Creating an Insecticide Resistance Management (IRM) Program

An intermediate level training module for crop protection

IRAC

Insecticide Resistance Action Committee

The Insecticide Resistance Action Committee

This training module is designed to provide information on how to practically manage insecticide resistance in agricultural and horticultural crops. The presentation is targeted at those that may have at least a basic understanding of insecticide resistance and are looking to implement practical resistance management in agricultural environments.

Disclaimer

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Creating an Insecticide Resistance Management (IRM) Program

- The sustainable and economically viable control of insect pests in agriculture is a challenge faced by farmers and growers worldwide.
- Maintaining the control of insect pests is made more difficult when insects develop resistance to insecticides, so it is critical for growers to incorporate resistance management into pest management programs.
- This IRAC training module aims to provide guidance to growers and their advisors on how to build a sustainable pest management program to maintain control of pests and delay the onset of resistance.
- There are five main steps to constructing an IRM program....

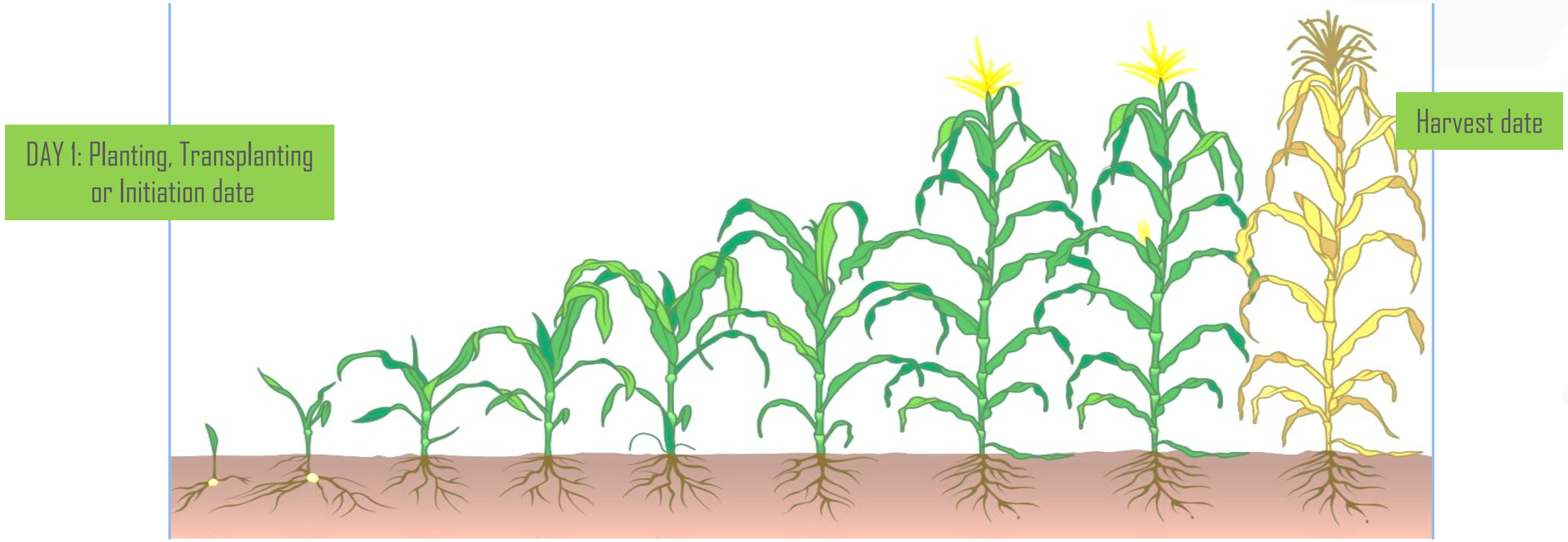
1. Building a crop phenology chart.
2. Incorporating the pest insects.
3. Creating windows of insecticide application.
4. Selecting the appropriate control solutions.
5. Incorporating alternative crop management techniques.

STEP 1: Crop phenology chart

The first step to building a successful pest management program is to create a crop phenology chart.

In many cases the start of the phenology chart will be the seed planting date, but it could be the seedling transplant or for perennial crops the start of regrowth after dormancy.

The end of the phenology chart is usually the harvest date, when insecticides are no longer needed to protect the crop value.



Note: The periods before planting and after harvesting are also important in developing a pest management and IRM program, but this will be covered later in the document.

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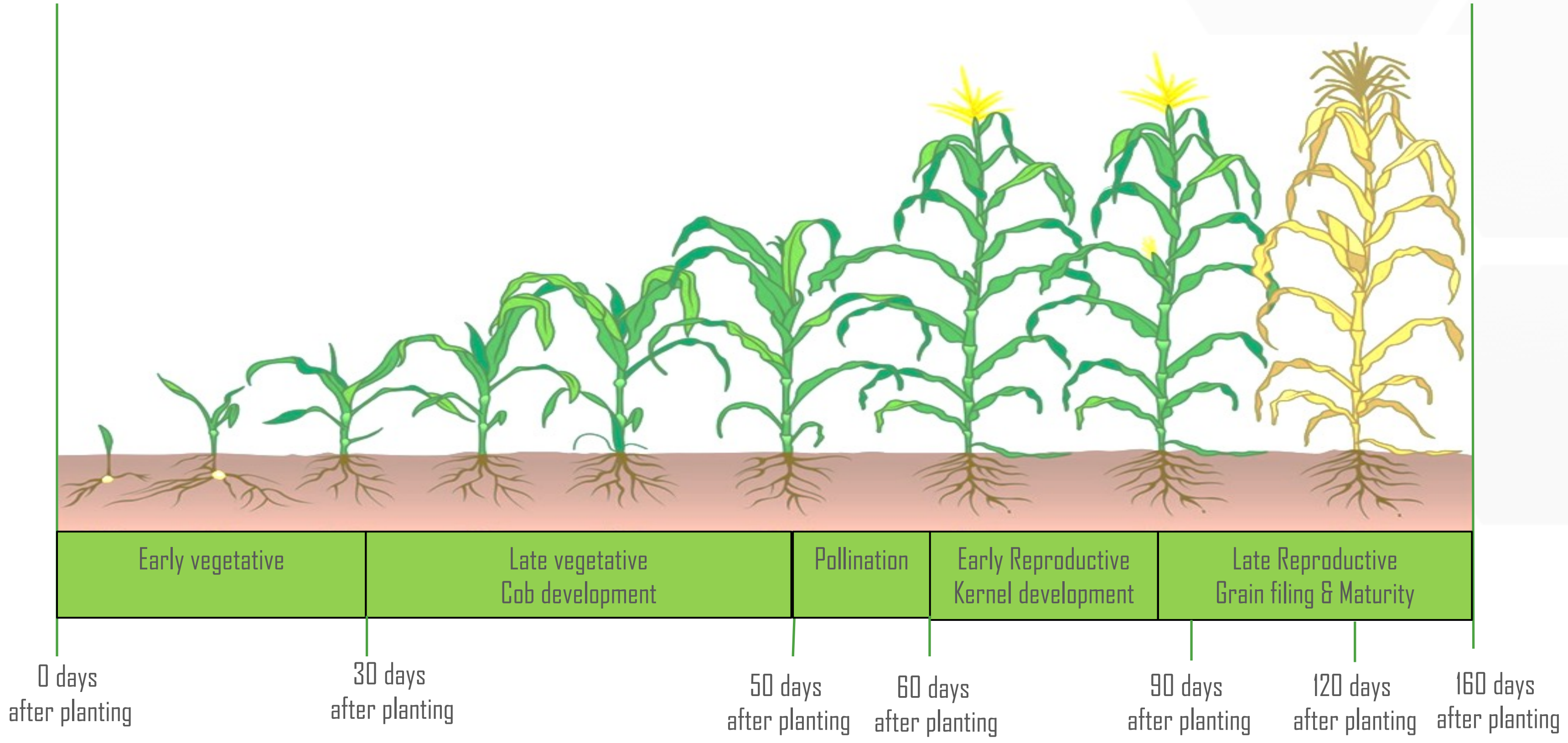
STEP 1: Crop phenology chart

- The next step is to add the major crop stages and growth stage intervals.
- Development time for each growth stage is often variable depend on climatic conditions and regions, therefore only approximate timings are required as the minimum.
- More detailed growth stage information and BBCH stages can be helpful if available.



