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Resistance Management

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Pesticides are used to control various types of pests, such as weeds, harmful insects, and diseases caused by bacteria and fungi. Pesticides are often the most effective and efficient and sometimes the only pest control tools available.

Resistance to pesticides is a serious, and growing, problem. Globally, there more than 600 species of pests that have developed some level of pesticide resistance. If resistance to a particular pesticide or "family" of pesticides evolves, these products are no longer effective in controlling the target pest reducing the options available for pest management. With few new pesticides (new modes of action) in the development pipeline, pesticide users must do all they can to extend the useful life of the products currently available.

This module will explain how resistance develops, the factors that contribute to it, and how it can be avoided or managed.

- Understanding Resistance
- What is pesticide resistance?
- Preventing Resistance
- Ways to stop the spread of resistance.
- Herbicide Resistance - Understanding resistance in weeds.
- Insecticide Resistance - Understanding resistance in insects and insect-like organisms.
- Fungicide Resistance - Understanding resistance in fungus and other plant pathogens.
- Spraying by the Numbers – resistance action classification scheme that distinguishes modes of action by group numbers

Resistance to insecticides was first documented in the early 1900's when scale insects demonstrated resistance to an inorganic insecticide. Between 1914 and 1946, 11 additional cases of resistance to inorganic insecticides were recorded. Following the introduction of synthetic organic insecticides in the 1940's, such as DDT, it was not long before the first cases of resistance were detected and by 1947, resistance to DDT was confirmed in houseflies. Since then with every new insecticide introduction, organophosphates, carbamates, formamidines, pyrethroids, Bacillus thuringiensis, spinosyns and neonicotinoids, cases of resistance appeared some 2 to 20 years after their introduction in a number of key pest species.

This phenomenon has been described as the 'pesticide treadmill', and the sequence is familiar. As a result of continued applications over time the pest evolves resistance to the pesticide and the resistant strain becomes increasingly difficult to control at the labeled rate and frequency. This in turn has often led to more frequent applications of chemicals. The intensity of the resistance and the frequency of pesticide-resistant individuals in the population both increase still further and problems of control continue to worsen as yet more product is applied.

The development of pest resistance has not been restricted to insecticides but has been documented in all types of organisms including bacteria, fungi, vertebrate pests and more recently weeds.

- Colorado potato beetle has developed resistance to 52 different compounds belonging to all major insecticide classes. Resistance levels vary greatly among different populations and between beetle life stages, but in some cases can be very high (up to 2,000-fold).
- In Hawaii and Japan, the diamondback moth developed a resistance to *Bacillus thuringiensis* about three years after it began to be used heavily.
- In England, rats in certain areas have developed such a strong resistance to rat poison that they can consume up to five times as much of it as normal rats without dying.
- DDT is no longer effective in preventing malaria in some places as the mosquitoes which transmit the disease have become resistant to the chemical, a fact which has contributed to a resurgence of the disease.
- In the southern United States, the weed *Amaranthus palmeri*, which interferes with production of cotton, has developed widespread resistance to the herbicide Roundup.

Resistance is defined as a change in the sensitivity of a pest population to a pesticide, resulting in the failure of a correct application of the pesticide to control the pest. Resistance can develop when the same pesticide or similar ones with the same mode of action are used over and over again.

It is often erroneously thought that pests change or mutate to become resistant. However, it is not the individual pest (insect, weed or microorganism) that changes, but the population. Over time, the number of resistant individuals increases until the entire population is resistant to the pesticide that is used to control them.

When a pesticide is applied to a crop or treatment site, a tiny proportion of the pest population (for example, one insect or weed in 10 million) may survive exposure to the pesticide due to its genetic makeup. When the pests that survive breed, some of their young will inherit the genetic trait that confers resistance to the pesticide. These pests will not be affected the next time a similar pesticide is used. If the same pesticide is applied often, the proportion of less-susceptible individuals in the population will increase.

When the pesticide applicator recognizes that the once-highly-effective pesticide no longer controls the pest at the same rate, higher rates and more frequent applications become necessary until eventually the pesticide provides little or no control. The population may then be said to have become resistant.

