Improving the Safety and Quality of Fresh Fruits and Vegetables: A Training Manual for Trainers

Section IV

Pesticides and Food Safety

Introduction

Pesticides and the handling that is required for their use are regulated in most developed countries. The goal of regulation is to protect human health and the environment. ***Protection*** is the key word.

If the regulatory system sets appropriate limits and pesticides are applied properly, consumers of fresh fruit and vegetables are protected from exposure to excessive pesticide residues on the product. Farm workers are protected from occupational exposure, people who are near farms are protected from incidental exposure and the environment is protected from pollution. This Module is an introduction to pesticides, their use and control of their residues.

Definitions

Formal definitions are provided for critical terms that will be used throughout this Section.

Pest

For the purpose of U.S. law and regulations, a pest is defined as any insect, rodent, nematode, fungus, weed, bacteria, virus, or other microorganism, or any form of terrestrial or aquatic plant that the U.S. Environmental Protection Agency (EPA) declares to be a pest under the law.

The EPA definition excludes microbes on or in a living human or other animal. Recall that in Section II on GAPs, these microorganisms were included because of their critical involvement in food safety. To meet the objectives of this manual, human pathogens, birds and all wild and domestic animals are included in the category of pests.

Pesticide

A pesticide is any algicide, antifouling agent, antimicrobial, attractant, disinfectant, fungicide, fumigant, herbicide, insecticide, miticide, pheromone, repellent, rodenticide, termiticide, or plant incorporated protectant.

The legal definition, for the purpose of U.S. law and regulations, includes the above categories but is written in a more general style. A pesticide is defined as any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pests or used as a plant growth regulator, defoliant or desiccant. This is found in the Federal Insecticide, Fungicide and Rodenticide Act (7 U.S.C. 136 et seq.), which includes not only the pesticide active ingredient but any inert materials as well.

Pesticide Residue

Residue refers to the amount of a pesticide chemical or ingredients in the pesticide mixture found in or on a raw agricultural commodity or in a processed food. The definition also includes residue of degradation products of the pesticide chemical, whether those products are the result of plant metabolism or some other degrading process. Thus the residue of concern may be the parent compound, a metabolite of the parent compound or a combination of the two.

Pesticide Tolerance

Tolerance is the amount of residue legally allowed to remain on or in the commodity at harvest. For the establishment and regulation of tolerances, agencies must consider the range of crops the pesticide is registered on or could be registered on in the future. They also must consider additional sources of residues in meat, poultry, milk or other food products if the pesticide is carried forward into the food processing industries.

Pesticide Registration

Registration of a pesticide is a scientific, legal and administrative process to enable authorities to control quality, levels, labeling, packaging and advertising of the product. Pesticides used in the U.S. and those used for products imported into the U.S. must be registered with the U.S. Environmental Protection Agency (EPA).

Control Methods to Mitigate Crop Damage from Pests

Growers have a number of options for pest control that can help to reduce the requirement for chemical pesticide applications. They should review all of the following methods as they develop their pest management strategies.

Biological Control. Living organisms, sometimes called biopesticides, are used to control pests. In a perfect world biological control would be the only method needed. Biopesticides fall into three major classes: (1) microbial pesticides contain a microorganism, e.g., a bacterium, fungus or virus that attacks a specific pest; (2) plant pesticides are substances that the plant produces from genetic material that has been added to the plant, and; (3) biochemical pesticides are naturally occurring substances, such as pheromones or plant growth regulators, that control pests. Biological control also includes the enhancement or release of predacious or parasitic insects or fungi to control insect pests or weed species.

Plant Resistance. Crop plants are bred to produce varieties that resist or tolerate disease, insects and other pests. They may be genetically modified to allow them to withstand herbicides so that only weed species are killed when treated with chemical pesticides.

Cultural Methods. This includes crop rotation, soil tillage, trap crops, strategic scheduling of planting or harvest time, and intercropping with other crops or with varieties that repel pests.

Mechanical and Physical Methods. These include techniques such as collecting pests with traps, suction devices or by hand and the use of fire, heat, cold, sound, barriers and screens.