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STEP 1: Crop phenology chart - Other Examples

Vegetative Stage		Reproductive Stage		Ripening Stage	
Transplant	Tillering	Panicle Initiation	Flowering	Milky & Dough (Maturity)	Harvest Maturity
0 – 20	20 – 50	50 – 65	65 – 90	90 – 105	105 – 120

TRANSPLANT RICE

- Phenology chart starts at the time of transplant.
- Pre-transplant pest control is important but will be considered later in the training.

APPLES

- Phenology chart starts at the time of the tree emerging from dormancy.
- Pre-dormancy pest control is important but will be considered later in the training.

Budding		Flowering		Fruiting		
Bud Swelling	Bud opening	Flower Bud	Flowering	Fruit Set	Fruit Development	Maturation
0 – 30	30 – 60	60 – 90	90 – 120	120 – 150	150 – 180	180 – 210

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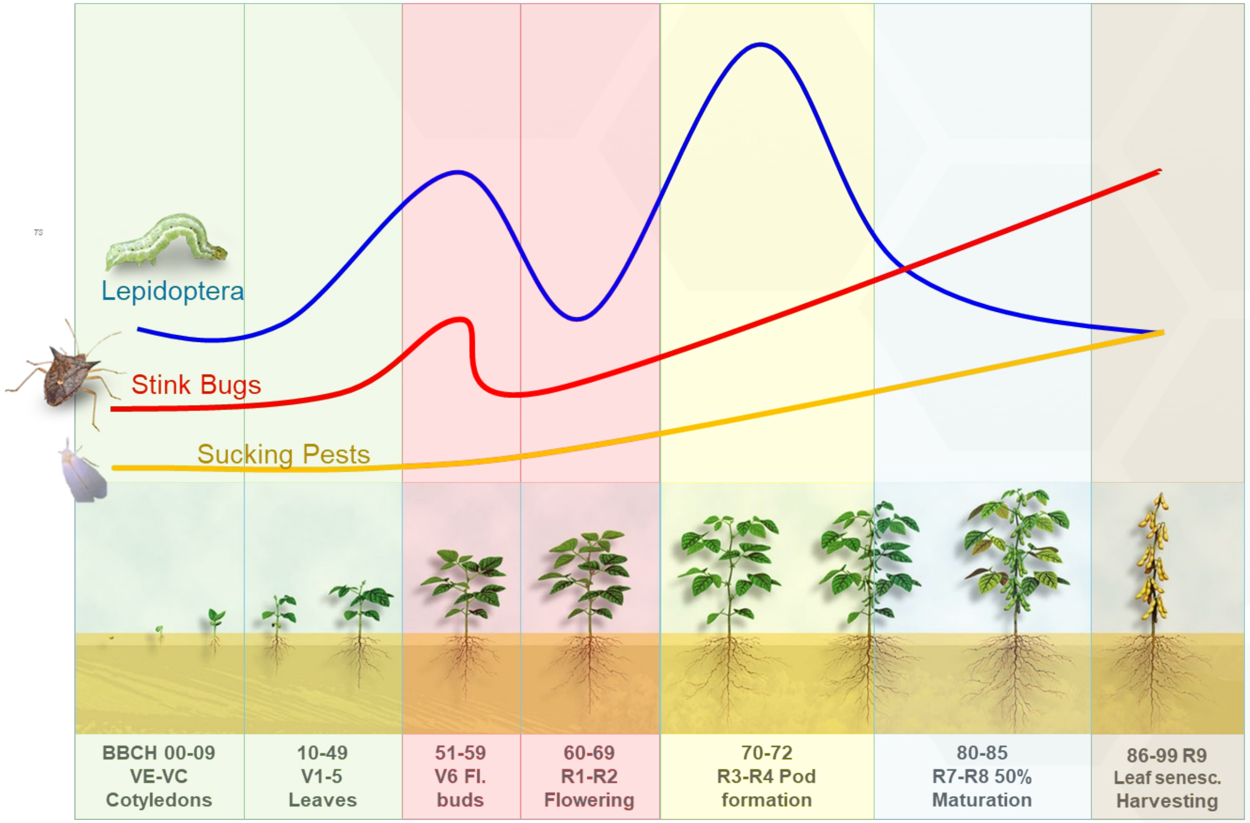
STEP 2: Adding the pests

- Insect pests are often not a permanent and continuous feature of an agricultural landscape.
- They increase and decrease in numbers during different time periods is often related to the different development stages of the crop, weather conditions, predator presence and pesticide use.
- Some pests also have synchronized development cycles, so different life stages (egg, larvae, pupae, adults) may be present in the crop at different times.
- It is an essential part of insect management to understand pest timings, including immigration and emergence, as well as what life stage is present when, as this can affect your insecticide choice.
- Insecticides should also only be applied when the pests present a risk to the crop. Pesticide applicators should take note of economic application thresholds.

Example: Natural variations in pest density in Brazilian soybean.



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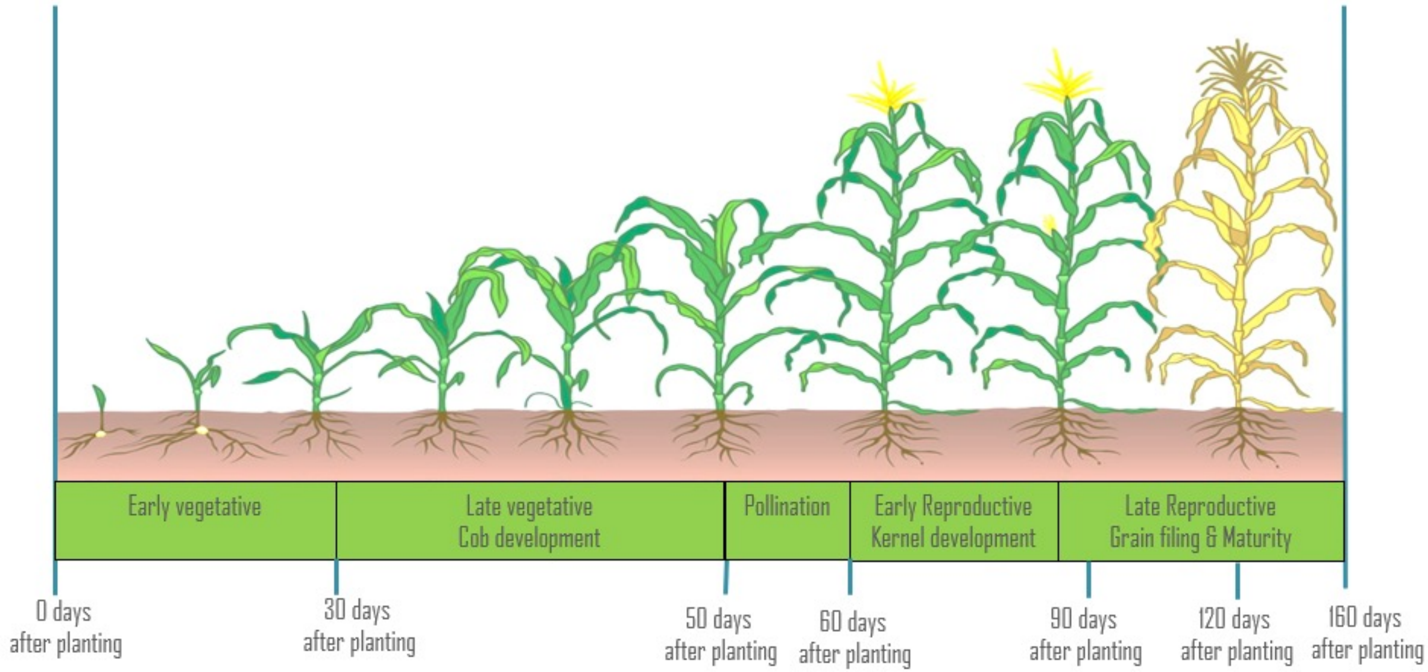
STEP 2: Adding the pests

- It is likely that there are a number of different pests which occur simultaneously or independently in a particular crop across the cropping cycle.
- Important pests should be added to the chart with a bar showing the period in which the pest appears in the crop.
- It is often useful to indicate whether the pest is a below-ground or above ground pest.
- It may also be useful to highlight periods when the pest may be present but may not need insecticide treatment.