The use of any single pesticide product against many consecutive generations of an insect, weed or disease can result in the development of resistance by applying selection pressure that favors individuals with genetic traits that permit them to survive exposure to a particular compound.

Pesticide resistance can become a problem when the same chemicals are used over and over to control a particular pest. After a period, the pest population may develop resistance to a chemical so that the chemical no longer effectively controls the pest population at the same rate, and higher rates and more frequent applications become necessary until eventually the chemical provides little or no control.

Although genetic factors may differ among pests that have become resistant, all cases of resistance are driven by this process of selection.

Pesticide resistance is increasing in occurrence. In the 1940s, farmers in the USA lost 7% of their crops to pests, while since the 1980's; the percentage lost has increased to 13, even though more pesticides are being used. Recent studies indicate there are now over 600 species of insects and mites resistant to pesticides. Over 270 weed species, over 150 plant pathogens, and about a half dozen species of rats are resistant to pesticides that once controlled them.

Populations of animals and plants possess the ability to respond to sustained changes or stresses in their environment in ways that enable the continued survival of the species. Such environmental stresses include physical factors (e.g. temperature or humidity), biological factors (e.g. predators, parasites or pathogens) and environmental contaminants. In any population, a small percentage of individuals will be better able to respond to new stresses because of unique traits or characteristics that they possess. Consequently, those individuals will survive and reproduce. This phenomenon is commonly referred to as "survival of the fittest."

Resistance to pesticides develops through genetic selection in populations of pests, including insects, pathogens, and weeds. Certain individuals in a pest population are less susceptible to a pesticide than other individuals. These less-susceptible pest biotypes are more likely to survive a pesticide application and produce progeny that are less susceptible. After repeated applications over several generations, the pest population consists primarily of resistant or less-susceptible individuals. Applying the same pesticide, or other chemicals with the same mode of action, is no longer effective.

Many pest species are exceptionally well equipped to respond to environmental stresses because of their short generation time and large reproductive potential. The use of chemical sprays to control insect and mite pests creates a potent environmental stress. There are now many examples of pests that have responded by developing resistance to one or more pesticides. Pesticide resistant individuals are those that have developed the ability to tolerate doses of a toxicant that would be lethal to the majority of individuals.

The mechanisms of resistance can vary according to pest species and/or to the class of chemical to which the pest is exposed. Resistance mechanisms include an increased capacity to detoxify the pesticide once it has entered the pest's body, a decreased sensitivity of the target site that the pesticide acts upon, or a decreased penetration of the pesticide through the cuticle. A single resistance mechanism can sometimes provide defense against different classes of chemicals and this is known as cross-resistance. When more than one resistance mechanism is expressed in the same individual, this individual is said to show multiple resistance.

Because the traits for resistance are passed from one generation to the next, continued stress from a pesticide may, over time, create resistance in the majority of individuals in a population. From a grower's perspective, this process would be expressed as a gradual decrease and eventual loss of effectiveness of a chemical.

Resistance to a particular chemical may be stable or unstable. When resistance is stable, the pest population does not revert to a susceptible state even if the use of that chemical is discontinued. When resistance is unstable and use of the chemical is temporarily discontinued, the population will eventually return to a susceptible state, at which time the chemical in question could again be used to manage that pest. However, in this situation, previously resistant populations may eventually show resistance again.

Of the factors that affect the development of resistance, which include aspects of the pest's biology, ecology and genetics, only a few factors can be effectively manipulated by the grower. The key factor that will delay the onset of resistance, and therefore prolong the effective life of a compound, is to limit the number of applications of the same or similar materials to one per season. Rotation of chemicals from different classes within or between years may further reduce the likelihood that resistance to any one material will develop. If resistance to a particular chemical does develop in a pest population, use of that material and materials in the same class, should be discontinued.

The best way to manage pesticide resistance is to focus on three strategies: avoid, delay, and reversal.

Avoid the development of pesticide resistance problems with the use of Integrated Pest Management (IPM) programs, which reduce reliance on chemical control. Integrating non-chemical approaches such as pheromone mating disruption and cultural controls can also help delay resistance.