Chemical Methods. This encompasses the use of any synthetic or organic chemical pesticide as defined earlier.

Integrated Pest Management (IPM). This is a pest management approach that uses all available pest control methods, which may include but is not limited to the judicious use of pesticides, to optimize a crop's ability to resist the pest with the least hazard to humans and the environment.

Hazards Associated with Pesticide Use

From the perspective of consumers, the primary concern for pesticide use is the possibility that excessive residues in food could cause acute or chronic illness. Cases of immediate illness from pesticide contamination are rare. Consumer groups tend to focus on the potential hazard of low-level pesticide intake over the long term. A myriad of chronic illnesses have been blamed on agricultural chemicals. This has contributed to the interest in organic farming and other natural approaches to diet and lifestyle. The human element is discussed in considerable detail in Module 5.

A second hazard associated with pesticide use is potential economic damage to adjacent nontarget crops or harm to beneficial insects, wildlife and the environment. Run-off, percolation or drift into water is of special concern since the pesticide could damage wells or flora and fauna far from the point of application of the substance.

The final hazard concerns the health and safety of workers who handle pesticides. In the U.S. and many other countries there are Worker Protection Standards (WPS) that regulate employers' responsibility to provide safety measures, including protective equipment, for handling practices as a matter of law. Some aspects of WPS are discussed in Modules 4 and 5. Despite legal requirements, there have been well documented and publicized abuses of the law that keep public concern heightened.

Legal Principles of Pesticide Residue Minimization

A goal of regulators and growers alike is to apply the minimum amount of pesticide that allows for adequate control of the pest. This in turn minimizes the amount of residue left on food. Legal requirements (the label) must be followed at all times. In addition to the label, each pesticide is accompanied by a Material Safety Data Sheet (MSDS) that must be made available to those who work with the material.

The pesticide must be legally allowed on the crop and the location to which it is applied. Environmentally sensitive areas, such as native wetlands, that surround or border a production area might be cause for placing a restriction on the pesticide use on that particular site.

As stated previously, the pesticide must be used according to label directions. These are based on extensive testing for potential adverse effects on humans, animals and the environment. The label directions include specific information on dose, timing of applications, etc. Additional sections of the label address personal safety requirements for handling the pesticide, protections for wildlife, storage and disposal instructions, and other requirements. Research trials provide results that can be used to develop models for the prediction of residue levels remaining on crops under specific sets of conditions, discussed in Module 3.

Following application of a pesticide, there is a minimum amount of time that must pass before anyone can reenter the field. Appropriate signage must be placed to alert workers of the danger of reentry.

A minimum interval must be allowed from the time of pesticide application to the time of harvest in order for the chemical to degrade to a level that is at or below the tolerance. This interval may be influenced by the crop site, weather and life cycle of the crop. All of these variables are considered in the development of a pesticide label.

There are three distinct periods in the life of a commodity during which pesticide residues are influenced by biological processes, the environment or other external factors, such as cultural practices. These periods are the time from application of the pesticide until absorption by the plant, the time from absorption until the product is harvested and the time that the product is held in the postharvest environment. Regulatory agencies require pesticide manufacturers to conduct adequate studies and submit data to determine the fate of pesticides during these periods and to predict residue levels. This allows regulatory agencies and growers to identify practices that minimize residues while allowing for the intended action of the pesticide.

Factors Affecting Pesticide Residues in Crops

There are a number of variables in the use of pesticides that can influence the amount of residue that will remain on the crop at harvest and beyond. Researchers and regulatory officials must consider as many of these as possible as they develop labels for pesticides. Growers may go a step further toward residue minimization if they tailor their production practices to limit the amount and improve the efficacy of any pesticides that they apply, taking care always to adhere to label requirements.

Answers to the following series of questions offer insight into the prediction of residue levels and identify some of the practices that growers may implement to minimize residues.