Corn Rootworm (***Diabrotica virgifera***)	LARVAE	ADULTS
Fall Armyworm (***Spodoptera frugiperda***)	LARVAE	
European Stemborer (***Ostrinia nubilalis)***	LARVAE	
Cotton Bollworn (***Helicoverpa armigera***)		LARVAE
Corn Jassid (***Dalbulus maidis***)	ADULTS & NYMPHS	

Note: The pests selected are for demonstration purposes only. This pest combination is not expected in any or all geographic regions and are selected to represent different pest types and timings.

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STEP 2: Adding the pests – Other examples

TRANSP

Vegetative Stage		Reproductive Stage		Ripening Stage	
Transplant	Tillering	Panicle Initiation	Flowering	Milky & Dough (Maturity)	Harvest Maturity

0 – 20 – 50 – 65 – 90 – 105 – 120

Water Weevil (***Lissorhoptrus oryzophilus***)	
Brown Planthopper (***Nilaparvata lugens***)	LARVAE
Yellow Rice Stemborer (***Scirpophaga incertulas***)	LARVAE
Whorl Maggot (***Hydrellia philippina***)	LARVAE
Panicle Mite (***Steneotarsonemus spinki***)	ADULTS & NYMPHS
Rice Stink Bug (***Leptocorisa acuta***)	ADULTS & NYMPHS

Note: The pests selected are for demonstration purposes only. This pest combination is not expected in any or all geographic regions and are selected to represent different pest types and timings.

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STEP 3: Creating Windows of Insecticide Application

GENERATION TIME
- Time to complete one generation under normal conditions.
- Transforming from a given life stage to the same life stage in its offspring.

- What is a window of insecticide application ?
  - A window of insecticide application is a period of time in which insecticides with the same mode of action can be applied to a crop or a defined geographic area.
  - Windows apply to all forms of insecticides. They apply to synthetic chemical, biological and genetically modified plants expressing insecticidal toxins, as well as applying to different application methods (foliar, soil applied, seed treatment, chemigation, etc).
  - A window of application is also known as 'application blocks' or 'windows'.
  - The duration of a window of application is defined by either the generation time of the target insect(s) or the duration of residual control provided by a single application of insecticide if it exceeds the generation time of the target insects.
  - The generation time of target insects can vary depending on temperature, host plant and other factors. If accurate information is not available, then IRAC recommends to use generalized windows. Using 30-day windows for many pests, but 15-days windows for pests with short lifecycles (e.g. aphids & mites).
  - In the case of insects with a very long generation time (e.g. some soil pests), the whole cropping cycle is considered the application window for that pest, with rotations to other modes of action recommended in the following cropping cycle.
  - Some insecticides provide long periods of pest control that may exceed a single generation of the target pest. When this occurs, the duration of the residual effect of a single application of the insecticide is considered the application window*

*EXAMPLE: Insecticide A provides 30 days control of aphids with a single application at the registered rate. However, the generation time of the target aphid is approximately 15 days. In this situation 30 days should be used as the length of the window, as the duration of effect of the insecticide can not be shortened.

Pest	Order	Actual generation time	Suggested window length
Cotton Bollworm *Helicoverpa armigera*	Lepidoptera	23-44 days	30-days
Diamondback Moth *Plutella xylostella*	Lepidoptera	14-28 days	30-days
Green Peach Aphid *Myzus persicae*	Hemiptera	11-17 days	15-days
Two-spotted Spider Mite *Tetranychus urticae*	Acari	9-14 days	15 days
American Serpentine leafminer *Liriomyza trifolii*	Diptera	18-25 days	30 days
Brown Neotropical Stinkbug *Euschistus heros*	Hemiptera	25-28 days	30 days
Wireworm / Click beetle *Agriotes obscurus*	Coleoptera	3.5-4 years	Annual Crop Cycle
Corn Rootworm *Diabrotica virgifera*	Coleoptera	12 months	Annual Crop Cycle
Pollen Beetle *Meligethes aeneus*	Coleoptera	35-57 days	30-days
Onion Thrips *Thrips tabaci*	Thysanoptera	8-13 days	15-days
Spotted Wing Fruit Fly *Drosophila suzukii*	Diptera	9-12 days	15-days
Tobacco Whitefly *Bemisia tabaci*	Hemiptera	25-29 days	30-days

STEP 3: Creating Windows of Insecticide Application – Commonly Asked Questions ?

Why is an application window based on generation time ?

- Insecticide resistance occurs when a genetic mutation that confers a reduced susceptibility to an insecticide is selected in an insect and then that mutation is passed on to its offspring in the following generations.
- The principle of resistance management is to minimise the number of generations that are exposed to the same insecticide by ensuring that growers switch to insecticide with a different mode of action.
- By implementing application windows based on generation time, growers can ensure that the chances of sequential generations being exposed to the same mode of action are reduced.

Why not just make sure that the next insecticide application is of a different mode of action.

- Direct rotation of insecticides with different modes of action is also a good resistance management strategy, however it can be challenging to implement this strategy in crops that require protection from repeated pest infestations or if growers have a limited number of effective insecticides available. It could mean that growers have to purchase several different insecticides, or it could mean that if the rotation cycle is too short, sequential insect generations get treated with the same mode of action.
- Insecticide application windows based on generation time allow for the implementation of resistance management, whilst providing convenience for growers.

Don't some insects have overlapping generations ?

- Not all insects synchronise their life cycle, so that they are all at the same life-stage at the same time.
- Eggs, larvae, pupae and adults may all be present at the same time for some insect pests (e.g. whiteflies)
- By having a windows based on generation time, it means that no matter the life stage, the next generation of each individual insect will be exposed to a different mode of action*.

*EXAMPLE: An insecticide is applied in Window 1 to plants that are infested with tobacco whitefly with both adults and nymphs present at the time of application. By the time both the nymphs and the adults have gone through their life cycle (approx. 30 days) they will have entered into application Window 2 where an insecticide with an alternative mode of action will be applied. This prevents sequential generations being exposed to the same mode of action irrespective of the life stage of the insect.

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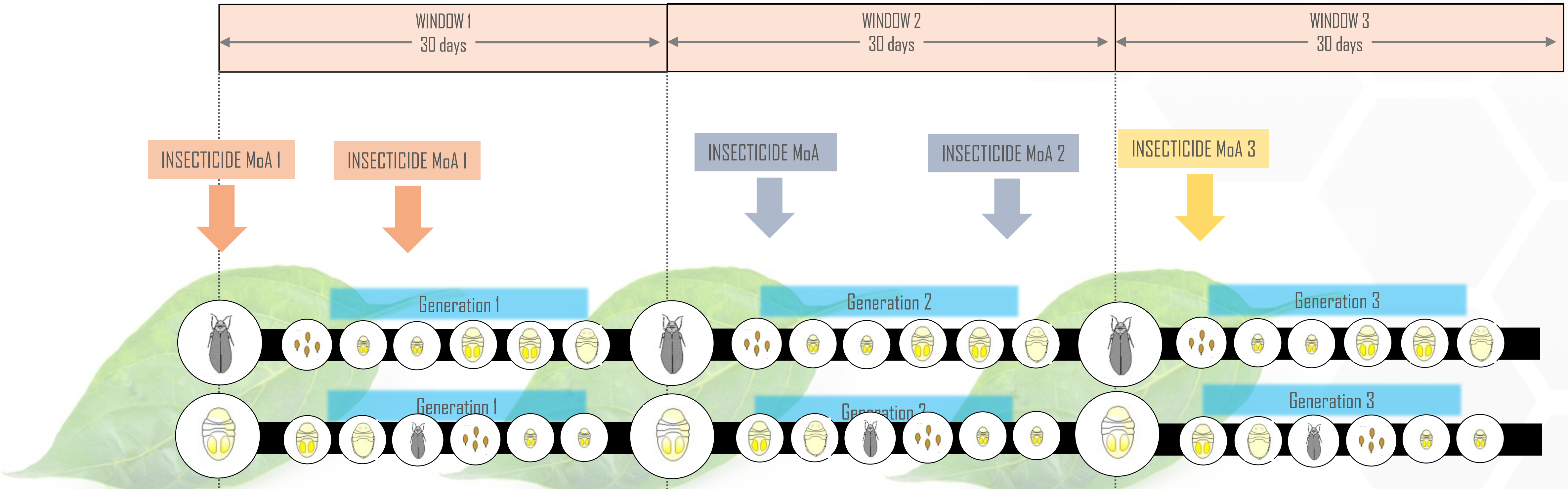
STEP 3: Creating Windows of Insecticide Application Overlapping Generations - Example