Crop or site management tactics used to prevent a pest from becoming established

- Plant pest-resistant crop varieties.
- Maintain optimum crop growth through proper fertilization, irrigation, etc.- a healthy crop is more competitive with weeds and often less susceptible to disease and insect attack.
- Rotate crops, particularly those with different pest problems.
- Use tillage at times for weed control (where erosion is not a problem)

Following these Integrated Pest Management practices also help prevent resistance:

- Scout fields regularly to respond quickly to changes in pest populations. Pest monitoring will help determine if pesticides are necessary (based on economic thresholds) and the best application timing (when pests are most susceptible), thus helping to reduce the number of applications. Application of pesticides to pest populations that are beyond the optimum timing (e.g. large weeds, late instar insect larvae or disease in the epidemic phase) can speed the development of resistance.
- When available and appropriate, choose selective pesticides that break down quickly (avoid persistent pesticides).
- Where practical, use spot treatments, barrier treatments or banded treatments to better target pest populations or the zone where pest control is required.
- Use bio-control if available.
- Control alternate hosts of insects and diseases.
- Clean tillage and harvest equipment before moving from fields infested with resistant species.

Delay resistance by using pesticides only when needed, as indicated by monitoring, and when pests are at a susceptible stage. If pesticides must be applied to the same crop or site, delay can also be achieved by rotating to a pesticide with a different chemical classes or mode of action (MOA). (e.g., organophosphates, carbamates, pyrethroids, biologicals, etc.) and by rotating their use.

Adhere to label rates for the specific pest, crop, conditions, and location. Follow label directions for proper application method (carrier type, volume, use of adjuvant, etc.) and rate. When applying the maximum label rate of a pesticide, combine as many resistance management strategies as possible because high rates enhance the selection pressure for resistance. Using rates lower than those recommended for a particular pest favors survival of the stronger individuals in the pest population.

Reversal of resistance can occur in some pest populations by allowing time between applications of a class of pesticide to permit resistant populations to become diluted by pesticide-susceptible individuals. However, no one can predict if or when resistant pests will change back to a susceptible population. The best practice is to reduce the chance of resistance developing in the first place.

Key elements of resistance management include minimizing pesticide use, avoiding tank mixes, avoiding persistent chemicals, and using long-term rotations of pesticide from different chemical classes.

Minimizing pesticide use is fundamental to pesticide resistance management. IPM programs incorporating pest monitoring in California, New York, Maryland, Canada, and elsewhere have demonstrated 25 to 50% reduction in pesticide use with an increase in crop quality. Ask your extension agent or consult a crop care advisor for information on setting up and maintaining an IPM monitoring program. Such a program will help determine the best application timing for pesticides (when they will do the most good), thus helping to reduce the number of applications.

The use of non-chemical strategies, such as pest exclusion (e.g. purchasing disease free transplants), host-free periods, crop rotation, biological control, and weed control may reduce the need to use chemicals and consequently slow the development of pesticide resistance.

Tank-mixes and Pre-packs are combinations of two or more pesticides applied as a single mixture. Tank-mixing allows for adjusting of the ratio of pesticides to fit local pest and soil conditions, while premixes are formulated by the manufacturer. The combinations are designed to improve individual pesticide application results and, if the combination is composed of pesticides with different modes of action, prevent or manage resistance. The different pesticides in the mixture must be active against the target pest so that biotypes resistant to one mode of action are controlled by a pesticide partner with a different mode of action.

Never combine two pesticides with the same mode of action in a tank mix (e.g., two organophophates such as acephate and chlorpyrifos). Such a 'super dose' often increases the chances of selection for resistant individuals. In some cases, mixing pesticides from two different classes provides superior control.

Theoretically, repeated use of any tank-mix or pre-pack combination may give rise to resistance, however the probability that resistance mechanisms to each chemical class in the tank mix will arise together is very low.

