Insecticide Resistance Action Committee

Insecticide Resistance Management Guidelines for Lepidopteran Pests

2019 v.2.4

IRAC Lepidopteran Working Group

IRAC (Insecticide Resistance Action Committee) International Structure and Working Groups

Charter: Champion principles that reduce insecticide selection pressure on pest populations to sustain agriculture. Lead industry experts in sponsoring research and educational outreach on Insecticide Resistance Management.

10 Member Companies (6 Crop Life)

- AgBiTech
- ADAMA
- BASF We create chemistry
- BAYER
- CORTEVA agriscience
- FMC
- MITSUI CHEMICALS AGRO, INC.
- NIHON NOHYAKU CO.,LTD.
- SUMITOMO CHEMICAL
- syngenta

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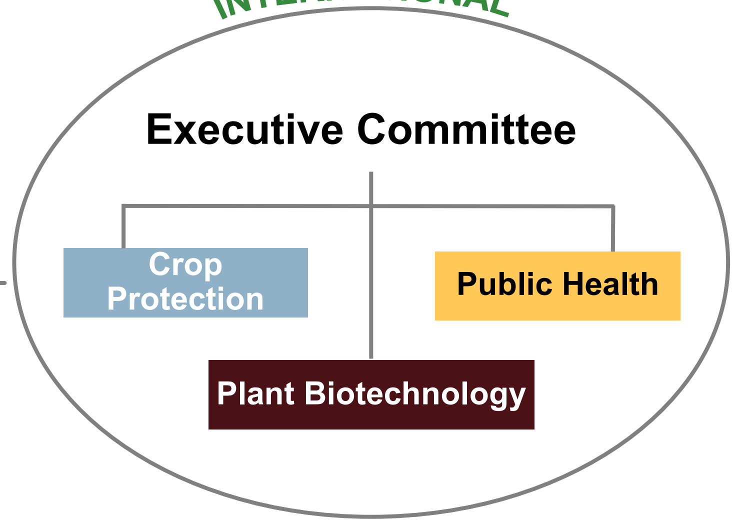

IRAC Country Groups

IRAC Spain	IRAC Brasil	IRAC S.Africa
IRAC Australia	IRAC SE Asia	IRAC India
IRAC USA	IRAC Philippines	IRAC Argentina

- Steering Group
- Outreach
- R. Database (MSU)
- Methods
- Mode of Action
- Public Health
- Biotechnology
- Coleoptera
- Sucking Pest
- Lepidotpera

Lepidoptera Insecticide Mode of Action Classification:

A key to effective insecticide resistance management

IRAC
Insecticide Resistance Action Committee

www.irac-online.org

Introduction and background

The agrochemical industry has developed a broad range of very effective insecticides for the control of lepidopteran pests. Unfortunately, as a consequence of the misuse or overuse of these insecticides, many species have developed resistance. Populations of *Plutella xylostella*, for example, have developed resistance to virtually every insecticide used against them. Additionally, there are numerous other species prone to resistance development. In recent years the industry has worked especially hard to develop new types of insecticides with novel modes of action, but this process is becoming ever harder and more costly. It is therefore vital that effective insecticide resistance management (IRM) strategies are implemented, to ensure that resistance does not develop to these new compounds, or to older chemistries that are still effective.

In order to help prevent or delay the incidence of resistance, IRAC promotes the use of a Mode of Action (MoA) classification of insecticides in effective and sustainable IRM strategies. Available insecticides are allocated to specific groups, based on their target site, as described below. By using sequences or alternations of insecticides from different MoA classes, resistance is less likely to occur. Available at the IRAC website www.irac-online.org, this IRAC MoA classification list provides farmers, growers, advisors, extension staff, consultants and crop protection professionals with a guide to the selection of insecticides in IRM programs.

Effective IRM strategies: Sequences or alternations of MoA

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.

Example:

MoA w	MoA x	MoA y	MoA z	MoA w	MoA x

Sequence of insecticides through season

Applications are often arranged into MoA spray windows or blocks that are defined by the stage of crop development and the biology of the lepidopteran species of concern. Local expert advice should always be followed with regard to spray windows and timing. Several sprays may be possible within each spray window, but it is generally essential 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; where this is known to occur, the above advice should be modified accordingly.

Nerve and Muscle Targets

Most current insecticides act on nerve and muscle targets. These insecticides are generally fast acting.

***Group 1* Acetylcholinesterase (AChE) inhibitors**
Inhibit AChE, causing hyperexcitation. AChE is the enzyme that terminates the action of the excitatory neurotransmitter acetylcholine at nerve synapses.
1A Carbamates (e.g. Methomyl, Thiodicarb) **1B** Organophosphates (e.g. Chlorpyrifos)

***Group 2* GABA-gated chloride channel blockers**
Block the GABA-activated chloride channel, causing hyperexcitation and convulsions. GABA is the major inhibitory neurotransmitter in insects.
2A Cyclodiene Organochlorines (e.g. Endosulfan) **2B** Phenylpyrazoles (e.g. Fipronil)

***Group 3* Sodium channel modulators**
Keep sodium channels open, causing hyperexcitation and, in some cases, nerve block. Sodium channels are involved in the propagation of action potentials along nerve axons.
3A Pyrethrins, Pyrethroids (e.g. Cypermethrin, λ-Cyhalothrin)

***Group 4* Nicotinic acetylcholine receptor (nAChR) competitive modulators**
Bind to the acetylcholine (ACh) site on nAChRs, causing a range of symptoms from hyper-excitation to lethargy & paralysis. ACh is the major excitatory neurotransmitter in the insect central nervous system.
4A Neonicotinoids (e.g. Acetamiprid, Thiacloprid, Thiamethoxam)

***Group 5* Nicotinic acetylcholine receptor (nAChR) allosteric modulators, Site 1**
Allosterically activate nAChRs (at SiteI), causing hyperexcitation of the nervous system. Acetylcholine is the major excitatory neurotransmitter in the insect central nervous system.
Spinosyns (e.g. Spinosad, Spinetoram)

***Group 6* Glutamate-gated chloride channel (GluCl) allosteric modulators**
Allosterically activate glutamate-gated chloride channels (GluCls), causing paralysis. Glutamate is an important inhibitory neurotransmitter in insects.
Avermectins, Milbemycins (e.g. Abamectin, Emamectin benzoate, Lepimectin)

***Group 14* Nicotinic acetylcholine receptor (nAChR) channel blockers**
Block the nAChR ion channel, resulting in nervous system block and paralysis. Acetylcholine is the major excitatory neurotransmitter in the insect central nervous system.
Bensultap, Cartap

***Group 22* Voltage-dependent sodium channel blockers**
Block sodium channels, causing nervous system shutdown and paralysis. Sodium channels are involved in the propagation of action potentials along nerve axons.
22A Indoxacarb **22B** Metaflumizone

***Group 28* Ryanodine receptor modulators**
Activate muscle ryanodine receptors, leading to contraction and paralysis. Ryanodine receptors mediate calcium release into the cytoplasm from intracellular stores.
Diamides (e.g. Chlorantraniliprole, Cyantraniliprole, Cyclaniliprole, Flubendiamide)

***Group 30* GABA-gated chloride channel allosteric modulators**
Allosterically block the GABA-activated chloride channel, causing hyperexcitation and convulsions.
Meta-diamides (e.g. Broflanilide)

***Group 32* Nicotinic acetylcholine receptor (nAChR) allosteric modulators, Site II**
Allosterically activate nAChRs (at site II), causing hyperexcitation of the nervous system. Acetylcholine is the major excitatory neurotransmitter in the insect central nervous system.
GS-omega/kappa HXTX-Hv1a Peptide

Midgut Targets

Lepidopteran-specific microbial toxins that are sprayed or expressed in transgenic crops.

***Group 11* Microbial disruptors of insect midgut membranes**
Protein toxins that bind to receptors on the midgut membrane and induce pore formation, resulting in ionic imbalance and septicemia.
***11A** Bacillus thuringiensis*
***11B** Bacillus sphaericus*

***Group 31* Host-specific occluded pathogenic viruses**
Host-specific occluded pathogenic viruses
Granuloviruses, Nucleopolyhedroviruses

Respiration Targets

Mitochondrial respiration produces ATP, the molecule that energizes all vital cellular processes. In mitochondria, an electron transport chain uses the energy released by oxidation to charge a proton gradient battery that drives ATP synthesis. Several insecticides are known to interfere with mitochondrial respiration by the inhibition of electron transport and/or oxidative phosphorylation. Insecticides that act on individual targets in this system are generally fast to moderately fast acting.

***Group 13* Uncouplers of oxidative phosphorylation via disruption of the proton gradient**
Protonophores that short-circuit the mitochondrial proton gradient so that ATP can not be synthesized.
Chlorfenapyr

***Group 21* Mitochondrial complex I electron transport inhibitors**
Inhibit electron transport complex I, preventing the utilization of energy by cells.
21A Tolfenpyrad

Growth and Development Targets

Insect development is controlled by the balance of two principal hormones: juvenile hormone and ecdysone. Insect growth regulators act by mimicking one of these hormones or by directly affecting cuticle formation/deposition or lipid biosynthesis. Insecticides that act on individual targets in this system are generally slowly to moderately slowly acting.

***Group 7* Juvenile hormone mimics**
Applied in the pre-metamorphic instar, these compounds disrupt and prevent metamorphosis.
7B Juvenile hormone analogues (e.g. Fenoxycarb)

***Group 15* Inhibitors of chitin biosynthesis affecting CHS1**
Incompletely defined mode of action leading to inhibition of chitin biosynthesis.
Benzoylureas (eg. Flufenoxuron, Lufenuron, Novaluron)

***Group 18* Ecdysone receptor agonists**
Mimic the moulting hormone, ecdysone, inducing a precocious molt.
Diacylhydrazines (e.g. Methoxyfenozide, Tebufenozide)

Unknown

***Group UN* Compounds of unknown or uncertain MoA**
Azadirachtin, Pyridalyl

***Group UNB* Bacterial agents (non-Bt) of unknown or uncertain MoA**
Burkholderia spp

***Group UNF* Fungal agents of unknown or uncertain MoA**
Beauveria bassiana, Paecilomyces fumosoroseus

Targeted Physiology: Rotations for resistance management should be based only on the numbered mode of action groups.