Images courtesy of Bayer Crop Science

Generation 1 is only exposed to MoA 1

Generation 2 is only exposed to MoA 2

Generation 3 is only exposed to MoA 3

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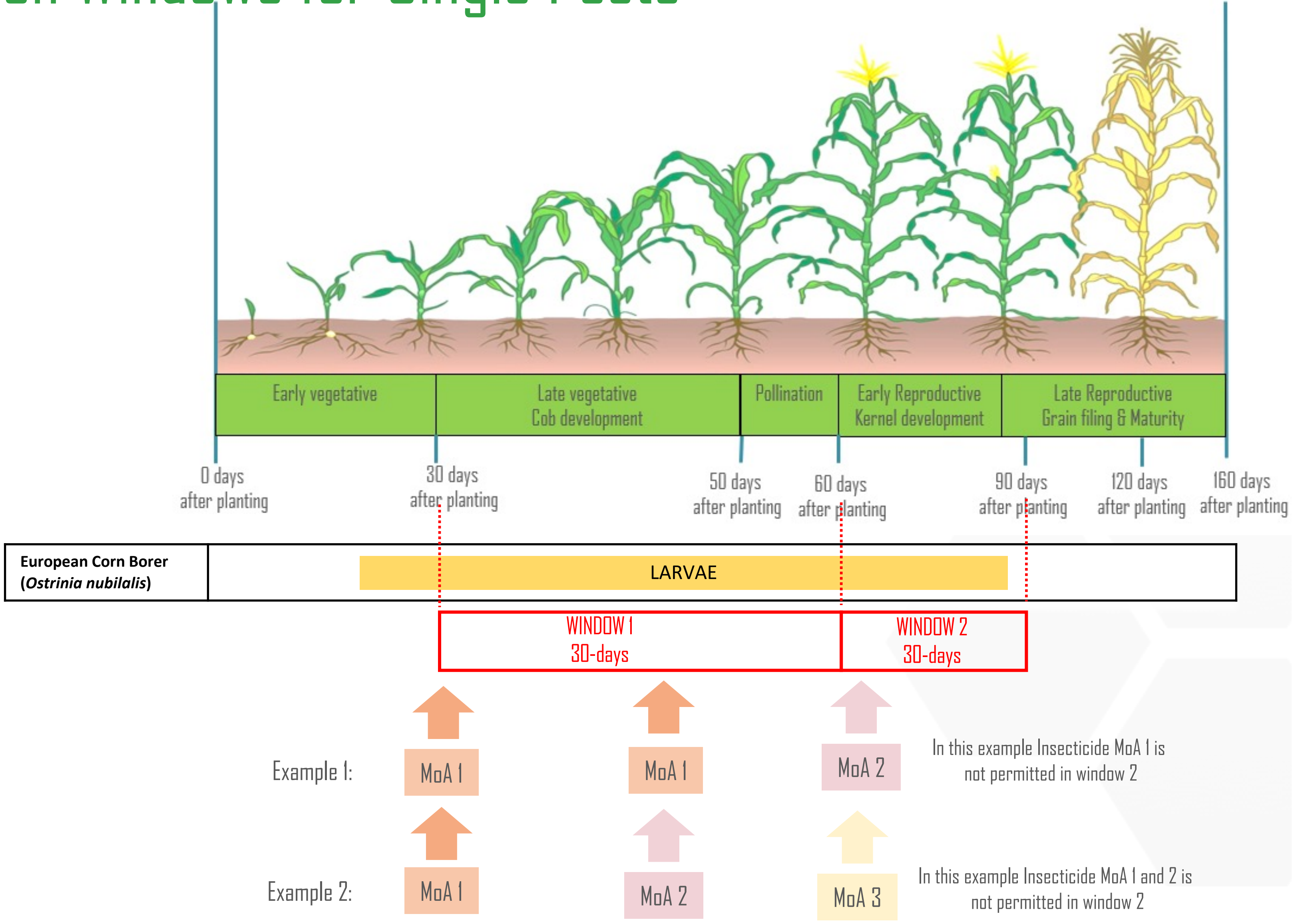
STEP 3: Creating Application Windows for Single Pests

- When dealing with a single pest, application windows can start with the first application of an insecticide.
  - In Example 1, the first insecticide application is made 30 days after planting and this initiates the first window. The duration of the window is 30-days as this is the approximate generation time of the target pest.
  - Single or multiple applications of insecticide may be made during this first window, but applying insecticides in the later half of the window should be avoided if the residual effects of the insecticide would intrude into window 2.
  - Single or multiple applications of insecticides may be made during the second window, as long as they don't have the same mode of action as the insecticides used in window 1
  - In example 2, insecticides with different modes of action are used in window 1. The grower then needs to ensure that neither of these modes of action are used in window 2.