Avoid persistent chemicals. Insects with resistant genes will be selected over susceptible ones whenever insecticide concentrations kill only the susceptible pests. An ideal pesticide quickly disappears from the environment so that persistence of a 'selecting dose' does not occur. When persistent chemicals must be used, consider where they can be used in a rotation scheme to provide the control needed and with a minimum length of exposure.

An example of a class of persistent materials that cause some concern with regard to vegetable pest resistance management are the new neonicotinoid compounds used to control silverleaf whitefly in tomatoes. Growers are advised to follow label recommendations carefully to avoid prolonged exposure to these materials, which could lead to the buildup of pest resistance.

When pesticides are the sole or predominant method of pest control, resistance is commonly managed through pesticide rotation. Resistance management strategies for insects, weeds, and fungal pathogens all include rotating classes of pesticides (e.g., pesticides with the same mode of action such as pyrethroids, organophosphates, carbamates, etc.).

However, the strategies used in rotations differ. For example, with fungicides, it is suggested that classes be rotated every application. With insecticides, it is sometimes suggested that longer-term rotations be used. This means that a class might be used for two or three consecutive applications, depending on the target pest and its life cycle, before rotating to a new class of materials. If insecticides are switched with every application, individuals are being subjected to numerous pesticides and selection for multiple resistance may occur. Short-term rotations of insecticides can basically function as a tank mix.

Pesticide manufacturers may, on product labeling, require that no more than a specified number of consecutive applications of a pesticide class be made before alternating to a different pesticide class. This manufacturer requirement is intended to extend the useful life of a product.

If there is only one chemical that is effective against a pest and other available products are only marginally effective, a good strategy to follow is to use the marginally effective materials at times when pest pressure is less severe and to reserve the effective material for those periods of time when control must be most effective.

For many reasons, the availability of pesticide products that can be used in rotation against pests is decreasing. The costs of developing a pesticide (i.e., the cost of research and testing, product development, etc.) are significant. Millions of dollars are spent on chemicals that may never become marketable products. Regulatory actions have affected pesticide availability. The U.S. Environmental Protection Agency has banned and restricted many pesticides in the past two decades.

Another factor in the decreasing availability of pesticides, especially from the supply of existing pesticides, is the EPA's reregistration of pesticides. This reregistration program often requires additional testing of pesticides to determine if their use would possibly endanger the health of humans and our environment. Between pesticide cancellations and the reregistration process, whole classes of active ingredients are at risk of being lost from future use.

Spraying by the Numbers

Increasing concern over pest resistance by industry has prompted industry-based formation of action committees that work to conserve pesticide efficacy and to limit crop losses due to development of pesticide resistance. Pesticide action committees have been formed for:

- Fungicides: FRAC - Fungicide Resistance Action Committee
- Herbicides: HRAC - Herbicide Resistance Action Committee
- Insecticides: IRAC - Insecticide Resistance Action Committee
- Rodenticide: RRAC - Rodenticide Resistance Action Committee

These action committees are technical working groups of CropLife International. Its website outlines the mission of these action committees to: facilitate communication and education on herbicide, insecticide, fungicide and rodenticide resistance. They promote the development of resistance management strategies in crop protection to maintain efficacy and support sustainable agriculture and improved public health.

To help ensure standardization and to make it easy to recognize different classes or modes of action, the U.S. Environmental Protection Agency (EPA) has requested that manufacturers voluntarily include a pesticide's MOA group number in a standard format on the label. To this end, the pest- specific Insecticide (IRAC), Fungicide (FRAC) or Herbicide (HRAC) Resistance Action Committees have created a classification scheme that distinguishes modes of action by group numbers. The Resistance Action Committees are an industry-organized group of pest management specialists that develops resistance management guidelines for global implementation. Products sharing the same group number have the same MOA. When a premix label displays the group number(s), the user can easily determine the modes of action included in the premix.

Pesticides are grouped by 'families' or 'classes' that share a common mode of action and chemical structure. The Mode of Action Group (A, B, etc.) refers to the biochemical process inhibited by the fungicide, such as cell wall synthesis, respiration, etc. Sub-groups (A1, A2, etc.) within a Mode of Action Group refer to specific biochemical target sites of action. A Group Name (e.g., Carboxylic acid, Benzamides) is given to each sub-group. A group will contain various compounds (insecticide, fungicide, or herbicides) that are known by their common name. The Common Name is printed in the Ingredients Statement of the fungicide label.