Nerve & Muscle | Growth & Development | Respiration | Midgut | Unknown or Non-specific

Designed & produced by IRAC MOA Team, January 2019,
Poster Version 5, Based on MoA Classification Version 9.1
Photograph courtesy of Nigel Armes
For further information visit the IRAC website: www.irac-online.org ,

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1. IRAC Member Companies are Responsible to Include Clearly Understandable IRM Information on Product Labels.

INSECTICIDE MANUFACTURERS SHOULD INCLUDE BASIC IRM ELEMENTS ON PRODUCT LABELS	
IRM ELEMENTS	**MINIMAL LABEL RECOMMENDATION**
1). MODE OF ACTION NUMBER AND CHEMICAL CLASS	• Place the IRAC MoA labeling on the first page (number and icon) … GROUP 1A INSECTICIDE GROUP 22 INSECTICDE GROUP 4 INSECTCIDE • If prohibited from first page then place the MoA icon and number in the Resistance Management label text. • State the chemical class of active ingredient(s) in label text.
2). MAXIMUM NUMBER OF APPLICATIONS	State the maximum number of product applications for each crop on the label per cropping season or per year
3). QUALITY LABEL IRM STATEMENT	**Contains at least the 3 'REQUIRED' components for a quality label IRM statement.** 1. State the IRAC MoA Number 2. Rotate products with different Modes of Action 3. Provide guidance to avoid treating consecutive generations with the same MoA.

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Additional Guidance: Product Label Format for Mode Action Number and Icon

Include the MOA classification on the label. Preferably place by the list of ingredients on the first page of the label or within the IRM statement, if permitted by local regulatory label guidelines.

Example 1: Solo Mode of Action

Example 1

Insecticide A® 20SC

Active ingredient: [Compound name]

Formulation details

GROUP	28	INSECTICIDE

Example 2: Mixture of 2 or more Modes of Action

Example 2

Insecticide B® 25SC

Active ingredients: [Compound names]

Formulation details

GROUP	3	INSECTICIDE
GROUP	28	INSECTICIDE

Example 3: Modes of Action with Sub-Groups

Note:

- When a product has two or more modes of action, use appropriate identifier numbers for each active ingredient.
- Letters representing the sub-group should be the same size as the MoA number.
- Letters should be capitalized.

Without Sub-Groups	With Sub-Groups
GROUP 11 INSECTICDE	GROUP 11A INSECTICDE
GROUP 22 INSECTICDE GROUP 4 INSECTCIDE	GROUP 22A INSECTICDE GROUP 4B INSECTCIDE

1. IRAC Member Companies are Responsible to Include Clearly Understandable IRM Information on Product Labels.

Examples of Insecticide Resistance Management (IRM) statements for inclusion in product labels

Include an IRM statement on the label. Propose the most comprehensive IRM statement legally permitted by local regulations. Two examples provided.

Example 1 – Short Version: Insecticide Resistance Management (IRM) - General Recommendations

- ____ (product name) contains _____ (active ingredient name), a Mode of Action Group Number XX Insecticide representing ____ chemistry.
- Avoid treating consecutive generations of the target pest with products having the same mode of action. Apply ____ (product name) using a "window" approach (duration of an insect generation or approximately 30 days). Rotate blocks of treatments with ____ (product name) or products with the same mode of action followed by blocks of treatments with other effective products with different modes of action. For short cycle crops (< 50 days), consider the duration of the crop cycle as a "window", thus alternate to different modes of action during subsequent plantings at the same farm location.

Example 2 – Comprehensive Version: Insecticide Resistance Management (IRM) – General Recommendations

- A resistance management strategy should be established for the defined crop area; including cultural and biological control practices, alternation of different mode of action insecticides, appropriate application timings and adequate spray volumes, to achieve the optimum crop coverage and pest mortality.
- Do not exclusively use ______(Product Name) and other products representing ___ chemistry with Mode of Action Group Number XX throughout a crop cycle. Apply____ (Product Name) and Group XX insecticides within a Window* to avoid exposure of consecutive insect pest generations to the same mode of action.
- * A window is defined by the duration of an insect generation or approximately 30 days. The period of residual activity provided by a single or sequence of product applications with the same mode of action should fit within a single insect generation window. Multiple applications of the same MoA insecticide are acceptable if they are used to treat a single insect generation or are used within a window.
- The use of multiple modes of action within a window is recommended. Following a window of any mode of action group, rotate to a window of applications of effective insecticides with different modes of action.
- For short cycle crops (<50 days), consider the duration of the crop cycle as a window, so it is recommended to alternate to different modes of action within the next crop cycle.
- As a general rule, the total exposure period of all windows with the same MoA applied throughout the crop cycle (from seedling to harvest) should not exceed 50% of the crop cycle. The total number of insecticide applications of the same MoA should not exceed 50% of the total number of insecticide applications targeted against the same pest species.
- Avoid using less than label rates of _____ (Product Name) when applied alone or in tank mixtures.
- Target the most susceptible insect life stages whenever possible.
- Monitor insect populations and apply at the most effective timing. If the insecticide gives weaker performance than expected, which cannot be attributed to factors such as poor application or adverse weather conditions, suspect a resistant strain of the insect may be present.

2. Use products at the recommended label rates and spray intervals with appropriate and maintained application equipment.

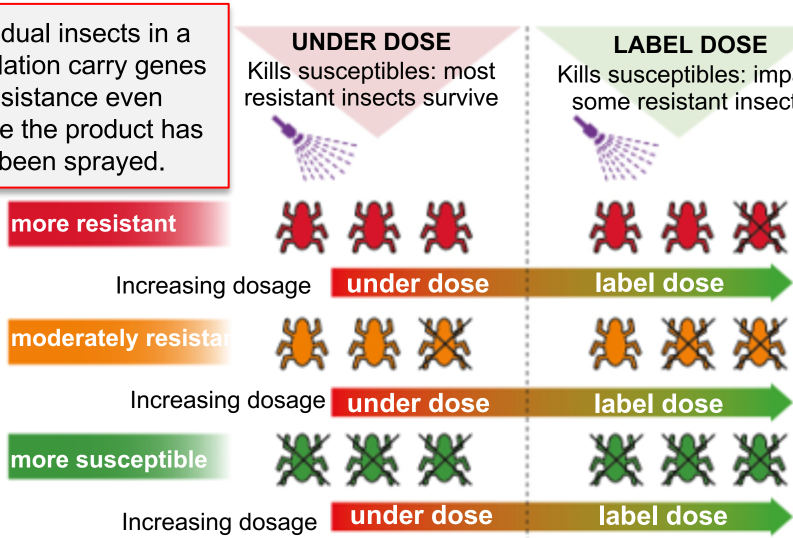
Example: Label Directions For Use

- **Follow recommended rate, interval between sprays, and application timing.**

Crop	Pest	Product use rate		Spray Volume	Spray Interval and Number of Applications/Season
		per 10 liter water	Per ha	Per ha	
Chilli	Fruit borer (Helicoverpa armigera, Spodoptera litura, Spodoptera exigua)	3 ml	150 ml	500 Liter	Spray at first egg lay Minimum interval between treatments is 7 days. Do not exceed 2 sprays in a crop season

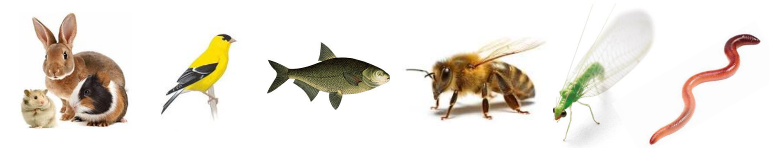
- Under-dosed applications can accelerate resistance.

Individual insects in a population carry genes for resistance even before the product has ever been sprayed.



! Always apply insecticides at recommended label rates to control susceptible, some moderately resistant and even a portion of the more resistant insects.

- Over-dosed applications may impact non-target organisms.

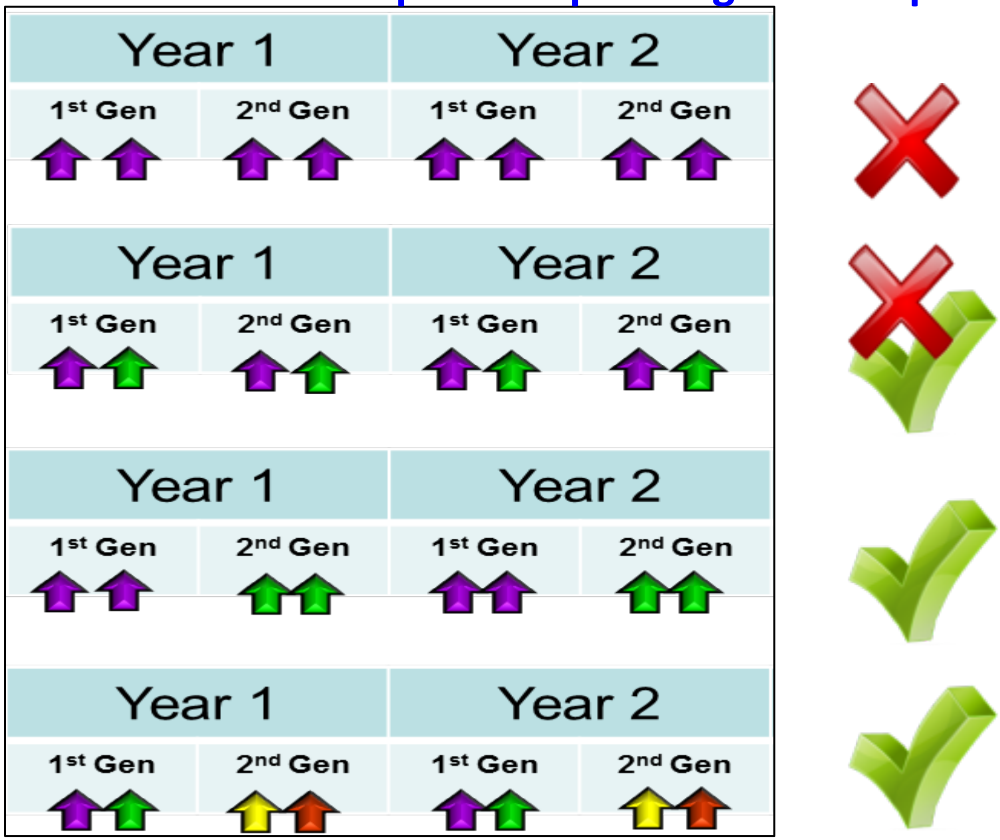


- Maintain spray equipment to deliver accurate rate to target area.