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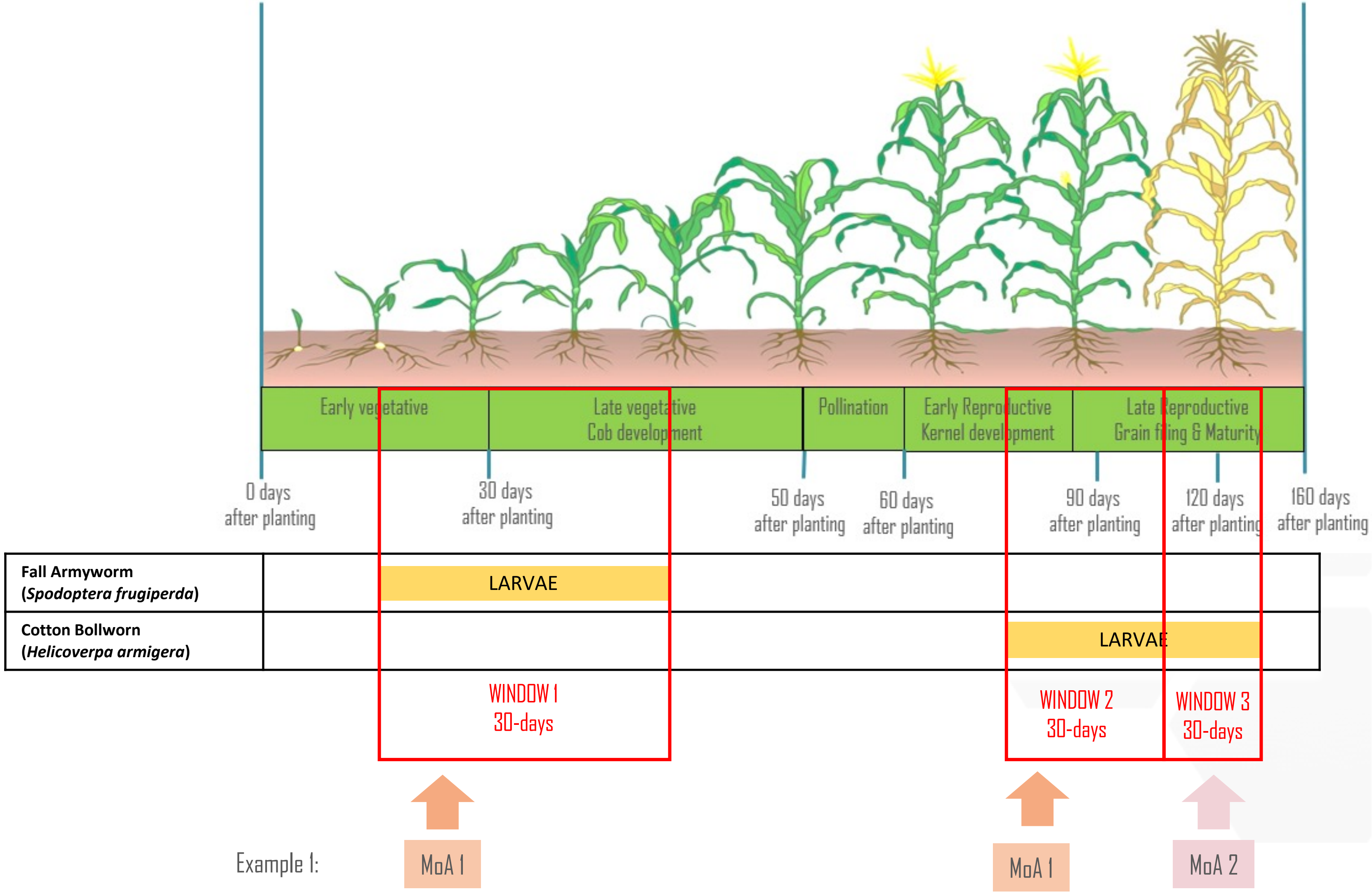
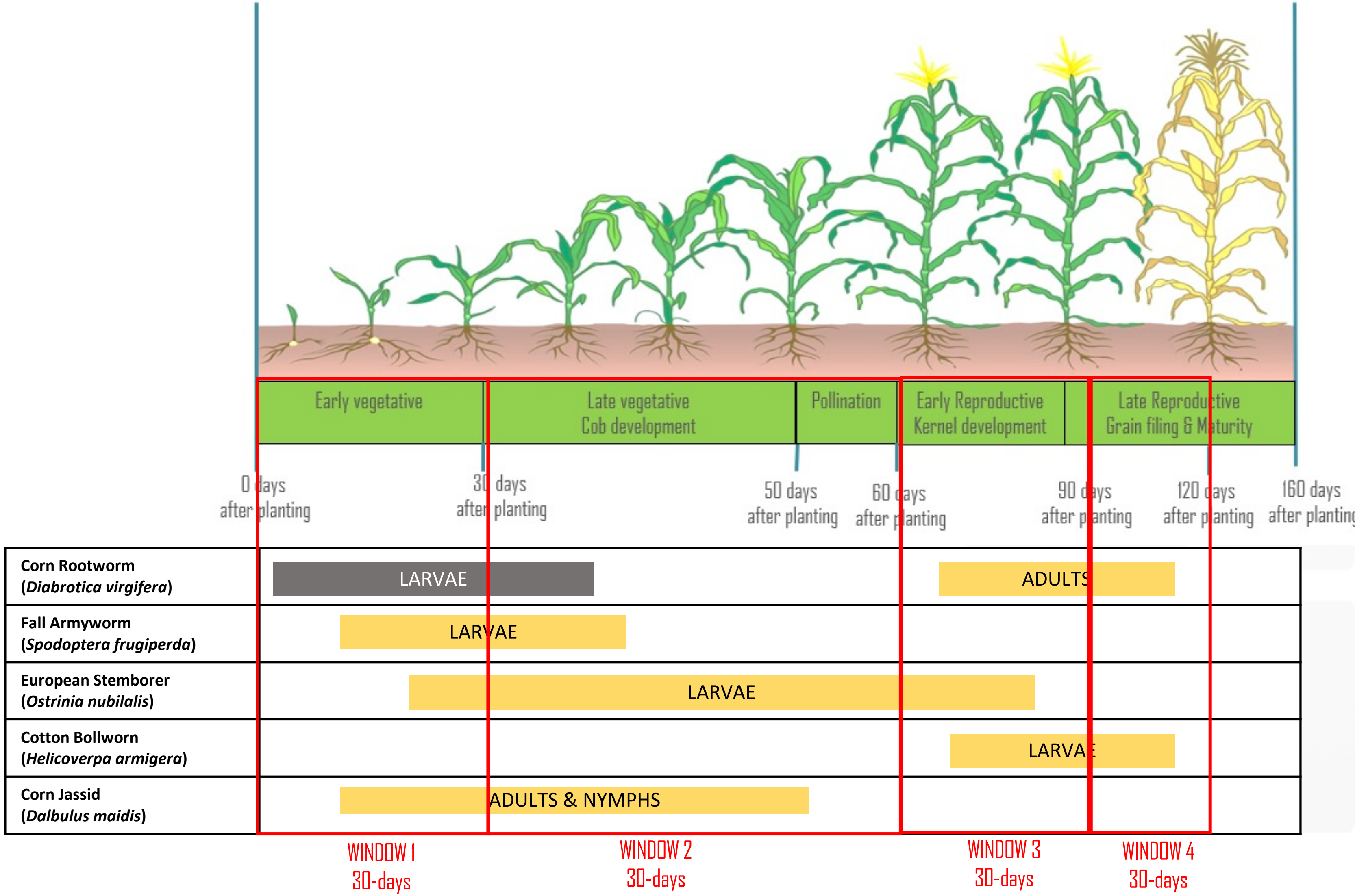
STEP 3: Creating Windows for non-overlapping multiple pests

- If multiple pests are expected at different times during the cropping season, but the pests occur at different times with no overlap it is possible to create separate periods of application.
    - In the example shown, fall armyworm occurs early in the crop and insecticides can be applied in window 1.
    - Cotton bollworm occurs later in the crop and there is no overlap with fall armyworm. Therefore, a second period of application can be established, starting with window 2.
    - In this example it is possible to use the same mode of action in window 2 as in window 1, because fall armyworm is not present in window 2 and that means the subsequent generation of fall armyworm will not be exposed to the same insecticide mode of action.



STEP 3: Creating Windows for overlapping multiple pests

- When dealing with overlapping multiple pests, it is often best to plan ahead and define windows of application based on the expected presence of the pests.
  - Note that in this example the presence of different pests overlap each other during the crop cycle. This means that application windows are required throughout the crop cycle, but not all the insects are present all the time.
  - In this example the growers know that they need to make a soil treatment at the time of seeding to control soil pests and early foliar pests. Application window 1 therefore begins at the time of sowing.
  - Once the first window is established, subsequent windows directly follow on, with the duration of the window based on the pests found within that window (in this case 30-days).
  - In this scenario, the same modes of action must not be used in sequential windows.

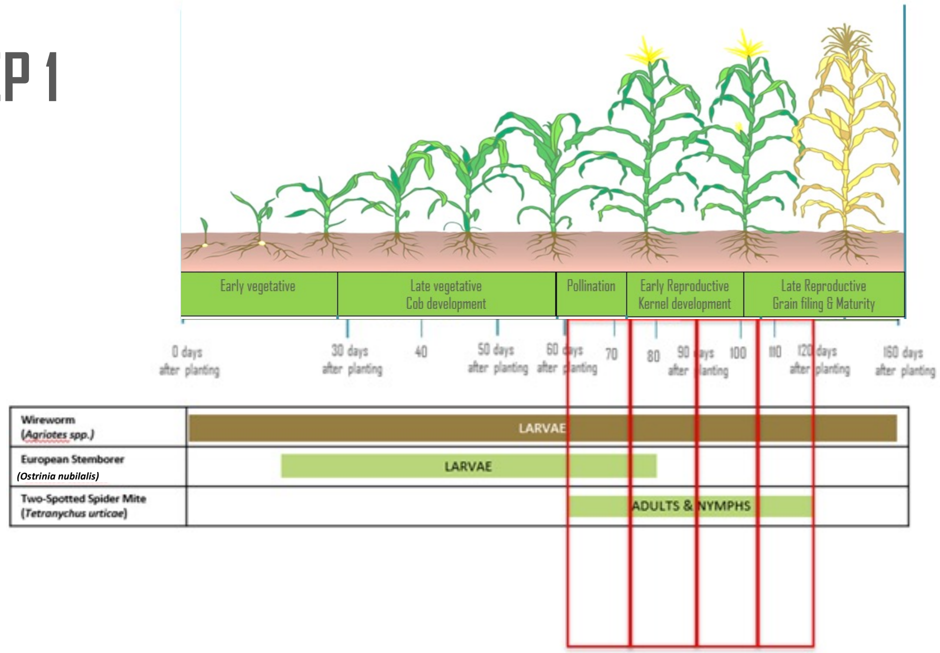


STEP 3: Creating Windows for overlapping multiple pests (1 of 2)