Where is the pesticide deposited in the field? This is determined largely by the method of application and the equipment used, both of which usually are crop specific. For example, a low-growing field of strawberries or leafy greens might be treated with a low-volume over-the-row precision applicator that places most of the pesticide directly onto the plants. In contrast, tree fruit may require an air blast applicator using a relatively large volume of spray material in order to reach the interior of the tree canopy. Overspray will be deposited on the soil and might be carried by wind into surrounding areas. The residue level in the crop depends largely on the amount of pesticide that is applied directly to the crop. An additional environmental concern is residue in the soil or nearby areas.

How much pesticide is applied? The maximum allowable application rate and number of applications are specified on the label. However, growers should not feel compelled to always use the maximum amount. The implementation of an Integrated Pest Management (IPM) program defined earlier, in which pesticides are applied only in response to pest pressure that is determined by professional scouts, is a way for growers to minimize chemical use and thereby residues.

How much unintended pesticide is deposited on or absorbed by the plant? Hopefully the answer to this question is zero. However, unintended exposure can occur when pesticides are carried by wind through the air (drift), by water that has been contaminated or by soil particles that are caught by the wind or suspended in water. It is the grower's responsibility to handle pesticides in a manner that does not allow unintended exposure of a crop. This can be challenging if a third party is contracted to do the pesticide application as it requires monitoring of the practices of others.

How much pesticide will penetrate into the plant? This is determined largely by the chemical formulation and the plant characteristics. Liquid formulations are generally more easily absorbed than dry formulations, which may require watering in order to reach their target. Waxy or hairy leaves tend to repel pesticides more than smooth surfaced leaves, but arguably hairy leaves could better trap the particles of a dry formulation. These variables are considered by those responsible for developing the pesticide label, but growers also should be aware that plant characteristics affect absorption.

How will the pesticide be degraded by the plant? There are three considerations: pesticide chemistry, plant species and weather. Water soluble pesticides generally are metabolized more quickly and are less likely to accumulate in the plant than fat soluble compounds. Different plant species are known to detoxify pesticides at different rates, depending on the specific pesticide. Cooler temperatures tend to slow the degradation. This is addressed in Module 3.

Where will the pesticide and its breakdown products end up in the plant? Obviously, the plant part(s) in contact with the pesticide will be the first host for the chemical, however translocation of pesticides can occur. Tissues or organs where pesticides accumulate are sometimes referred to as storage "depots." Older classes of pesticides are more fat-soluble and more likely to be stored in parts of the plant with higher oil content. The newer, more water-soluble classes are more likely to be removed through transpiration. Storage in the plant also can be influenced by timing of application relative to the type and developmental stage of the crop. One should note if the plant is using or storing energy during the season in which a pesticide is applied. This may indicate whether the pesticide is moving into the leaves, fruit or down into the roots.

How much of the pesticide and its breakdown products will remain in the plant? Several factors are involved and the relationships between these factors are complex. Different plant parts may absorb pesticides and facilitate their translocation within the plant at different rates. Once the pesticide has entered plant cells, biotransformation reactions can occur to degrade the pesticide. These are discussed in more detail in Module 3. Finally, the time that elapses between pesticide application and harvest is a factor. If this interval is increased it allows more time for biotransformation or other degrading processes to reduce residues to the tolerance, or preferably, below the tolerance.

Can a plant metabolize more than one pesticide at a time? If multiple pesticides are mixed and applied in one treatment, or if some residue(s) remains in a plant when the next application is made, the plant will need to detoxify more than one pesticide at a time. In this case pesticides may be competing for the same biotransformation enzymes and degradation may be slower.

What happens after the crop is harvested? Recall that the legal tolerance for residue is set for the time of harvest, but postharvest procedures can impact the residue level. Washing fruits and vegetables helps to remove surface residues. Processing, depending on the specific process, may either reduce or concentrate residues. Cooking almost always reduces residues. Peeling fruits and vegetables effectively removes surface residues, but also alters the nutritive value, as it removes vitamins and nutrients contained in the skin.

What happens to pesticides in animal feed, forage or pasture? Animals, including humans, have their own biotransformation processes. The important point to emphasize is that pesticides for plant production must be used in strict accordance with the label in order to minimize the amount of residue that animals ingest.