3. Rotation of insecticide MoA groups prevents rapid selection of resistant populations.

- **Avoid selection for insecticide resistance by rotating insecticide modes of action used within and between pest generations.**
- **Use products of the same MoA within a discrete period of time commonly called a 'window'. A window is defined by the duration of an insect generation or approximately 30 days. The period of residual activity provided by a single or sequence of product applications with the same mode of action should fit within a window.**

MoA Rotation Concept: Examples of good and poor IRM rotation practices:



No Alternation/Rotation
High selection pressure.
No recovery of sensitive population.

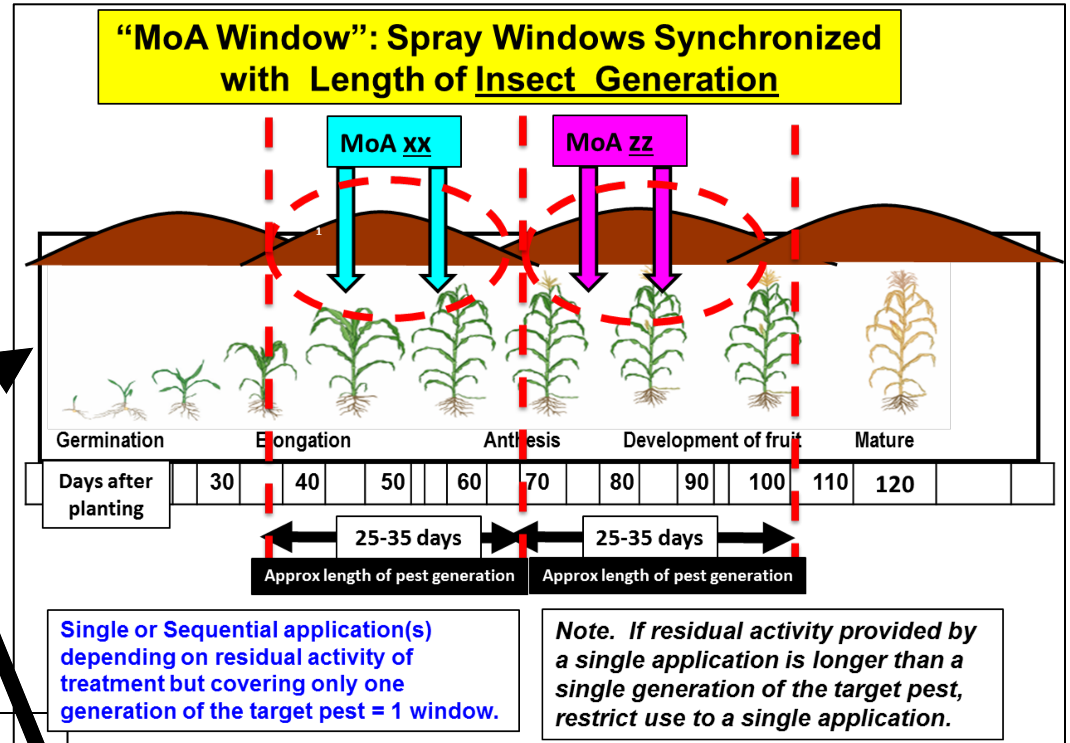
Rotation Within a Generation
Consecutive generations exposed to same MoAs. Selection pressure over all generations. Risk of resistance development for both MoA

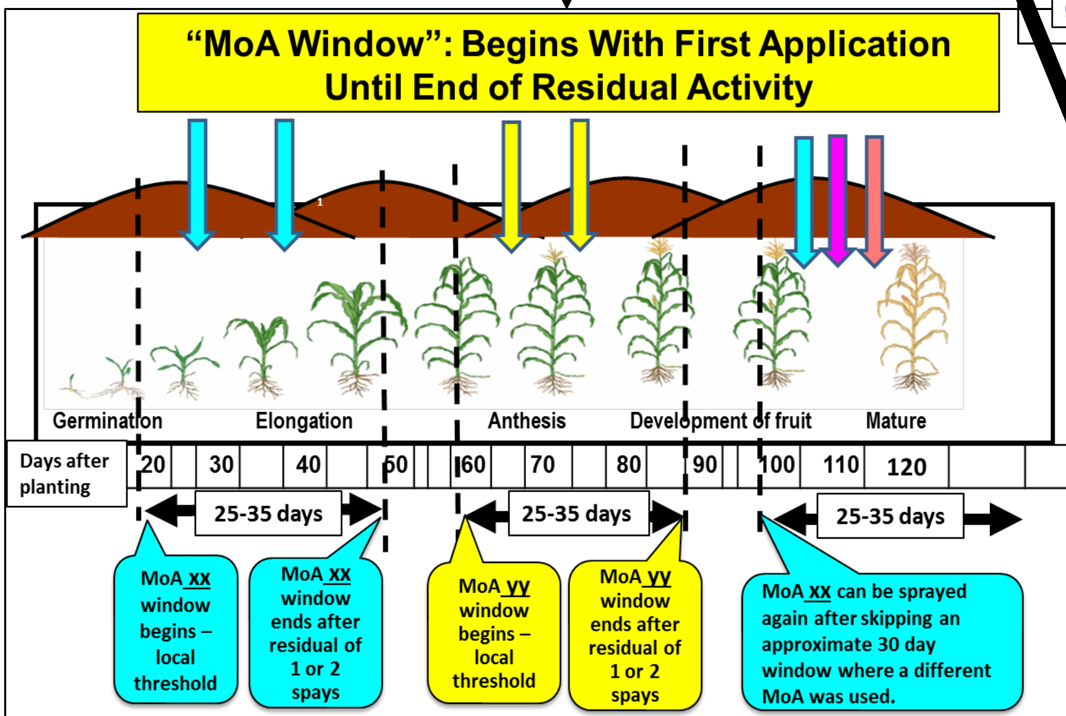
Rotation Between Generations
Consecutive generations are not exposed to same MoA. Break in selection pressure between generations allows recovery of susceptible population.

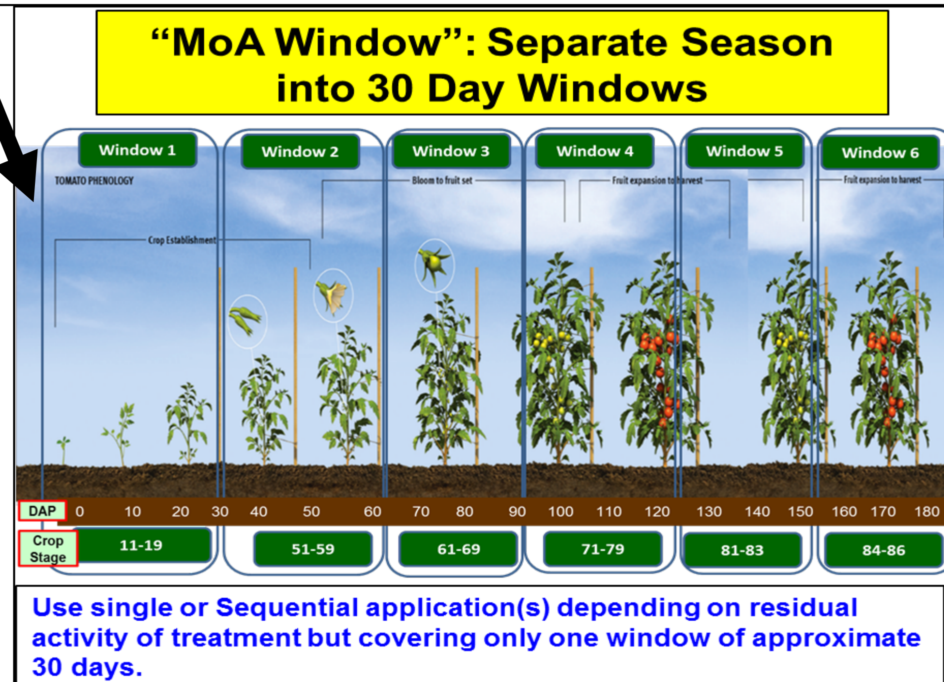
Rotation Within and Between Generations
Ideal situation for lower selection pressure. May not be practical due to limited number of effective products with different modes of action.

3. Rotation of insecticide MoA groups prevents rapid selection of resistant populations.

Examples of different approaches to rotation of Modes of Action in windows







3. Rotation of insecticide MoA groups prevents rapid selection of resistant populations.

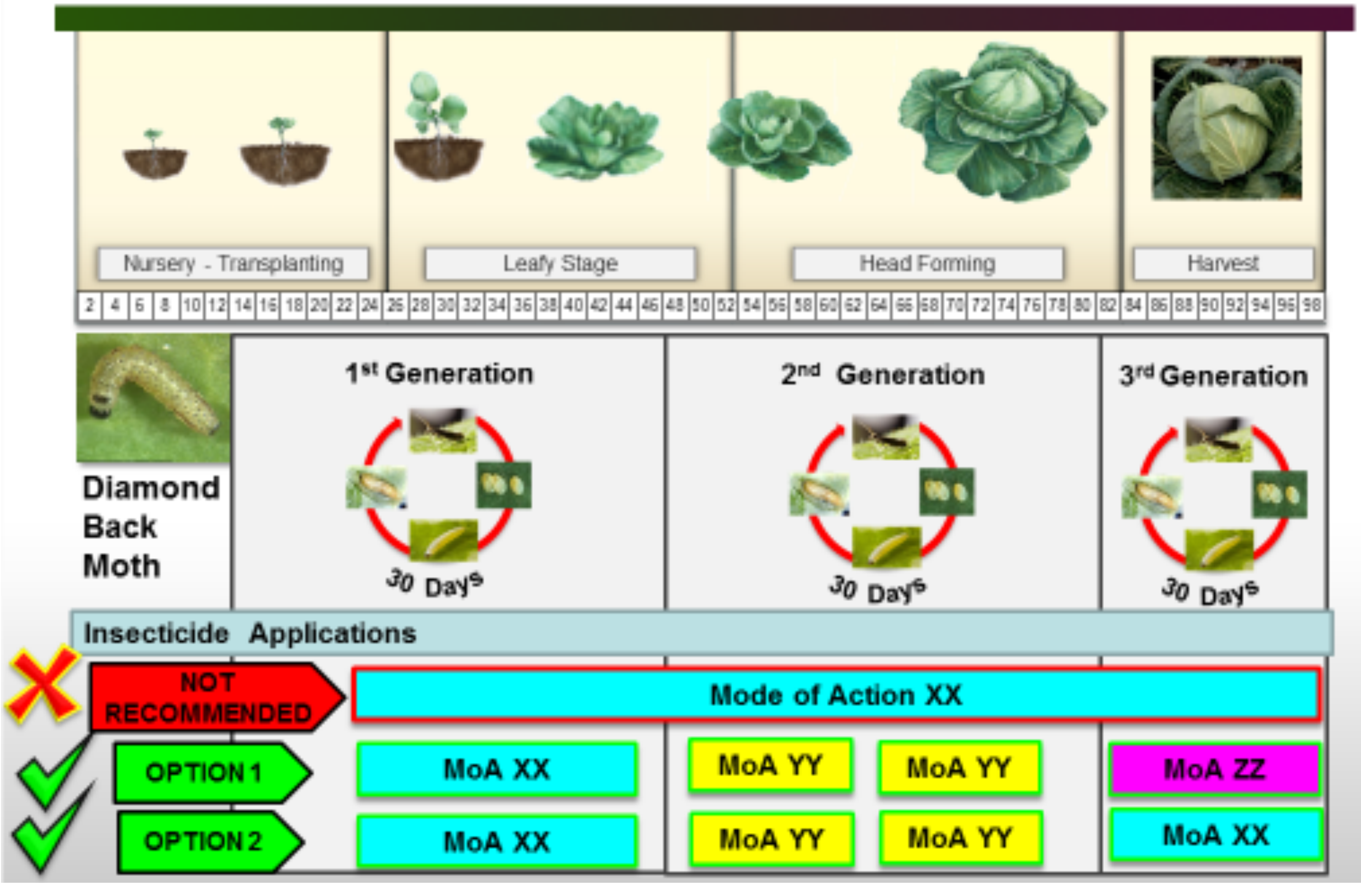
a). Do not use products with the same single mode of action throughout a crop cycle.