If a product contains more than one active ingredient (pre-mix), both RAC Codes will be listed in the RAC Code box. If RAC codes are not found on the front of the label, they may be located within the resistance management section of the label.

Products with the same RAC Code have similar mode of action and therefore could exhibit cross resistance. Thus it is critically important to know the group code for the fungicides being used for a particular pest problem to avoid alternating among chemically similar compounds. In the absence of other alternatives, it may be possible to rotate between subgroups (e.g., D1 and D2) if it is clear that cross resistance mechanisms do not exist in the target populations.

Consult local expertise or visit the various RAC Group websites (Fungicides - **http://www.frac.info/**) , (Herbicides - **http://hracglobal.com/**), (Insecticides - **http://www.irac-online.org/**) for more information.

In addition to considering MOA group numbers in the selection of herbicides, review all resistance management recommendations printed on the herbicide label. This may include information on the best management practices for a particular product, target species of most concern and the maximum number of consecutive applications that should be made before rotating to products containing herbicides with different group numbers. Although the development of weed resistance to herbicides is relatively new; the problems caused by the march of resistance weeds like Palmer Amaranth in agronomic crops across the south has recently drawn a lot of attention. Even though herbicide-resistant weeds pose their biggest threat to agronomic crops, fruit or vegetable growers should not let their guards down.

Just as with fungicides and insecticides, growers need to be thinking about what they are doing, what they are spraying, and how they are managing weeds and adopt a multi-faceted program approach to stay ahead of the evolution of herbicide-resistant weeds.

Tillage is an effective solution, but many tomato, pepper, eggplant and melon crops are grown on plasticulture, where tillage is not an option. Growers must turn to labor-intensive hand weeding.

Even if they don't yet have herbicide-resistant weeds, growers should rotate their herbicidal modes of action. If you use one herbicide this year, make sure you switch to another mode of action next year.

Tank mixes or premixes that contain two or three different modes of action also are effective. If a weed is resistant to one herbicide's mode of action, the others might control it. This process may be more expensive short term but by delaying or preventing development of resistant weeds, it will be beneficial.

Cultural practices, such as cover crops or mechanical cultivation, also can help reduce the total use of chemicals, and that's a good thing.

As with other pests, the more growers rely solely on chemicals, the more potential for the emergence of resistant will exist.

It is important to remember most pest control failures are not due to resistance. Before assuming pests surviving a pesticide application are resistant, eliminate other possible causes of poor control such as:

1. The pest was not identified correctly and the wrong pesticide was used;
2. An incorrect dosage of pesticide was used or the pesticide was applied in an improper manner;
3. The pesticide was not applied at the appropriate time (i.e., pest target was not in the area at the time of

treatment or was in a life stage not susceptible to the pesticide); and,

4. Pests re-infested the area following the pesticide application.

Other reasons for failures include:

1. Pest resurgence--the natural enemies (i.e., predators and parasites) of the pest as well as the pest are eliminated by a pesticide application, the natural enemy populations can take longer to rebound than the pest population, therefore pest populations increase rapidly as the pesticide residues decrease; and
2. Secondary pests--certain pests that usually do not occur at significant levels can reach damaging levels after a pesticide application because their natural enemies are eliminated by the pesticide.

A proactive approach using all applicable Integrated Pest Management tactics is the most effective way to avoid pest resistance. Effective IPM-based programs will ensure that all control tactics, including pesticides, are used at the proper time and only to reduce pest damage to acceptable levels. This will reduce costs from unnecessary pesticide applications, insure that control tactics are used when they will be most effective and reduce or delay the possibility of resistance developing in a pest population.

The primary objective of this approach is to reduce selection pressure by: 1) selecting and using pesticides correctly; and, 2) managing fields, farms, or sites to create conditions less conducive for pest survival.

Doing what it takes to avoid resistance is a better alternative than having to pay the price for overcoming resistance once it occurs.

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