Interaction of the individual factors affecting pesticide residue levels is complex. Large research trials conducted over long periods of time are required in order to answer the questions presented here. All pesticides, including new chemical formulations, must be evaluated for the intended crops. This is a costly process but a necessary one in order to assure the safety of consumers, pesticide handlers and the environment.

Summary

The goal of pesticide regulation is to protect human health and the environment.

For regulatory purposes, the definition of pests includes certain animals, microorganisms and plants. For food safety purposes, human pathogens, birds, and wild and domestic animals are included in the definition.

A pesticide is defined as any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pests or used as a plant growth regulator, defoliant or desiccant.

Residue refers to the amount of pesticide, its degradation products, or ingredients in the mixture found in or on a raw agricultural commodity or in processed food.

Tolerance is the amount of residue legally allowed to remain in or on the commodity at harvest.

Pest damage may be mitigated by a number of methods, including biological control, plant resistance, cultural practices, mechanical and physical methods, and chemical applications.

IPM includes consideration of all possible methods and judicious use of the best methods for a given crop/pest/environment situation.

Potential hazards associated with pesticide use include contamination of food, damage to the environment, negative health effects in workers who handle pest control substances, as well as workers' families, and consumers of foods treated with pesticides.

The likelihood of adverse effects on human health and the environment is sharply reduced when proper pesticide handling and application methods are utilized.

Pesticide residues can best be minimized by strictly following the label requirements for the use of the material. ***The label is the law.***

Many environmental and biological factors influence the amount of residue that is left on food. Interactions of these factors are complex and can be identified only through exhaustive research.

Introduction

Once a pesticide has been applied to a crop its fate is determined by a myriad of biological and environmental factors. In an ideal situation, pesticides would take action upon the intended pest and then rapidly be degraded to less toxic compounds. This is seldom the case. The fate of the pesticide must be determined in order to establish guidelines for the safe use of the product. This Module focuses on the interaction between environment and pesticides.

Factors Influencing Pesticide Movement

When analyzing the fate of pesticides, it is important for scientists to identify the specific locations in the environment where pesticides can occur. These locations are above ground, at ground level and below ground. Wherever the pesticides tend to end up, they may be degraded by different processes that are addressed later in this Section. The time required for degradation can be relatively short (a few hours) to extremely long (many years). It is important to understand where pesticides may accumulate and the time required for degradation in that location.

A pesticide application may be directed at the plant, the soil, or both. Pesticides that reach the plant may penetrate the plant, adhere to the plant surface or drip off on to the soil. The anatomical characteristics of the plant, such as the presence of a waxy cuticle, the chemical characteristics of the applied substance, and the weather all impact where the pesticide eventually resides.

Liquid formulations may "pool" on the plant surface due to surface tension. These may dry on the plant, volatilize into the atmosphere or drain off on to the soil. Volatilization is the conversion of a solid or liquid to a gaseous state and is affected by temperature and the vapor pressure of the pesticide. Knowledge of the fate of the material helps to determine its persistence in the above-ground environment.

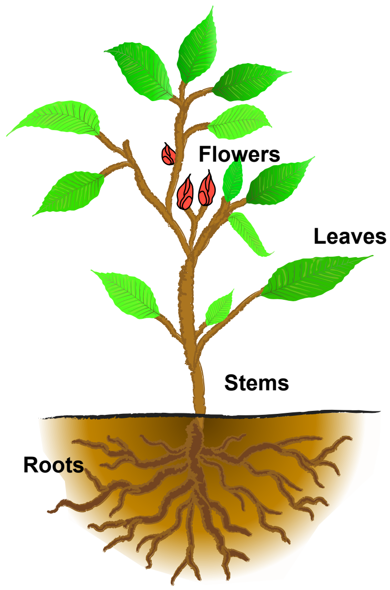
Pesticides that reach the ground level have similar fates as described above, e.g., they adsorb to the soil surface, penetrate through the soil or are volatilized from the soil surface. They may also move off-site through drift, run-off or leaching.