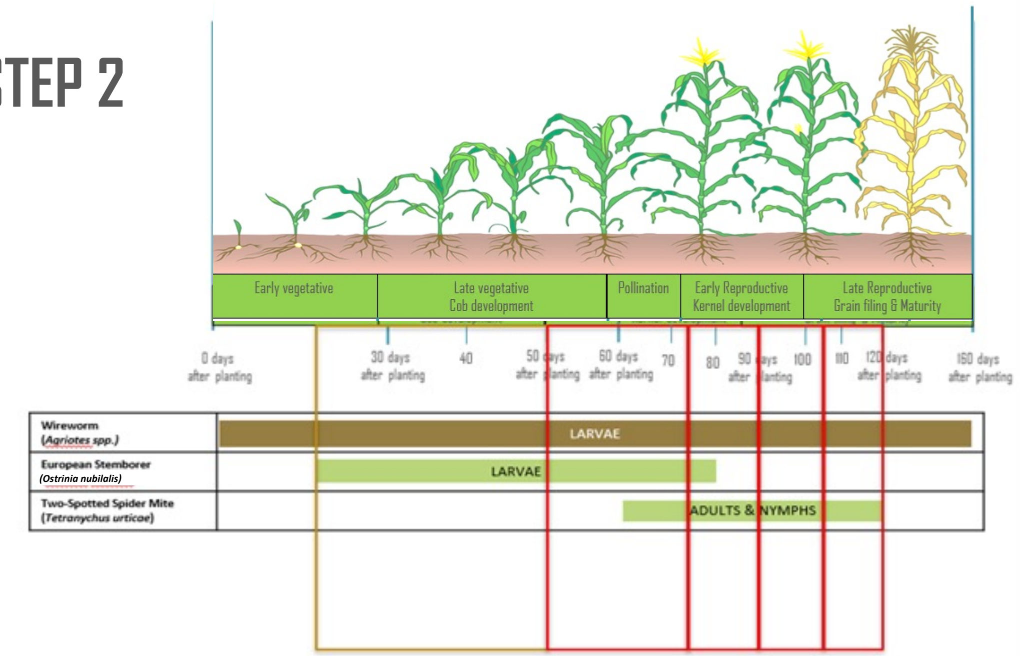
- Not all pests have the same life-cycle and some have generation times longer or shorter than 30-days.
- In a situation where you have multiple pests, with different generation times, it is best practice to establish the windows for the pest with the shortest generation times first.

- EXAMPLE: STEP 1 – Establish 15-day windows for spider-mites
  STEP 2 – Establish 30-dav windows for stemborers [1]

STEP 1



STEP 2



– NOTE 1 – The second stemborer window cannot extend for 30-days because it would overlap with the second spider-mite window. As there are no spider-mites present in the period before the first spider mite window, the window is combined to make a 25-day window.

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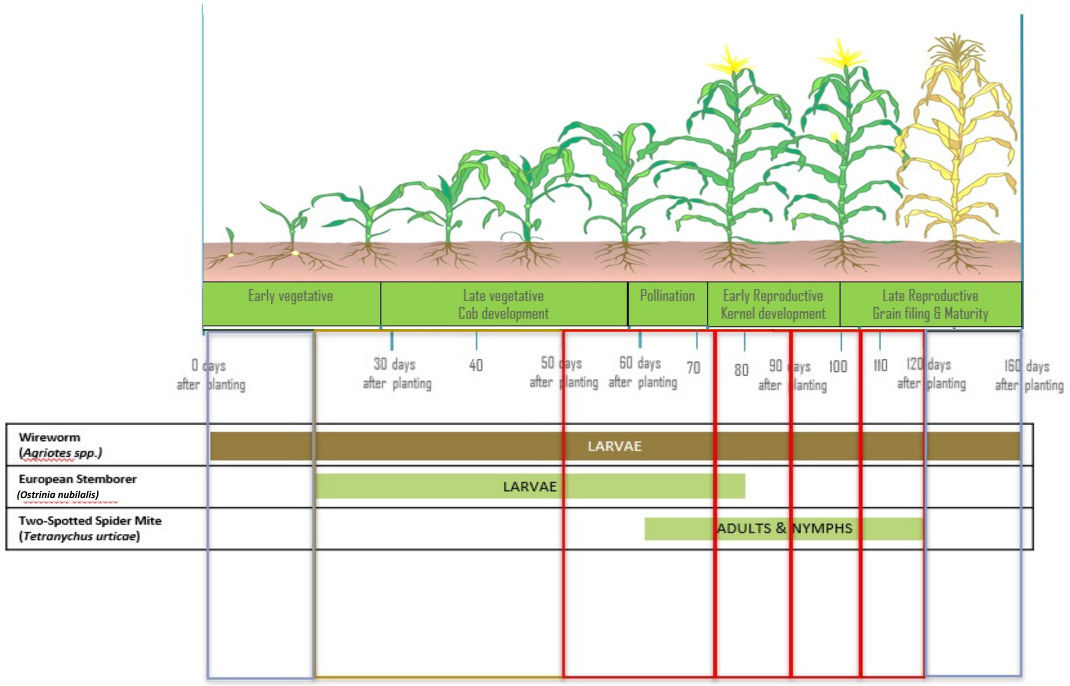
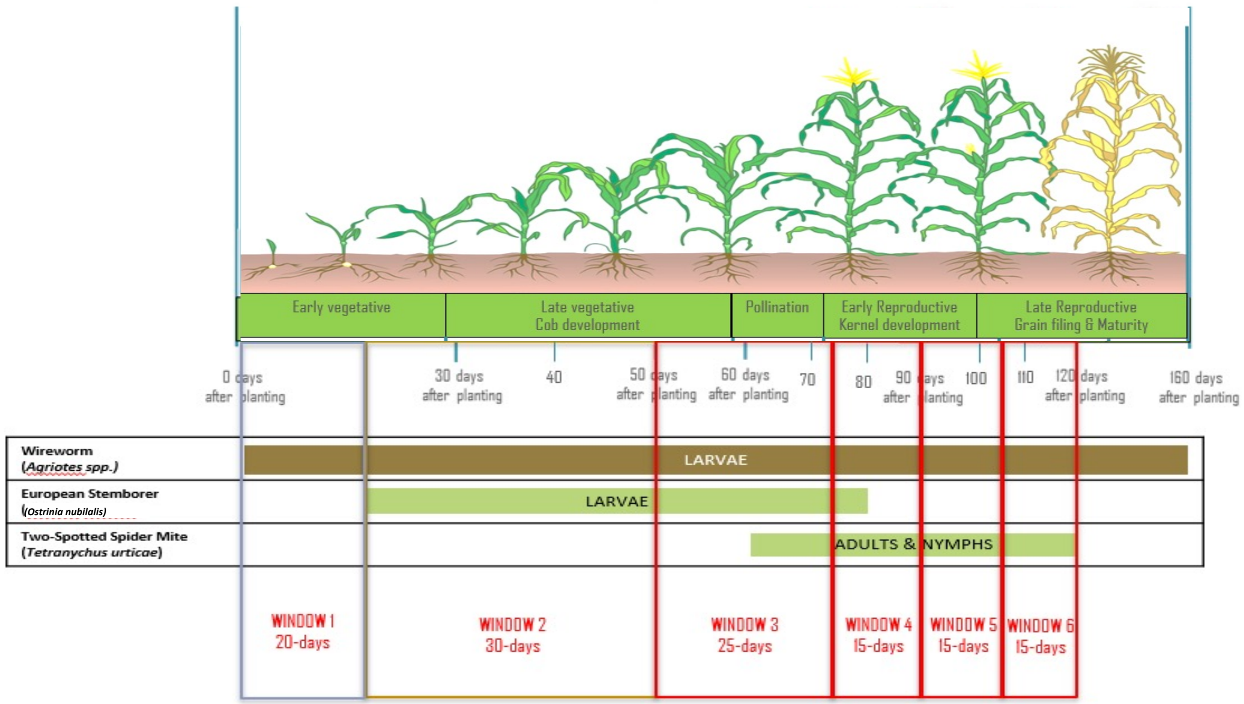
STEP 3: Creating Windows for overlapping multiple pests (2 of 2)

- EXAMPLE: STEP 3 – Establish remaining windows for wireworms
  STEP 4 – Remove any unnecessary application windows [2,3]





- NOTE 2 – The final wireworm window can be removed, as soil treatments for wireworms are generally made into the soil at planting and no treatment is made on mature plants.
- NOTE 3 –Windows 1 & 2 could be combined to produce a 50-day window as only one generation of each of the present pests would be exposed to the insecticides used and because the insecticides generally would be applied in different locations (soil and foliar). This can be left to the discretion of the program manager.