b). Apply insecticides of the same mode of action group within a window to avoid exposure of consecutive insect pest generations to the same mode of action.

c). Multiple applications (generally 1-2) of the same MoA insecticide applied back to back (sequentially) are acceptable if they are used to treat a single insect generation or are used within a single window. The residual activity of the multiple applications should fit within the window.

d). Following a window of any mode of action group, rotate to a window of applications of effective insecticides with a different MoA

MoA Rotation Example: Resistance management strategy developed for brassica crops in Philippines



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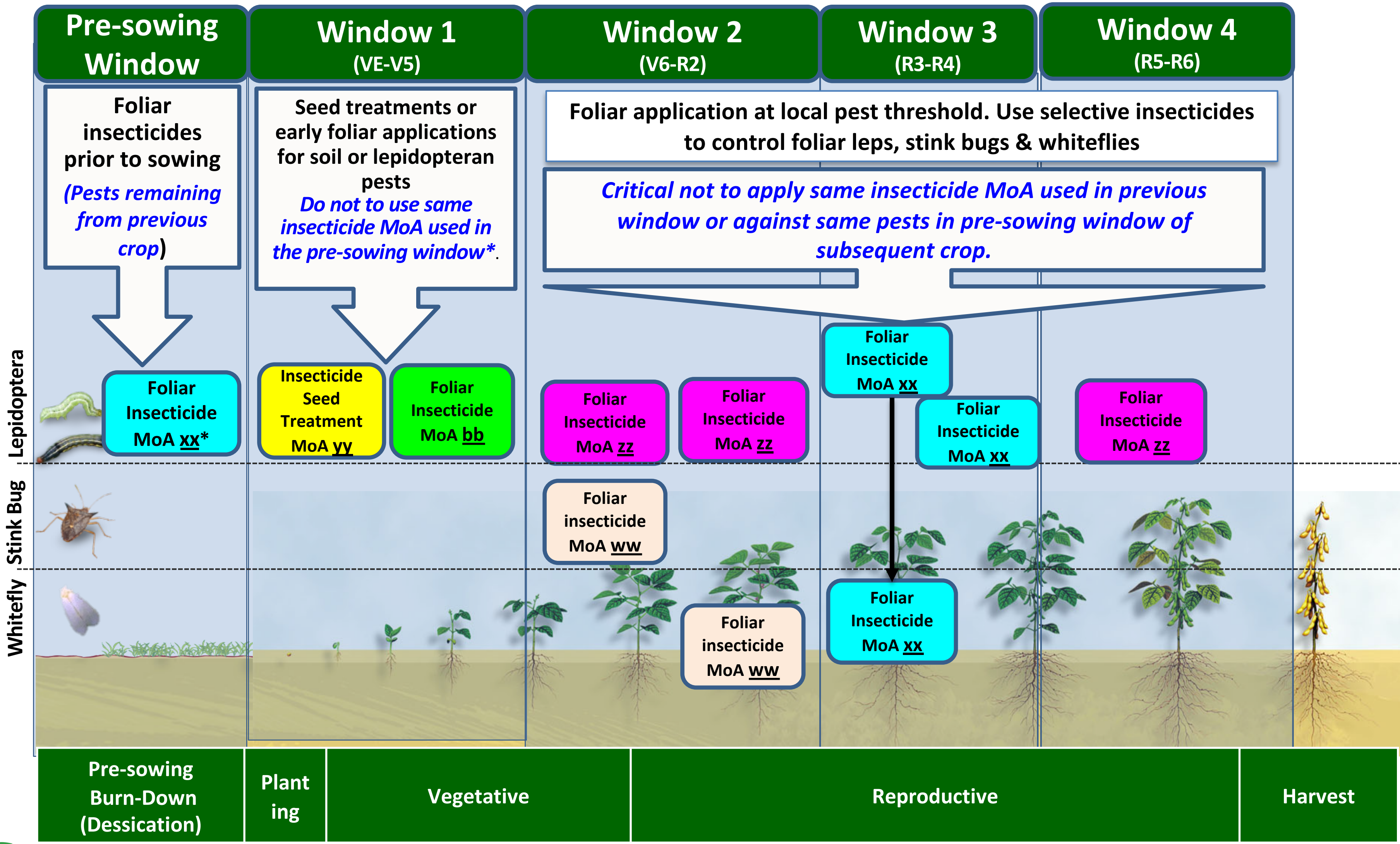
3. Rotation of insecticide MoA groups prevents rapid selection of resistant populations.

e). The use of multiple modes of action within a window is recommended provided that different modes of action are used in the following window.

EXAMPLE: Brazil Soybeans



IRAC ** If pre-sowing or foliar application occurs within a few days of planting it can be considered as the same treatment window.*

3. Rotation of insecticide MoA groups prevents rapid selection of resistant populations.

e). ROTATE PRODUCTS WITHIN OR BETWEEN INSECT GENERATIONS???

General Example: Insecticide Rotation Scheme for Cabbage Based on Number of Different MoA Products Available

MULTIPLE MoA PRODUCTS AVAILABLE

Different MoA products *can be* used in the **same** window

FEW MoA PRODUCTS AVAILABLE

Apply products with the same MoA in the **same** window

All MoA products must be rotated in the next window

Leaf stage	Head formation	Pre-harvest
MoA **A + B**	MoA **C + D**	MoA **E + F**

Leaf	Head formation	Pre-harvest
MoA **A + A**	MoA **B + B**	MoA **A + A**

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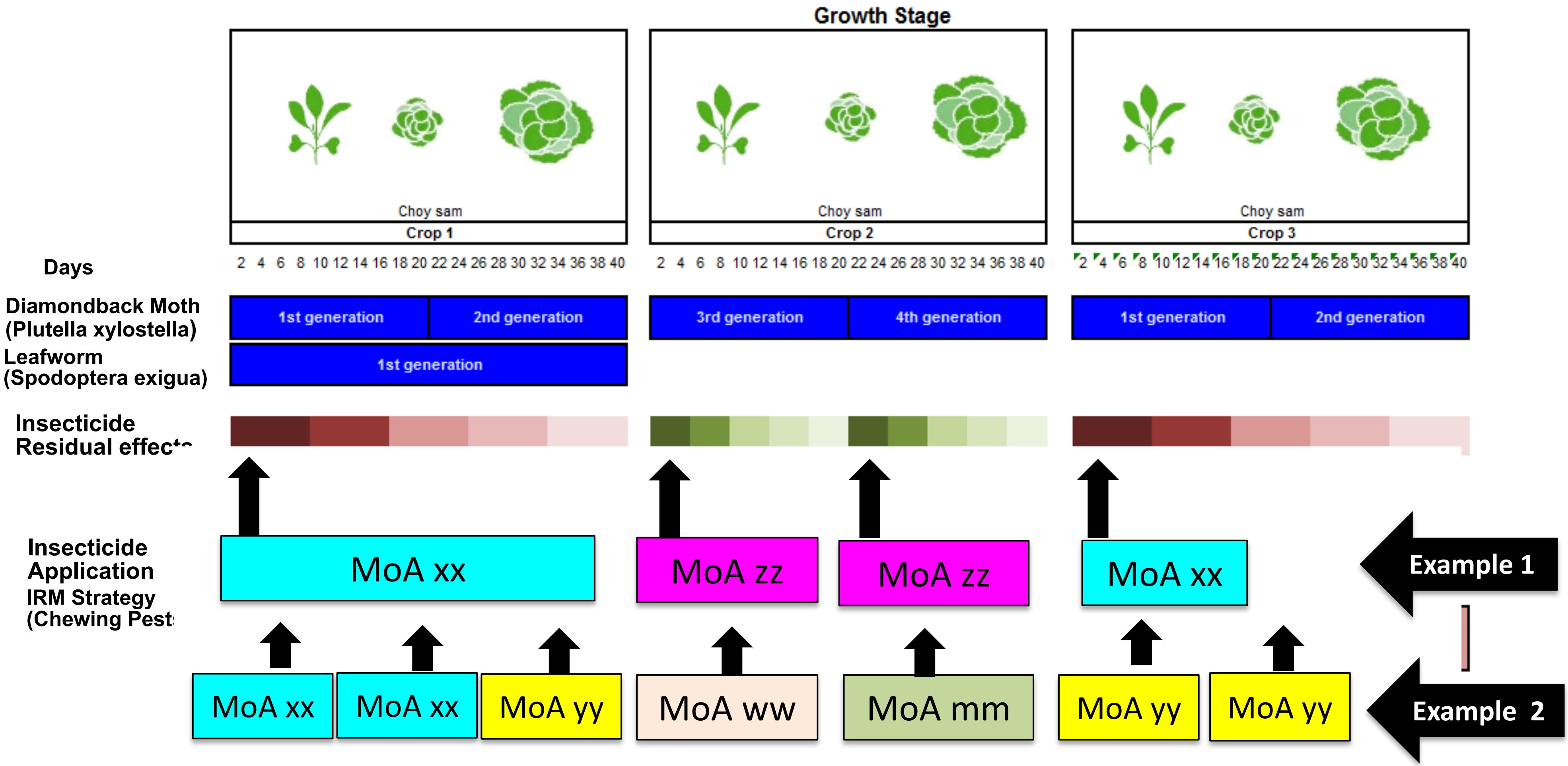
3. ROTATION OF INSECTICIDE MOA GROUPS PREVENTS RAPID SELECTION OF RESISTANT POPULATIONS.

f). <u>For short cycle crops (<50 days),</u> consider the duration of the crop cycle as a window. Alternate to different modes of action within the next crop cycle at the same farm location.