Run-off is a major concern. This is the movement of the pesticide off-site laterally in water, which can occur after rain or irrigation. Run-off can result in the contamination of surface water or poorly constructed wells and endanger humans, domestic animals and wildlife. Run-off is affected by the slope of the land, with steeper slopes increasing the likelihood of run-off. Barriers or terraces may be needed to reduce run-off. If these are not effective, retention ponds may be constructed to capture the water.

Soil type strongly influences the likelihood of run-off. Clay soils contain many binding sites that can retain pesticides in their matrices. Sandy soils have less capacity for retaining pesticides. However, clay is not as easily penetrated as sand and heavy rainfall or irrigation may carry pesticides away from clay very rapidly. Strips of vegetation, particularly grass, that are strategically located around fields can deter run-off because the pesticide can be taken up by the vegetation, making it unavailable to be moved off-site in water. Frequent tillage, on the other hand, tends to promote soil erosion and increase run-off.

Pesticides that move below ground may adsorb to roots, penetrate the roots, adsorb to soil particles or leach out of the root zone. Adsorption to soil is influenced by soil texture, permeability, pH, temperature and organic matter content. These factors also influence leaching. Leaching is the downward movement of pesticides in water, which can result in the contamination of groundwater. The properties of the pesticide, particularly its solubility and how strongly it tends to adsorb to roots, influence its persistence in the root zone. In addition to factors mentioned above, leaching also is affected by the pesticide application method and rate, amount of rainfall or irrigation and tillage practices.

The Figure on the following page summarizes the fate of pesticides in various locations. Growers must consider many factors as they develop their management strategies for pesticide use. Practices that increase the efficacy of pesticide applications will usually protect the environment and reduce costs.



Above Ground
retention
volatilization
penetration
absorption

Ground Level
volatilization
chemical degradation
microbial degradation
runoff
leaching

Below Ground
adsorption
leaching
absorption

Pesticide Degradation

Understanding pesticide degradation is important, both to reduce residues and to protect the environment. A few pesticides have as their active ingredient relatively small molecules containing mineral elements such as copper, zinc or manganese. These minerals tend to remain in the soil. Most pesticides are either large organic molecules or biological agents that are subject to degradation processes in the environment. Those that are not readily degraded are generally considered to be undesirable because of environmental concerns. DDT is one such pesticide that was used on a very large scale decades ago but has been disapproved in most countries because of its persistence in the environment and concerns about wildlife, such as reduction of bird populations due to eggshell thinning.

Three types of pesticide degradation will be discussed: chemical, microbial and photodegradation. Combinations of these processes are usually involved.

Chemical Degradation

Chemical degradation takes place naturally over a period of time. The period can be quite long unless aided by other processes. Each pesticide has its own specific half-life, which is the period of time necessary for half of the amount of pesticide to be degraded by chemical processes under a particular set of environmental conditions. Warmer temperatures and alkaline pH typically increase the rate of degradation reactions.

Microbial Degradation

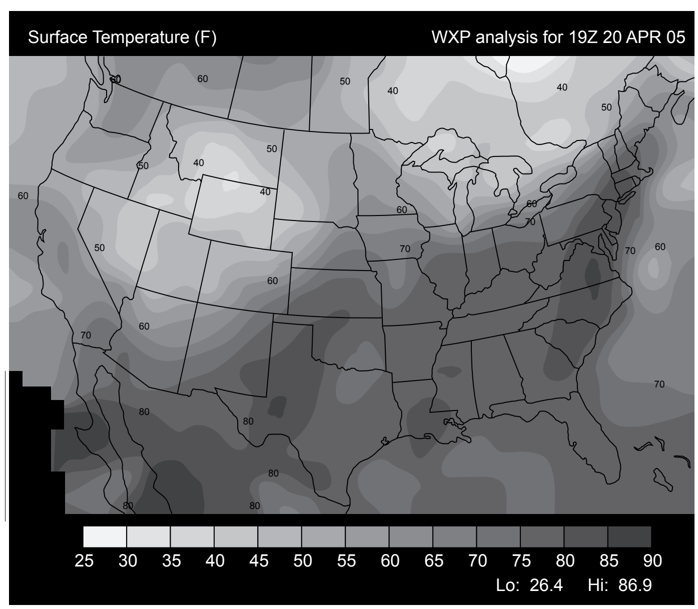
Microbes in the soil secrete enzymes that can degrade pesticides. Soil conditions that influence the rate of microbial degradation include moisture content, temperature, organic matter, aeration and pH.

