Treated with *Bacillus thuringiensis* var. *galleriae*

Water check





**Bacillus  
thuringiensis va.  
galleriae for adult  
Japanese beetle?**

Provides **good reduction** in feeding injury by Japanese beetle

Provides **fair mortality** of Japanese beetles and mortality is slow

Persistence of effects probably **a few days**



**Bee hazard warnings  
and use restrictions?**



**None. You can apply this  
product to plants in bloom  
when bees are visiting.**

**After application:**

**Are they dead?**

**(probably not)**

**Are they still feeding?**

**(probably not)**



# Controls Most Effective for Control of Japanese Beetle Adults.....

- ~~Most pyrethroids (e.g., cyfluthrin, permethrin, bifenthrin)~~
- ~~Carbaryl~~
- ~~Imidacloprid~~
- ~~Acetamiprid~~
- Chlorantraniliprole
  - Acelepryn
- *Bacillus thuringiensis var. galleriae*
  - BeetleGON
  - BeetleJUS



Do not treat  
plants with  
flowers in  
bloom!

....and can be used on plants in bloom!

# Microbial Insecticides

- **Microbes Used as Insecticides**
  - **Bacteria**
  - **Viruses**
  - **Fungi**
    - **Microsporidia**
- **Insecticides Derived from Microbes**

# Spinosad

- **Microbial derived insecticide (spinosyns)**
  - Secreted by a bacterium (*Saccharopolyspora spinosa*)
- **Low mammalian toxicity**
  - Low hazard to most beneficial insect
  - Some formulation allowed in Certified Organic production
- **Target Species**
  - Leaf chewers (caterpillars, beetles, sawflies)
  - Thrips

# Some Spinosad Formulations

Turfgrass, ornamentals, many fruits and vegetables



Agricultural label - Organic



Agricultural label



One of many products sold through nurseries



Caterpillars



Sawflies



Some insects that are well-controlled by spinosad

Leaf beetle larvae



Thrips



"WORKS LIKE A CHARM"

**MAGIC**<sup>®</sup>

BRAND

**PEST SCOURGE**

INSECTS

MITEs

WEEDS

- KILLS EVERYTHING
- USE ON ALL PLANTS
- WORKS INSTANTLY
- COMPLETELY SAFE

DISEASES

ITS AGENTS

RODENTS



# There are over two dozen modes of action of insecticides and miticides



## IRAC - Insecticide Mode of Action Classification

Insecticide Resistance Action Committee [www.irac-online.org](http://www.irac-online.org)

### Introduction

Insecticide Resistance Action Committee [IRAC] promotes the use of a Mode of Action (MoA) classification of insecticides as the basis for effective and sustainable insecticide resistance management (IRM). Insecticides are allocated to specific groups based on their target site. Reviewed and re-issued periodically, the IRAC MoA classification list provides farmers, growers, advisors, extension staff, consultants and crop protection professionals with a guide to the selection of insecticides or acaricides in IRM programs. Effective IRM of this type preserves the utility and diversity of available insecticides and acaricides. Sample MoA groups are shown below.

### Effective IRM strategies: Sequences or alternations of MoA

All effective insecticide resistance management (IRM) strategies seek to minimise the selection of resistance to any one type of insecticide. In practice, alternations, sequences or rotations of compounds from different MoA groups provide sustainable and effective IRM for pest Lepidoptera. This ensures that selection from compounds in the same MoA group is minimised, and resistance is less likely to evolve.

Applications are often arranged into MoA spray windows or blocks that are defined by the stage of crop development and the biology of the pest species of concern. Local expert advice should always be followed with regard to spray windows and timings. Several sprays may be possible within each spray window but it is generally essential to ensure that successive generations of the pest are not treated with compounds from the same MoA group. Metabolic resistance mechanisms may give cross-resistance between MoA groups, and where this is known to occur, the above advice must be modified accordingly. IRAC also provides general recommendations for resistance management tactics regarding specific MoA groups, e.g. neonicotinoids (Group 4A).



### Growth & Development targets

- Group 7 Juvenile hormone mimics
- 7A Juvenile hormone analogues (e.g. Methoprene)
- 7B Fenoxycarb, 7C Pyriproxyfen
- Group 10 Mite growth inhibitors
- 10A Clofentazine, Hexythiazox, 10B Etoxazole
- Group 15 Inhibitors of Chitin biosynthesis, Type 0
- Benzoyleurea (e.g. Flufenoxuron, Novaluron)
- Group 16 Inhibitors of chitin biosynthesis, type 1
- Buprofezin
- Group 17 Moulting disruptor, Dipteran Cyromazine
- Group 18 Ecdysone agonists / moulting disruptors
- 18 Diacylhydrazines (e.g. Methoxyfenozide, Tebufenozide)