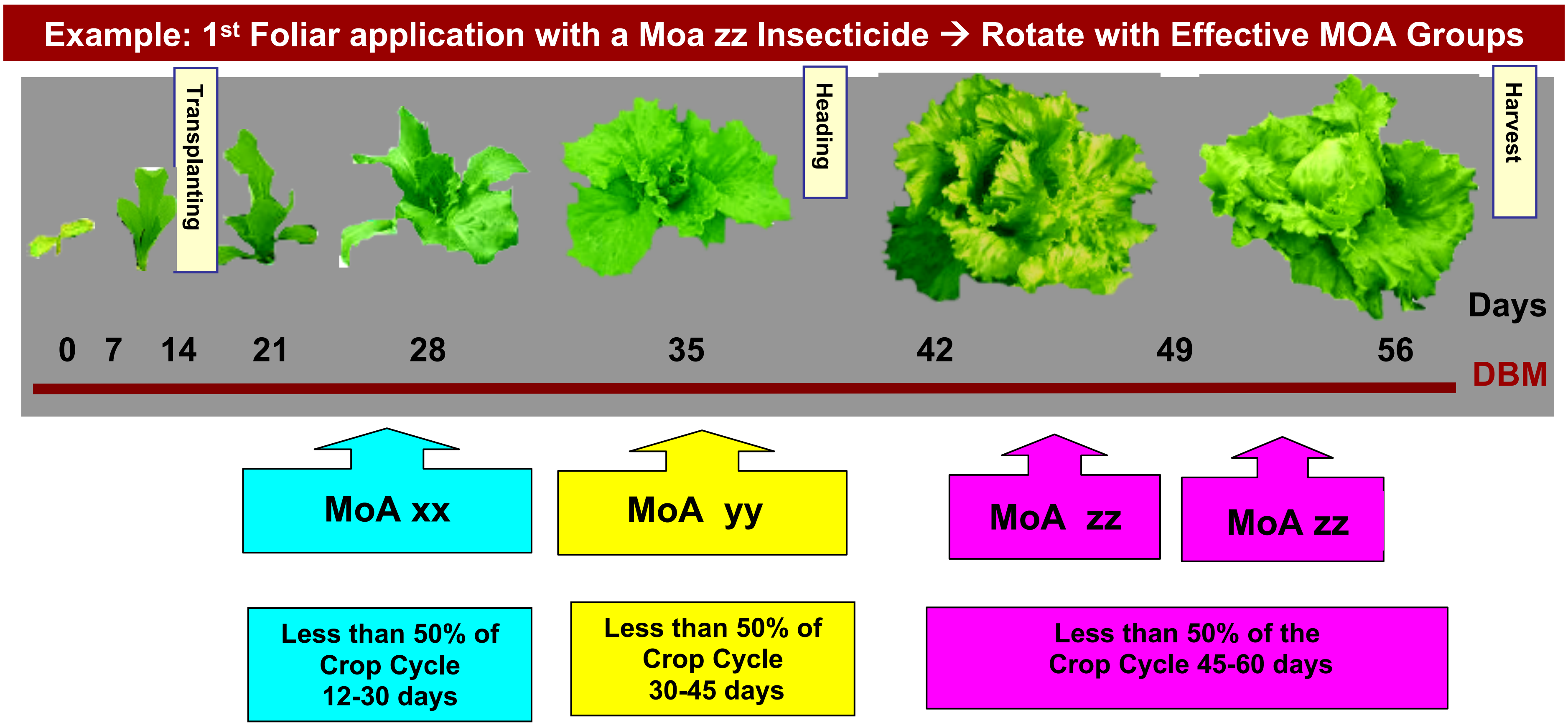
For Short Cycle Crops, a 'Treatment Window' is the same as a Crop Cycle



3. ROTATION OF INSECTICIDE MOA GROUPS PREVENTS RAPID SELECTION OF RESISTANT POPULATIONS.

g). Do Not Expose > 50% of Crop Cycle to the Same MOA Group. The total number of insecticide applications of the same MoA should not exceed 50% of the total number of insecticide applications targeted against the same pest species.

Foliar Application Example: Leafy Vegetables – Use treatment windows (approx 30 day windows) and avoid exposure of > 50% of crop cycle.

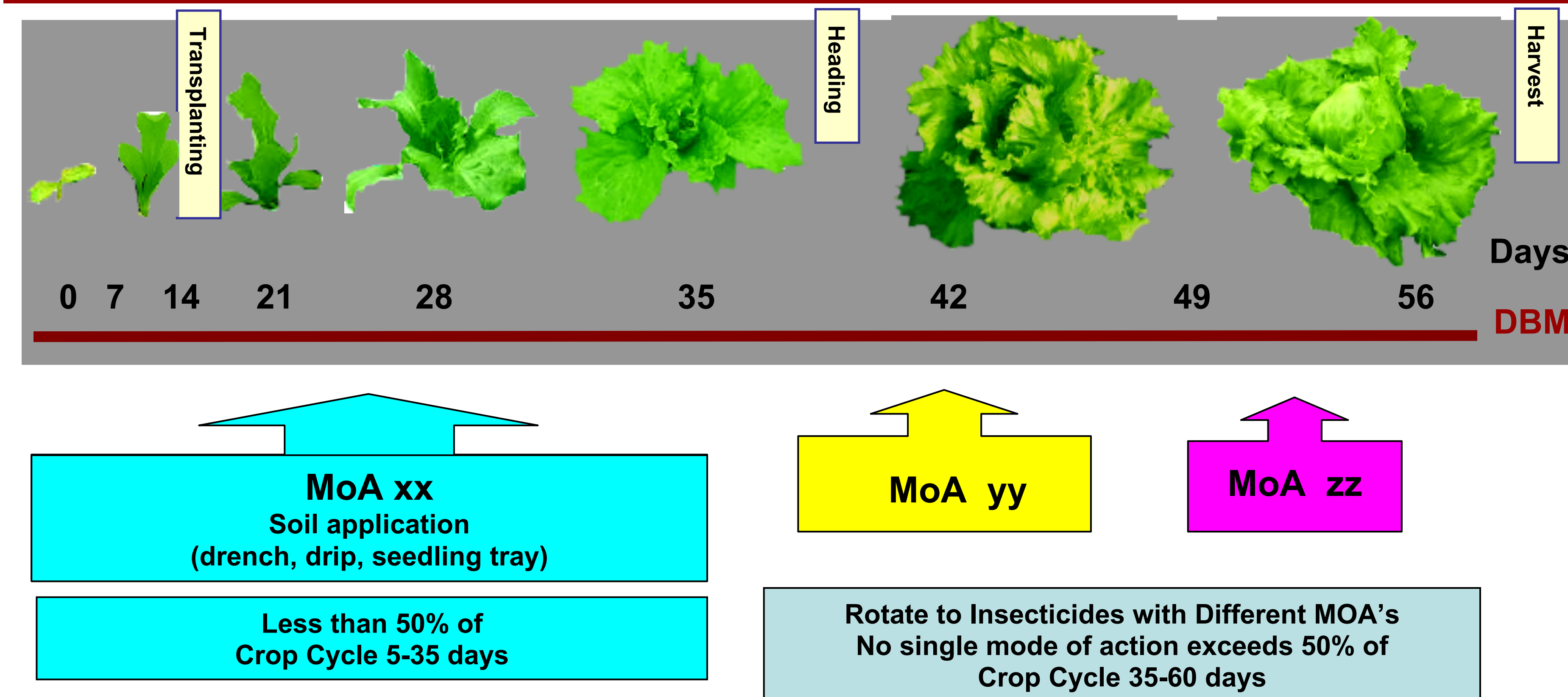


3. Rotation of insecticide MoA groups prevents rapid selection of resistant populations.

g). <u>Do Not Expose > 50% of Crop Cycle to the Same MOA Group.</u> The total number of insecticide applications of the same MoA should not exceed 50% of the total number of insecticide applications targeted against the same pest species.