The repeated use of a specific pesticide on a site can create conditions that are favorable for an increase in the population of microorganisms that metabolize the substance. These are classified as aggressive soils.

Aggressive soils have been a problem with certain herbicides in the U.S. where the microbial population has become so high that the herbicide is degraded before it can have its full effect on weed control. Microbial activity is generally highest in the root zone, with moderate activity in the subsoil and minimal activity in groundwater. Pesticides that leach into groundwater or enter via a poorly constructed well may persist there for many years.

Photodegradation

Photodegradation, as the name implies, is caused by ultraviolet light striking the pesticide molecule. Warmer temperatures work in combination with ultraviolet light to speed the process. The following map of the U.S. shows that soil surface temperatures in the southern states and along the eastern seaboard are substantially higher than the rest of the country. Generally, pesticides would be expected to degrade faster in these warm areas. Day length also is a factor in photodegradation. Tropical regions, especially near the equator where there is little change in climate or day length throughout the year, may be more predictable with regard to pesticide persistence in the environment.



Crop Removal

Pesticide residues remaining in the crop at harvest are removed from the site. This eliminates one source for pesticide residue buildup in the soil. It also is the compelling reason that pesticide use must be managed appropriately to ensure that residues in the edible product are below tolerance and do not cause harm to consumers.

Summary

To establish effective regulations for the use of pesticides, scientists must understand the fate of the substance once it has entered the environment.

In an ideal situation, pesticides would take action upon the intended pest and then rapidly be degraded to less toxic compounds.

Scientists who study the fate of pesticides tend to focus on three locations in the field environment: above ground, ground level and below ground.

Pesticides may volatilize from the plant or soil and escape into the air.

Movement of pesticides into surface water by run-off, or into groundwater by leaching or via a poorly constructed well, is a concern for the safety of humans, domestic animals and wildlife.

Pesticide run-off and leaching is influenced by field topography and soil characteristics.

Pesticides may be degraded by the action of light, heat, chemicals or microbes.

Pesticide-degrading microbes in the soil may multiply into high populations and break down the pesticide before it can take action against the pest. These are termed aggressive soils.

Some pesticides are removed from the field on the harvested crop. This is a compelling reason for the management of residue levels to avoid causing harm to consumers of the product.

Introduction

The application of a pesticide will result in some amount of the material entering the plant. The fate of the pesticide within the plant is extremely important for the prediction of residue levels at harvest.

Internalization of Pesticides into Plants

The first step of internalization requires that the pesticide gain entry into the plant tissues. This can occur through either passive or active mechanisms, or both. All of the plant organs, e.g., leaves, flowers, stems, fruits, roots and tubers have potential entry sites.

Plants have a number of natural openings, such as stomata and lenticels, through which pesticides may enter passively. Damage to plants, such as tears, bruises, scrapes and scratches also provide a point of entry. The damage caused by sand or debris carried by the wind can be significant, as can the injury caused by equipment moving through the field. Any type of opening in the tissue is a potential point of passive entry.

Active entry of pesticides is a more complex biological process and not all pesticides penetrate in this fashion. Systemic pesticides are, by definition, designed to be carried inside the plant tissues. The binding and transport mechanisms for the translocation of pesticides at the cell level are well beyond the scope of this discussion, but would be classified as active entry.

Passive and active entry both are influenced by the pesticide formulation, weather conditions, particularly temperature and humidity, and plant morphology. Waxy leaves may repel the formulation while hairy surfaces tend to retain the applied material. Warm temperatures and high humidity can encourage entry by increasing the rate of metabolic activity of the plant and by causing the pesticide to persist on the plant surface for a longer period of time.