### Nerve & Muscle Targets

- Group 1 Acetylcholinesterase (AChE) inhibitors
- 1A Carbamates (e.g. Thiodicarb),
- 1B Organophosphates (e.g. Chlorpyrifos)
- Group 2 GABA-gated chloride channel antagonists
- 2A Cycloidiene Organochlorines (e.g. Endosulfan),
- 2B Phenylpyrazoles (e.g. Fipronil)
- Group 3 Sodium channel modulators
- 3A Pyrethrins, Pyrethroids (e.g. Cypermethrin,  $\lambda$ -Cyhalothrin)
- Group 4 Acetylcholine receptor (nAChR) agonists
- 4A Neonicotinoids e.g. Imidacloprid, Thiamethoxam)
- 4C Sulfoxaflor, 4D Flupyradifurone
- Group 5 Nicotinic acetylcholine receptor channel agonists (Allosteric)
- Spinosyns (e.g. Spinosad, Spinetoram)
- Group 6 Chloride channel activators Avermectins (e.g. Abamectin, Emamectin benzoate, Lepimectin)
- Group 9 Modulators of Chordotonal Organs
- 9B Pymetrozine, 9C Flonicamid
- Group 14 Nicotinic acetylcholine receptor channel blockers Nereistoxin analogs (e.g. Cartap hydrochloride)
- Group 19 Octopamine receptor agonists Amitraz
- Group 22 Voltage dependent sodium channel blockers
- 22A Indoxacarb, 22B Metaflumizone
- Group 28 Ryanodine receptor modulators
- Dismides (e.g. Flubendiamide, Chlorantraniliprole, Cyantraniliprole)



### Respiration targets

- Group 12 Inhibitors of mitochondrial ATP synthesis
- 12A Difenthiuron, 12B Organotin miticides (e.g. Cyhexatin), 12C Propargite, 12D Tetraifon
- Group 13 Uncouplers of oxidative phosphorylation via disruption of H proton gradient Chlorfenapyr
- Group 20 Mitochondrial complex III electron transport inhibitors
- 20A Hydramethylinon, 20B Acequinolyl,
- 20C Flucrypyrim
- Group 21 Mitochondrial complex I electron transport inhibitors
- 21A METI acaricides (eg. Pyridaben, Tebufenpyrad)
- Group 23 Inhibitors of acetyl CoA carboxylase
- Tetronic & Tetramic acid derivatives (e.g. Spirodiclofen)
- Group 25 Mitochondrial complex II electron transport inhibitors Cyenopyrafen, Cyflumetofen

### Midgut Targets

- Group 11 Microbial disruptors of insect midgut membranes
- 11A *Bacillus thuringiensis*
- 11B *Bacillus sphaericus*

### Unknown

- UN Compounds of unknown or uncertain mode of action (e.g. Azadiractin, Bifenazate, Pyridatyl, Pyrifluquinazon),

# Insecticide Resistance Action Committee (IRAC) Web Site

<http://www.irc-online.org/>

**Check the section on Mode of Action to learn of the various classes of insecticides that have been developed**

**Presently there are 28 insecticide groups recognized with different modes of action.**

# **This presentation will be posted at the Insect Information Website**

- **Housed at** Department of  
Bioagricultural Sciences and Pest  
Management
  - **Search** “BSPM CSU”
- **Within** “Entomology”
- “Insect Information”
  - **Extension presentations are posted at the  
bottom of the page, most recent at end**

### Insect Information

All materials needed in another accessible format can be made available upon request.

#### Arthropods of Colorado Fact Sheets

This is a listing of about 200 downloadable fact sheets related to insects and other "bugs" found in Colorado. It contains fact sheets that are written for the Colorado Arthropods of Interest series and the Extension fact sheets that are related to insects.

Fact Sheets

#### Miscellaneous Insect Information

This contains a variety of downloadable fact sheets and pamphlets on diverse miscellaneous subjects, from "Bug Mugs" and "Life in a Colorado Water Garden" to "Mystery Bites and Itches" and "Commercially Available Sources of Biological Control Organisms: Sources and Uses in Colorado."

Resources

#### Some Entomology Hot Links:

- Colorado Hemp Insect Website
- Western Colorado Entomology Website
- IPM Images/Bugwood (Cranshaw)
- IPM Images/Bugwood (Pearls)
- Entomology Resources List
- Honey Bee Swarm Hotlines



# Top of the Insect Information Website

# Bottom of the Website page

#### Hemp Insect Information

This links directly to the Hemp Insect Website, which includes information being developed to better recognize and manage insects associated with industrial hemp.

Hemp Insect Website

#### Master Gardener Information

This includes the handouts and PowerPoint presentations (as PDF) used in Master Gardener Entomology training. These will get updated annually at the end of the winter/spring training programs.

- Handouts
- PowerPoint Presentations Used in 2018

#### Recent Extension Presentations

This is a listing that provides the PowerPoint presentations (as PDF) of most Extension entomology programs conducted during the past 12 months.

PowerPoint Presentations/Webinars





# Thank you!

[whitney.cranshaw@colostate.edu](mailto:whitney.cranshaw@colostate.edu)