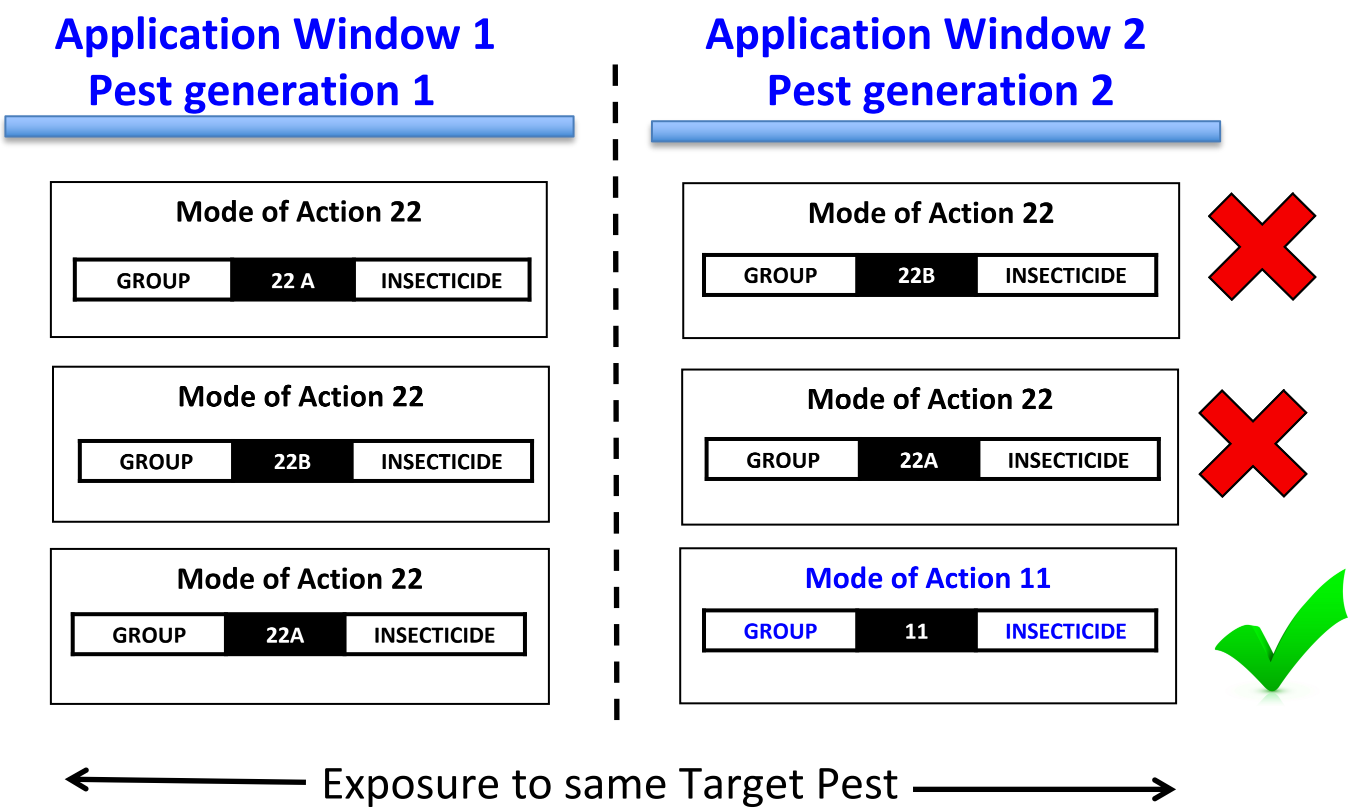
<u>Foliar Application Example</u>: Leafy Vegetables – Use treatment windows (approx 30 day windows) and avoid exposure of > 50% of crop cycle.

Example: 1st Foliar application with a Moa zz Insecticide → Rotate with Effective MOA Groups



3. Rotation of insecticide MoA groups prevents rapid selection of resistant populations.

h). <u>Avoid rotating products in different sub-groups</u> of the same MoA unless there are no effective alternatives.



<u>Guidance for using Subgroups</u>

- Avoid using the same MoA products over sequential generations.
- Application of same MoA products with different subgroups apply resistance selection pressure at the insecticide target site.
- Rotate same MoA products with different subgroups over multiple generations only if there are no other alterative insecticide MoAs available.

4. Plan and utilize Integrated Pest management (IPM) practices to protect crops from pest damage and reduce the risk of insecticide resistance.

IPM considers all available techniques which are economic, safe, and environmentally-sound to reduce pest populations. IPM practices do not exclusively rely on insecticides, hence insecticide resistance selection pressure is reduced and the risk of resistance minimized.

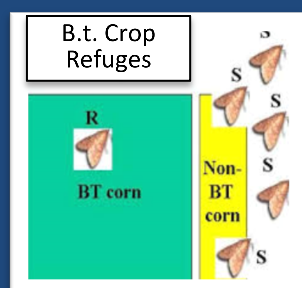
A Pest Thresholds

a) Monitor pest species and natural enemies
b) Make rational pest control decisions

C Biological control

a) Artificially introduce or use natural enemies to reduce pest populations.
b) Manage cropping to encourage beneficial species
c) Consider alternative microbial insecticides

IPM



B Agronomic practices

a) Crop rotations
b) Crop-Free periods
c) Clean-up infested crop residues
d) Use resistant crops
e) Include non-treated refuges

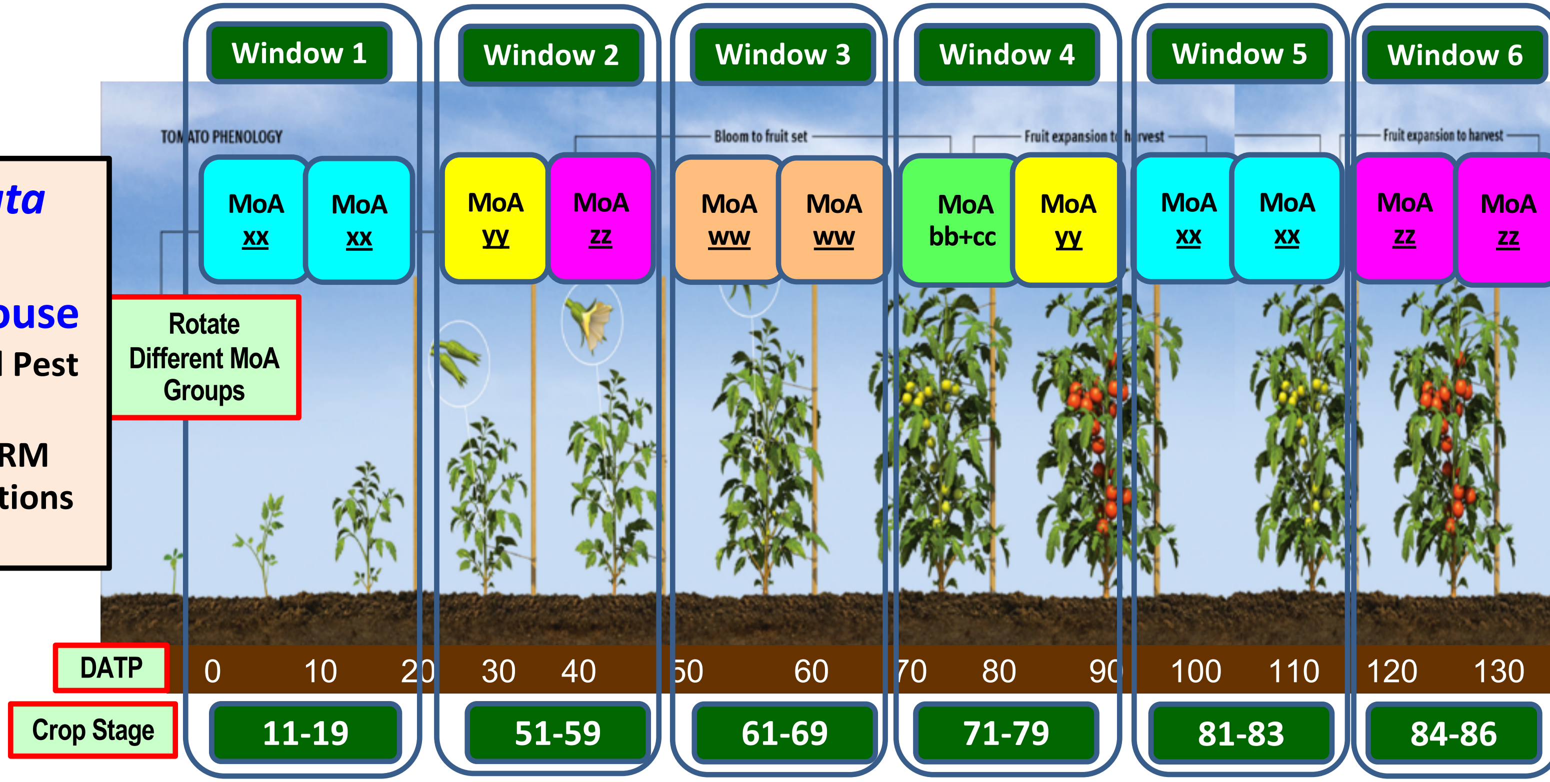
D Chemical control

a) Use selective insecticides responsibly and rotate MoA
b) Apply insecticides when effects on beneficials are minimal
c) Consider alternative application systems e.g. granules, seed treatment, traps

4. Plan and utilize Integrated Pest Management (IPM) practices to protect crops from pest damage and reduce the risk of insecticide resistance.

Tuta absoluta
Tomato
EU Greenhouse

IPM - Integrated Pest Management Practices, with IRM Insecticide Rotations



Pre-Season

- Remove cull piles
- Kill weed 2nd hosts
- Renovate GH
- Moth-proof GH (fix screens)
- Monitor adults-Pheromone Traps
- Choose tolerant varieties
- Use pest free transplants

During-Season

- Manage the removal of in-season infested pruned stems and fruit
- Use phermones and sticky traps to monitor and mass trap adults.
- Use phermone dispensers for Mating Disruption
- Sprat entomopathic nematoeds and nonchemical products that will not select for insecticide resistance.
- Augment and conserve natural enemy populations
- Use optimal spray volume, maintain and calibrate spray equipment

Post-Season

- Remove cull piles
- Kill weed 2nd hosts
- Renovate GH
- Moth-proof GH
- Solarize soil
- Rotate to non-host crop

& Incorporate an area-wide host free period:

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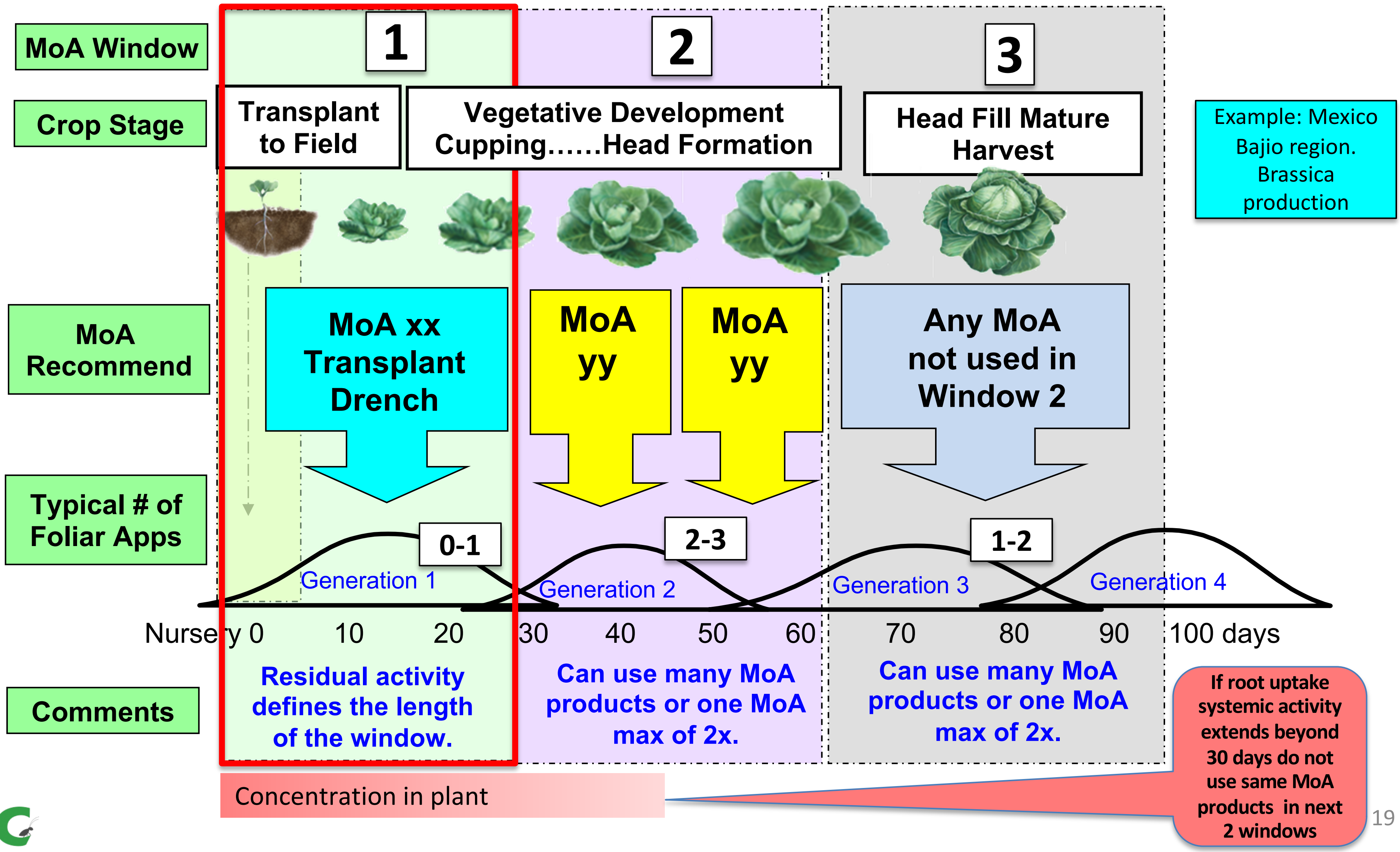
5. Consider the systemic properties of some soil and seed-applied products.

Systemic activity may extend the residual efficacy and the length of the MoA spray window and needs to be considered when planning a program to minimize resistance development. Generally, it is recommended to use an effective foliar product with a different mode of action after a seed treatment or a soil root uptake application (transplant drench, drip, etc.).



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6. Using insecticide mixtures.

- **Refer to the IRAC-mixture-statement and IRAC leaflet-on-use-of-mixtures.**
- **Like single active ingredient products, insecticide mixtures should be used with careful consideration of the characteristics of the individual active substances, use pattern, and pest complex targeted.**
- **Rotate different MoA products. Do not treat consecutive generations.**

Mixtures objectives:

- Broaden pest spectrum,
- Improved pest management,
- IRM is not the primary focus

Mixtures Rotation Strategy:

Application Window 1 – Pest generation 1

Mode of Action A+B®

GROUP	3	INSECTICIDE
GROUP	28	INSECTICIDE

Mode of Action A+B®

GROUP	3	INSECTICIDE
GROUP	28	INSECTICIDE

Mode of Action A+B®

GROUP	3	INSECTICIDE
GROUP	28	INSECTICIDE

Application Window 2 – Pest generation 2

Mode of Action A+B® (✗)

GROUP	3	INSECTICIDE
GROUP	28	INSECTICIDE

Mode of Action A® (✗)

GROUP	3	INSECTICIDE

Mode of Action C® (✓)

GROUP	5	INSECTICIDE

← Exposure to same Target Pest →

Mixture = Co-formulated product or Tank mixture of two or more insecticide active substances

Guidance for using mixtures

- Do not rely on Mixtures for resistance management
- Do not use the same MoA across windows
- Use Mixtures in rotation with other MoA

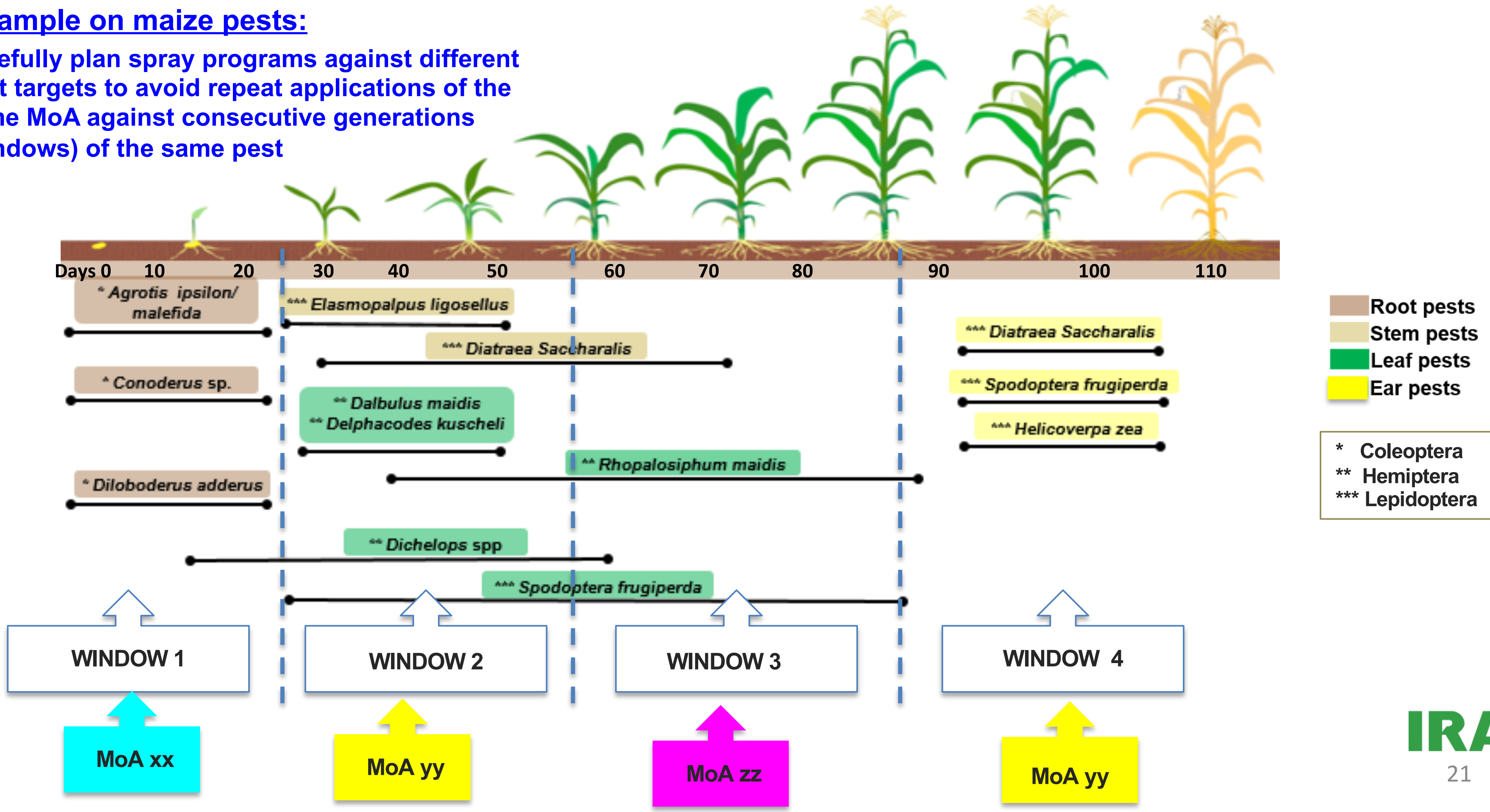
Note: Mixtures become less effective if resistance has developed to one of the MoA's.

7. Using insecticides with same Mode of Action against different pests in the same crop.

- **Applying insecticides against more than one pest species during the cropping season is recommended. Same MoA rotation rules apply.**
- **Prior to the season, plan the season-long spray program in compliance with IRM principles.**
- **Consider the timing of different pest species, their overlapping generations, and the risk of resistance development.**
- **Avoid repeated applications of the same mode of action across multiple treatment windows if the same insect species pest is present.**
- **Where two different species appear simultaneously always use the higher recommended rate for the more difficult to control species.**

Example on maize pests:

Carefully plan spray programs against different pest targets to avoid repeat applications of the same MoA against consecutive generations (windows) of the same pest



IRAC

8. Avoid using insecticides with the same Mode of Action where resistance is known

- **Avoid continuous use of the same Mode of Action on a resistant population since it may increase resistance levels.**
- **Do not use higher than recommended label rates.**
- **This recommendation is valid for solo and mixture products that contain the ineffective MoA.**

Example on Diamondback Moth, *Plutella xylostella*:

Chemical Control of *Plutella xylostella*

- Select insecticides based on known local effectiveness and selectivity
- Rotate insecticides by mode of action group, using a window approach
- Use only insecticides registered for diamondback moth control
- Always follow the directions for use on the label of each product

MoA	Primary Site of Action	Chemical Sub-group or Exemplifying Active
1	Acetylcholinesterase inhibitors	1A:Carbamates 1B:Organophosphates
2	GABA-gated Cl channel antagonists	2B: Phenylpyrazoles (Fiproles)
3	Sodium channel modulators	3A: Pyrethroids, Pyrethrins
4	Nicotinic acetylcholine receptor agonists	4A: Neonicotinoids
5	Nicotinic acetylcholine receptor allosteric activators	Spinosyns
6	Chloride channel activators	Avermectins, Milbemycins
11	Microbial disruptors of insect midgut membranes and derived toxins	*Bacillus thuringiensis var. kurstaki*
13	Uncouplers of oxidative phosphorylation via disruption of the proton gradient	Pyrrols
15	Inhibitors of chitin biosynthesis, type 0	Benzoylureas
18	Ecdysone receptor agonists	Diacylhydrazines
21	Mitochondrial complex I electron transport inhibitors	21A: Tolfenpyrad
22	Voltage-dependent Na channel blockers	22A: Indoxacarb 22B: Metaflumizone
28	Ryanodine receptor modulators	Diamides
UN	Compounds of unknown/uncertain MoA	Azadirachtin, Pyridalyl

IRAC Insecticide Resistance Action Committee

The Diamondback Moth, *Plutella xylostella:*
Resistance Management is Key for Sustainable Control

www.irac-online.org

Plutella xylostella Resistance Mechanisms

Several biochemical mechanisms are described as conferring resistance to insecticides in *P. xylostella*. Many of these mechanisms listed below act together and can confer resistance factors of 1000-fold or greater.