Distribution of Pesticides in the Plant

The movement and redistribution of pesticides within plants can be a critical factor in the activity of the applied substance. Some pesticides are applied to the soil, absorbed by the roots and translocated to aboveground parts where they have activity against pests feeding on leaves. Understanding the mechanism(s) of movement may provide insight into pesticide distribution within the plant.

There are two general "zones" for pesticide movement within plants. The apoplastic zone has been characterized by some as nonliving tissues. This includes the xylem and cell wall space. Cell wall chemists and physiologists take issue with the idea that the apoplast is dead space since there is enzyme activity and other metabolic processes that occur within the xylem and cell walls. For this discussion, the important point is that water moves relatively freely in the apoplast. Water-soluble and weakly lipophilic (fat-soluble) compounds are more likely to be transported through the system with the movement of water.

In contrast the symplastic zone, which includes the phloem, is very much alive. More lipophilic substances are moved in the symplast by active transport, which involves chemical "pumps" that move substances from cell to cell across membranes. Enzymes, co-factors and a myriad of metabolic processes are involved in active transport. A pesticide molecule that is designed to be transported in this manner must have a structure that will withstand the chemical rigors of the process. Movement to centers of metabolic activity, such as the tips of roots and shoots, occurs via active transport in the phloem. Cell to cell diffusion is a passive process occurring in the symplastic system.

The movement of some chemicals is restricted to one of these two routes, while other chemicals are able to move throughout both systems.

Biotransformation, Degradation and Detoxification

The terms listed in the heading have similar definitions but there are some subtle distinctions. Biotransformation, as the name implies, is the modification of a compound through a biological process that usually is enzyme-mediated. Degradation can occur during biotransformation, but there are degradation processes that are not of a biological nature, discussed in the previous module. Degradation does not necessarily lead to detoxification, which is the complete removal or degradation of toxic compounds. Some products of degradation can still be toxic. We must be cautious in the use of these terms interchangeably.

Plants, insects, microorganisms, and mammals, including humans, all tend to metabolize foreign compounds such as pesticides by the same major metabolic pathways. What happens to the end products of the metabolism often differs in different species. This is obvious in a direct comparison of the detoxification mechanisms in animals and plants.

In mammals, biotransformation enzymes are produced by the liver. They may be active only in the liver or be distributed through the body. A key result of the biotransformation process is the conversion of molecules to more water-soluble forms, making the degradation products able to be filtered by the kidneys and excreted in urine. Chemicals that remain in a lipophilic form are less likely to be excreted in the urine. Instead they tend to be deposited in fatty substances including breast milk and body fat and may persist for a long time. They also can be present in sweat.

In plants, biotransformation enzymes produced throughout the plant are active at the site of production. Degradation products can be secreted into vacuoles and stored within the cells. Other products may be lost from the plant through evapotranspiration.

Plants have mechanisms for the degradation or sequestration of many pesticides. This process usually is independent of the mode of action of the pesticide. Mode of action refers to the manner in which a pesticide kills or controls the pest.

Biotransformation is related to reactive groups in the pesticide molecule that are susceptible to enzymatic or chemical attack. There may be only one reaction, or a combination of reactions, to degrade or detoxify any particular pesticide. When there are a number of reactions that act sequentially these are referred to as a pathway.

Often there is more than one pathway by which an organism (plant, animal or microbe) degrades a chemical and all of these processes will be taking place at the same time. Having multiple reactions and multiple pathways acts as a backup system to help protect all organisms and to degrade chemicals as rapidly as possible. The rate of biotransformation within the plant parts may vary even for the same pesticide. This is influenced by environmental factors such as temperature and humidity, the time of year and the overall health of the plant. Three phases of biotransformation have been identified: transformation, conjugation and sequestration.

Phase I (transformation) occurs in various ways and depends upon the chemistry of the pesticide ingredients, the formulation and the concentration of the applied product. Numerous enzymes are involved, including esterases, lipases and proteases. Cytochrome P450 enzymes are of particular importance. The results of Phase I are that reactive intermediates are formed with the degradation of the primary molecule. Reactive intermediates are chemicals with exposed sites that can be acted upon by other processes in the next phase of biotransformation.