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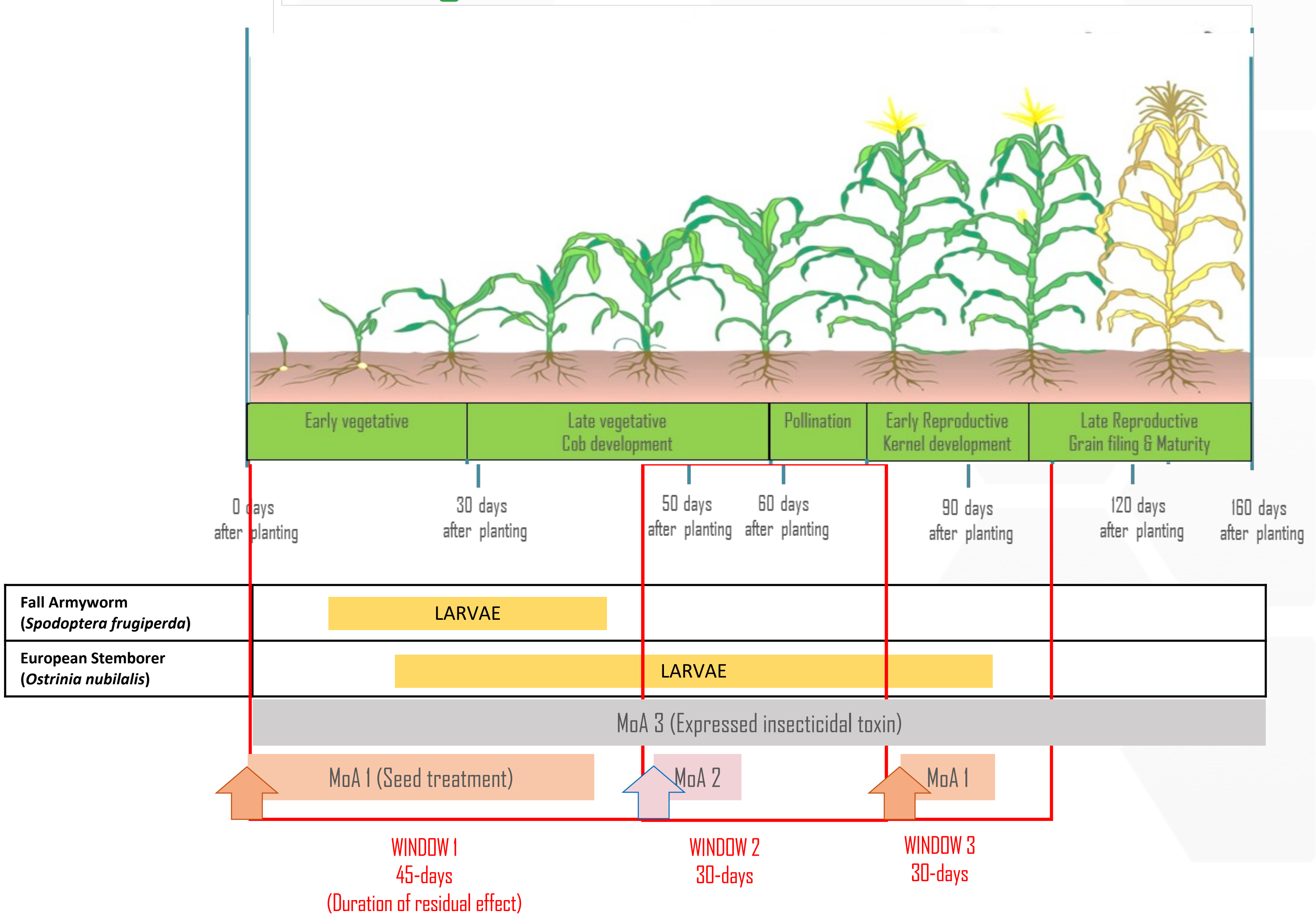
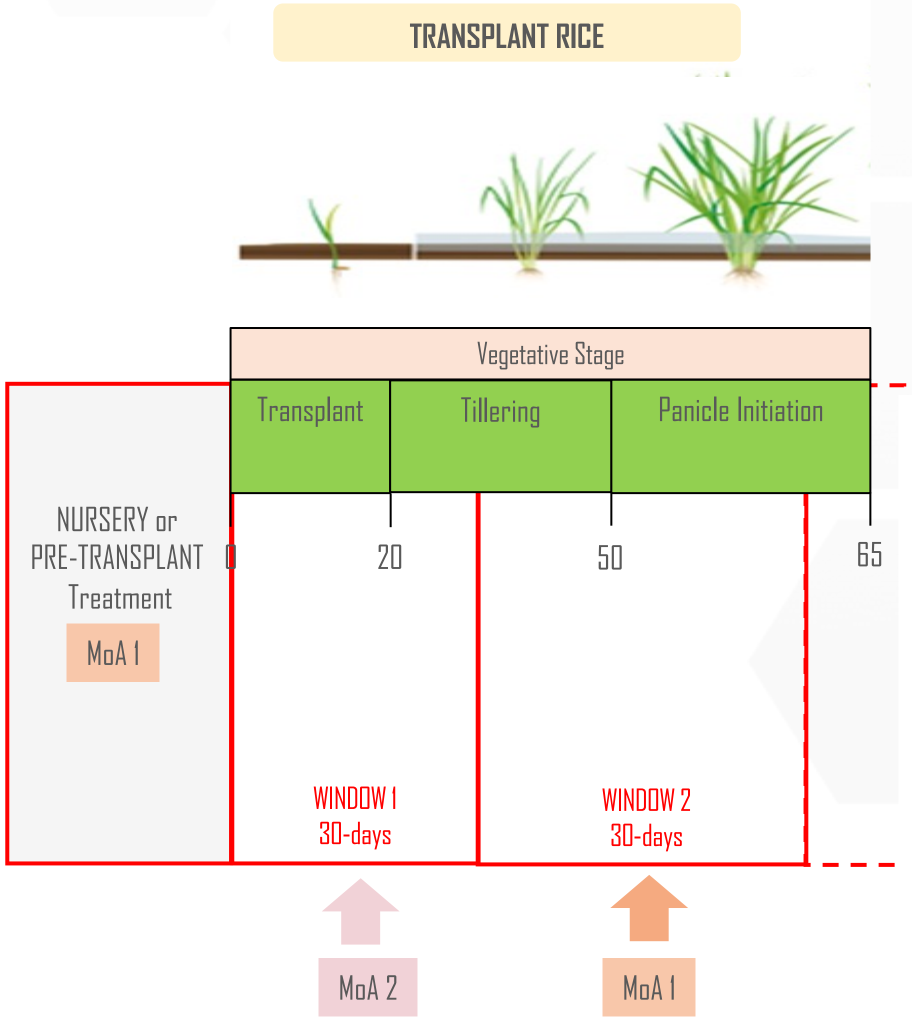
STEP 3: Pest control treatments with a long duration of effect

- Some pest control solutions have a long duration of effect, which may exceed the duration of a single generation of a target pest.
  - Insecticide seed treatments or soil applied insecticides are examples of technologies that provide a long duration of effect.
  - The duration of effect of some insecticides can also exceed the generation time of some pests when the generation time of those pest are very short (e.g. mites, aphids and flies).
  - When an insect control solutions duration of effect is longer than the target pest's generation time, the duration of effect of the insect control solution becomes the default length of the window.
- The duration of effect of genetically modified crops which express insecticidal toxins can also be very long.
  - For crops which have been modified to express insecticidal toxins, it is recommended not to use any other insect control solutions with the same mode of action (e.g. sprayable BTs).
  - Other insect control solutions should be used following application windows as normal.