1. Enhanced metabolic detoxification mechanisms
2. Insensitive acetylcholinesterase
3. Reduced Cry1C binding to target site in midgut membrane and reduced conversion of Cry1C protoxin to toxin
4. Knock-down resistance – mutation(s) in voltage-gated sodium channels providing pyrethroid resistance.
5. Other mechanisms – include modified GABA-gated chloride channels and reduced penetration.

Determine if the target pest is resistant to commonly applied insecticides. Avoid using all products that contain the resistant MoA insecticide on a farm where resistance has been identified.

Additional guidance

9. The use of non-specific mode of action products helps to prevent the development of resistance.

Plant protection products such as oils and soaps which have a non-specific Mode of Action are good resistance management tools which should be recommended for use in rotation or combination with insecticides, provided that they similarly control both susceptible and resistant target pest populations.

10. Monitor problematic pest populations in order to detect first shifts in sensitivity.

Baseline sensitivity data for representative field populations of pests should be established by industry experts before the products became widely used. Re-examining the insecticide sensitivity of pest populations at regular intervals can be used to detect changes in susceptibility.

Monitoring methods for many of the major agricultural pests have been established by IRAC and can be found on the IRAC website www.irac-online.org/teams/methods/. Reporting of field failures to IRAC company representatives is also a good way detect early shifts in pest sensitivity.

11. Where local information is known about cross-resistance between different MoA groups.

Although in most situations rotation between different Mode of Action (MoA) insecticides will be useful, there have been some cases of metabolic cross resistance between molecules belonging to different groups. Therefore, it is recommended to consult local experts to find out the known status of resistance in your area. Avoidance of cross-resistance may help to build up a more effective rotation strategy.

12. Never use a product of questionable origin or composition.

Products from unknown or non-approved sources may not have the advertised composition, in which case efficacy may be affected and IRM becomes impossible. Moreover, illegal products may pose risks for users and the environment.

13. Make sure to follow appropriate country label instructions.

On the internet, using search engines, it is possible to locate product labels from most countries where the product is registered. Directions for use, even for the same crop, vary from country to country. Make sure to verify that the label pertains to the country of intended use, so that important instructions such as application rates and methods do not inadvertently contribute to generate or worsen resistance problems.

14. The use of the same insecticide to control different types of insect pests (Lepidoptera, Coleoptera, sucking insects).

These Lepidoptera IRM guidelines also apply to non-Lepidopteran pests unless more specific recommendations are available.

Insecticide Resistance Action Committee

Insecticide Resistance Management Guidelines for Lepidopteran Pests

2019 Text version

IRAC Lepidopteran Working Group

IRAC Lepidoptera Working Group

The guidelines presented here are designed by the Lepidoptera Working Group of the Insecticide Resistance Action Committee (IRAC). Our objective as industry technical experts and IRAC members is to provide a reference document for designing IRM strategies for lepidopteran pests. The information provided is based on published information and to the best knowledge of IRAC International at the time of writing (February 2017).

As pest problems and control practices differ considerably between countries, crops and climatic conditions, these guidelines are meant to be flexible and allow experts to develop, adapt and implement these options to take local conditions into account. However, exceptions will need to be addressed by experts on a case by case basis.

Introduction

Resistance to insecticides is a 'heritable change in the sensitivity of a pest population' that is reflected in the repeated failure of a product to achieve the expected level of control when used according to label recommendations for that pest species. The aim of this guideline is to summarize strategies that companies, influencers and growers can use to slow the development of resistance and provide more effective and sustainable pest control.

IRAC Mode of Action Classification

Lepidoptera insects can be controlled by insecticide compounds with different mode of action (MoA). Repeated use of any insecticide can lead to resistance to that specific insecticide. In addition, if insects become resistant because of a change in the binding site of the insecticide, insects will become resistant to all insecticides with the same mode of action.

The IRAC MoA classification is intended to identify insecticides acting at specific target sites where mutations could confer cross-resistance to all compounds acting on the same site. It provides a guide to the selection of insecticides for use in an effective and sustainable insecticide resistance management (IRM) strategy.

A summary list of insecticide MoA and corresponding chemical groups with more details on insecticide Modes of Action can be found on the IRAC web site irac-online.org and the IRAC MOA App can be downloaded on to your cell phone.

The IRAC Mode of Action group numbers are now included on product labels in many countries. Additionally, statements providing insecticide resistance management guidance are also often given on the labels.

Status of Resistance to Lepidoptera insecticides

There are many published instances of Lepidopteran species where resistance to insecticides has developed and others which have the potential to develop resistance. For the latest information please refer to the IRAC web site irac-online.org.

Guidelines:

1. IRAC member companies are responsible for including IRM information in product labels.
The principle is to provide clear IRM information using language and a format understandable to farmers. Moreover, IRAC member companies recommend stating on product labels the maximum number of applications and the maximum amount of insecticide applied per crop /year. Implementation in countries depends on the local regulatory label guidelines.

2. Always use products at the recommended label rates and spray intervals with the appropriate application equipment.
Insecticides used at rates higher or lower than recommended on the label can result in resistance and/or unwanted effects on non-target organisms and the environment. Ensure that all the spray equipment is well maintained and there are no blocked nozzles or filters since this results in incorrect rates. Target the most susceptible insect life stages whenever possible.

3. Rotation of insecticide Mode of Action groups prevents rapid selection of resistant populations.
Farmers can avoid prolonged selection for insecticide resistance by rotating and diversifying the insecticide modes of action used in a crop cycle. **The recommended approach is to use products of the same MoA within a discrete period of time commonly called a "window". A window is defined by the duration of an insect generation or approximately 30 days. The period of residual activity provided by a single or sequence of product applications with the same mode of action should fit within a window.**

a) Avoid exclusive use of any mode of action group insecticides throughout a crop cycle.
b) Apply insecticides of the same mode of action group within a window to avoid exposure of consecutive insect pest generations to the same mode of action.
c) Multiple applications (generally less than 3) of the same MoA insecticide are acceptable if they are used to treat a single insect generation or are used within a window. Make sure that the residual activity of the multiple applications fits within the window.
d) Following a window of any mode of action group, rotate to a window of applications of effective insecticides with a different mode of action.
e) If insecticides from several mode of action groups are available, then the use of multiple modes of action within a window is recommended provided that different modes of action are used in the following window.
f) For short cycle crops (<50 days), consider the duration of the crop cycle as a window, so it is recommended to alternate to different modes of action within the next crop cycle.
g) As a general rule, the total exposure period of all windows with the same MoA applied throughout the crop cycle (from seedling to harvest) should not exceed 50% of the crop cycle. The total number of insecticide applications of the same MoA should not exceed 50% of the total number of insecticide applications targeted against the same pest species.
h) Avoid rotating products in different sub-groups of the same MoA except if there are no effective alternatives.

4. Use Integrated Pest management (IPM) practices to protect crops from pest damage and reduce the risk of insecticide resistance.

IPM considers all available techniques to discourage the development of pests, which are economic, safe and environmentally-sound. It does not exclusively rely on insecticides, hence in IPM systems selection pressure by specific modes of action is reduced and the risk of resistance minimized.

IPM strategies consist of basic components:

a) Understand pest threshold levels resulting in economic losses. Observe pest populations in the field to identify species, pest stages, population densities, and presence of natural enemies so rational pest control decisions can be made.

b) Integrate effective control techniques including cultural, chemical, biological and plant biotechnology pest control measures, which minimize effects on non-target organisms:
   - Use resistant or damage tolerant crop varieties.
   - Practice sanitation and removal of infested post-harvest crop residues.
   - Avoid year round cultivation of susceptible crops to limit survival of treated pest populations.
   - Integrate non treated refuge crops into the cropping system (to allow breeding of treated survivors with untreated populations to dilute resistance genes).
   - Deploy mating disruption.

c) Plan the use of selective insecticides to conserve and complement the efficacy of beneficial organisms.

d) Contributions of beneficial organisms to pest control can be significant in many cropping systems and can also play an important role in resistance management. Beneficials can effectively control target pests regardless of insecticide resistance and thus may slow down the resistance selection process. Different application techniques e.g. soil drench or seed treatment can help conserve beneficial organisms since they may escape direct exposure. Choose insecticides that are safe to beneficial insects and time insecticide applications during periods of low beneficial activity or during their protected life stages when direct contact with the insecticide is limited.

5. Consider the systemic properties of some soil and seed-applied products.

The systemic properties of some active ingredients allow these products to be applied either directly to the soil, as a seed treatment or as foliar spray. Systemic activity may extend the residual efficacy and the length of the MoA spray window and needs to be considered when planning a program to minimize resistance development. Generally, it is recommended to use an effective foliar product with a different mode of action after either a seed treatment or a soil root uptake application.

6. Using insecticide mixtures.

IRAC has issued advice about the use of insecticide mixtures. For guidance refer to the IRAC-mixture-statement and IRAC leaflet-on-use-of-mixtures. As with applying single active ingredient products, insecticide mixture products should be used with careful consideration of the characteristics of the individual active substances, use pattern and pest complex targeted. In most cases, the primary objective for the use of an insecticide mixture (tank-mix or pre-formulated mixture) is not resistance management, but a broader spectrum or improved pest management.

7. The use of insecticides of the same Mode of Action against different pests in the same crop.

Multiple uses of different insecticides against more than one pest species in the same crop are feasible, but should be considered within the framework of insecticide resistance management programs and developed at local level, taking into account changes in pest populations, overlapping of different species, the relative importance and the risk of resistance development. Good resistance management practices such as avoiding repeated applications of the same mode of action across multiple treatment windows due to application against multiple pest species are key to successful IRM implementation. Where two species appear simultaneously always use the higher recommended rate for the more difficult to control species.

8. Avoid use insecticides from the same Mode of Action where resistance is known.

Continuous use of the same Mode of Action on a resistant population may escalate resistance levels and should be avoided, particularly if the product is used at higher than recommended rates. This recommendation is valid for solo and mixture products that contain the ineffective MoA.

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