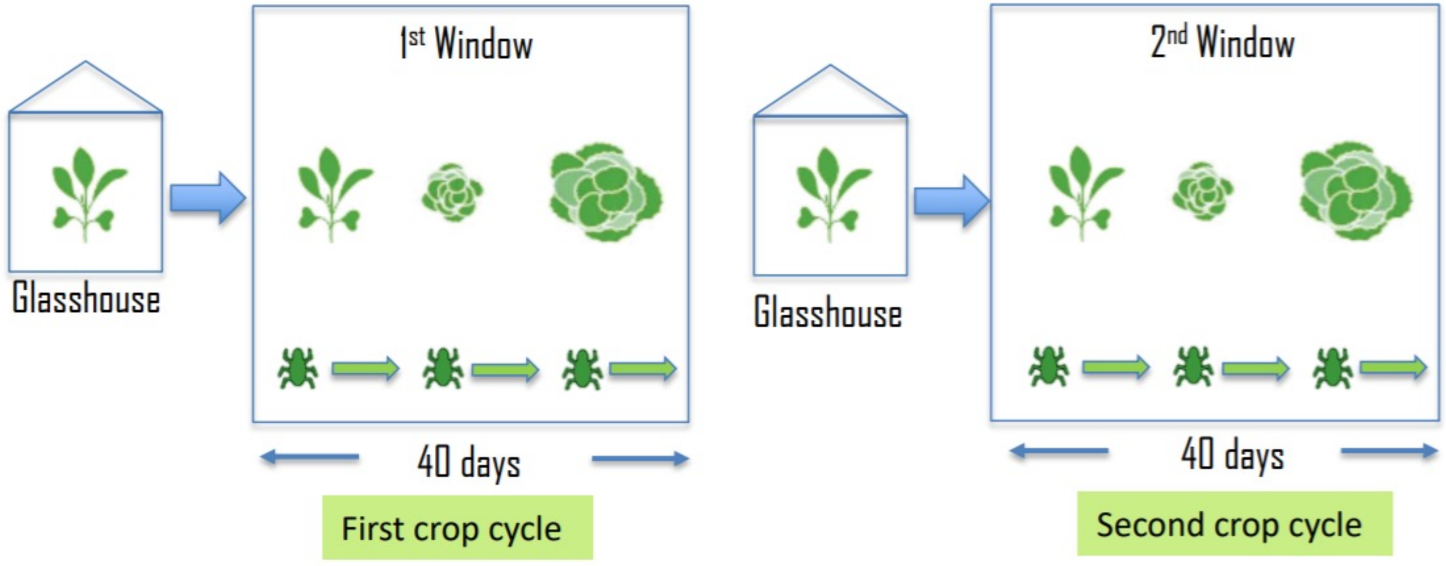
STEP 3: Insecticide use prior to the regular growing season

- When planning your insecticide program, consider any potential insecticide treatments made prior to the regular growing season, such as transplanting or nursery treatments.
- Where possible, try to avoid using the same insecticide mode of action used prior to transplanting.
- In the example shown, MoA 1 is used as a pre-planting treatment in the plant nursery. The grower avoids using MoA 1 in the first window of application to avoid sequential treatment.
- Pre-plant burn-down applications of insecticides are sometimes used to reduce or eliminate insects that may have occurred in the previous crop. These should also be treated in the same way as pre-transplant applications.



STEP 3: Short season crops with multiple plantings

- For short cycle crops with multiple plantings (e.g. lettuce), it may be necessary to consider the durations of the crop cycle as a single window of application.



	Window 1	Window 2	
Example I:	MoA 1	MoA 2	MoA 2
Example II:	MoA 2	MoA 3	MoA 1

NOTE – If insecticides have been used in the nursery glasshouse, try to avoid using the same mode of action in the following crop cycle.

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STEP 4: Selecting Appropriate control solutions

- When the time comes that insect pest controls are needed, then it is critical to be prepared and make the right choice.
  - **Plan ahead:** Investigate what insect control products are available.
  - **Review your options:** Consider the properties of your solution.
  - **Use local knowledge:** Keep updated on local conditions, such as resistance or product use restrictions.
  - **Only use products when needed:** Use economic pest thresholds.
  - **Assess the impact of your choices:** Think about the impact on natural pest predators other beneficials and the environment. Utilise pest control tools and application methods which have the least impact where possible.

It can help to make a list of pest control options to make the best choice and manage unexpected pest situations.

Insecticide	Insects controlled	Mode of action	IPM fit	Cost	Restrictions	Known Resistance in your region and surrounding regions ?
Insecticide A	Aphids Whitefly	xx	No impact on beneficials	$15 per ha	Can't use during flowering	No
Insecticide B	Lepidoptera	xx	Good IPM fit but xxx sensitive	$ 25 per ha	Maximum 1 application	Some cases of resistance reported
Insecticide C	Lepidoptera	xx	Can impact non/target insects	$5 per ha	Maximum 3 applications	Known widespread resistance, had to increase doses over past few years
Insecticide AC	Lepidoptera Aphids Whitefly Thrips	xx + xx	Can impact non/target insects	$18 per ha	Maximum 2 applications, but not during flowering.	Some lepidoptera resistant.

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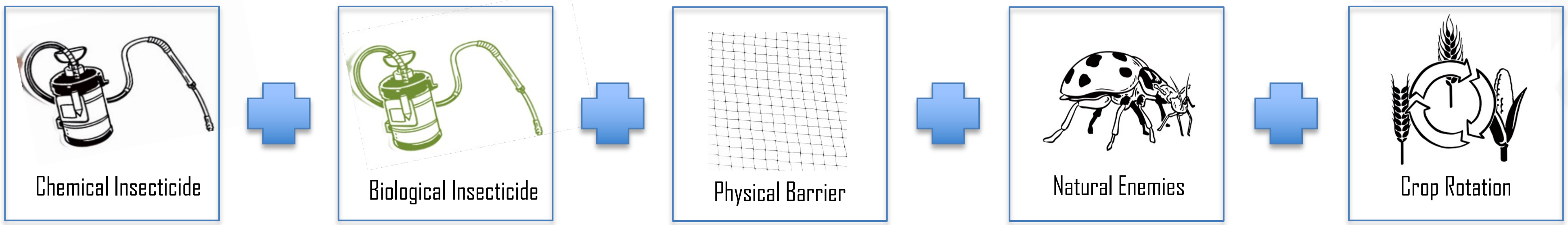
STEP 5: Incorporating alternative crop management techniques

- Incorporate Integrated Pest management (IPM) practices into your IRM and pest management program.
- IPM discourages the development of pest populations by using diverse techniques that are economic, safe and environmentally sound.

- IPM strategies consist of basic components:
  - Apply at established pest threshold levels for insecticide applications. Identify species, pest stages, population densities, and presence of natural enemies so rational pest control decisions can be made.
  - Integrate effective control techniques including cultural, chemical, biological and plant biotechnology pest control measures, which minimize effects on non-target organisms:
    - Use pest resistant or damage tolerant crop varieties.
    - Practice sanitation and removal of infested post-harvest crop residue and other pest insect host plants, including the consideration of weed management.
    - Avoid year-round cultivation of susceptible crops to limit survival of treated pest populations.
    - Consider deploying disruptive insect pheromones where appropriate.
    - Conserve beneficial organisms, such a pollinators, insect predators and parasitoids.

Example of an IPM combination



SUMMARY & LEARNINGS

- There are five main steps to constructing an IRM program.
    1. Building a crop phenology chart
    2. Adding the pest insects.
    3. Creating windows of insecticide application.
    4. Selecting the appropriate control solutions.
    5. Incorporating alternative crop management techniques.
- An IRM program should be tailored to the local situation and therefore local knowledge of the crop and environment, the pests and the control options available to the grower are essential.
- The use of IRM programs are not a guarantee that insecticide resistance will not develop, they offer the best way to slow resistance development and provide sustainable pest management.