Phase II (conjugation) is the binding of the reactive intermediates from Phase I to naturally occurring plant constituents such as carbohydrates or amino acids. Glutathione S-transferase is an important enzyme in Phase II reactions. The conjugated products are soluble and may be either less toxic or more toxic than the parent compound.

Phase III (sequestration) occurs when the conjugates from Phase II reactions become bound to insoluble structures within the plant. This non-extractable bound residue has restricted mobility in the symplast. Sequestered toxic substances are less available to the plant to cause adverse physiological effects.

There are three major sequestration pathways. Substances may be transported into the cell vacuoles, which act as “holding tanks” for the molecules. They may also be exported into the extracellular space and remain soluble. Finally, they may bind to lignin or other cell wall components. Bound residues in plants may or may not be bioavailable to predators.

The older generation of pesticides included compounds such as DDT, which was broad spectrum in its activity, lipophilic and persistent in the environment. The newer generation of pesticides includes materials that are more specific in their activity, are water soluble and have a half-life of hours to weeks. They are less likely to be sequestered and more likely to be degraded. These newer chemicals are generally considered to be more environmentally friendly than the older generation.

Plants are very efficient at recycling some pesticides. Plant cells use the breakdown products to synthesize chemicals for their own use. This has become an important emerging area of research. The National Center for Environmental Research sponsors studies on the use of plants to remediate contaminated sites.

Postharvest Factors and Residues

Once the edible portion of the plant has been harvested, degradation of pesticide residues may continue postharvest. Washing may remove some residues if they are on the product surface but systemic pesticide residues are not significantly reduced. Depending on the commodity, transportation, storage and marketing may require from days to months after harvest. It is important to characterize the persistence of residues during this period, even though tolerances are set based on the time of harvest.

As noted in Module 1, processing can either concentrate or degrade residues depending on the nature of the process, e.g., if it involves heat or chemical treatments. The focus of this discussion is on fresh produce that will be consumed raw.

In the U.S., the Environmental Protection Agency (EPA) has the responsibility for oversight of pesticide registration, which requires extensive studies on the toxicology and the development of risk profiles. Most residue data are available only through formal requests made under the Freedom of Information Act.

Prior to the approval of a pesticide, the EPA requires that residue studies be conducted on at least one root crop, one leafy vegetable and one fruit or fruiting vegetable. Collectively, these studies for pesticide registration and for other purposes have identified different fates, depending on the properties of the pesticide and of the plant in question. In some cases residues have been shown to remain mostly as the parent compound, indicating that the plant does not substantially degrade the pesticide. For other plant/pesticide combinations, residues appear mostly as metabolites, indicating substantial degradation by the plant. Studies also have shown that the final location of the residues vary widely. Depending on the combination of pesticide and plant, residues (either as parent compounds or as metabolites) may show up primarily in the leaves, fruits, seeds, tubers, roots, vines or stems.

Biotransformation of pesticides in plants is a highly complex group of processes. Studies of the mechanisms involved in biotransformation are costly but are necessary to determine if pesticides can be used without adverse effects on humans or the environment. Crops with residues exceeding tolerance, or having residue for which no tolerance exists, can be confiscated.

Summary

The application of a pesticide will result in some amount of the material entering the plant.

Entry into the plant may occur actively or passively, or by both mechanisms.

The movement and redistribution of pesticides in plants can be critical to its mode of action.

Biotransformation is the modification of a pesticide through biological processes that yield degradation products.

Detoxification is the modification of the pesticide molecule to a point at which there is little or no remaining toxicity.

The three phases of biotransformation are transformation, conjugation and sequestration.

Degradation of pesticides continues after the commodity is harvested. Residue studies are required to determine if pesticides can be used safely.

The EPA is the regulatory agency for pesticides in the U.S.

Introduction

Growers should be aware of handling practices that provide the best efficacy for the product while avoiding injury to people, animals or the environment. Many of the land-grant universities in the U.S. have Best Practices manuals and other publications available online at no cost. This Module is an overview of the principles that would be covered in detail in a manual. Some of the points made in this Module are discussed elsewhere in this Section.

Sources of Excess or Unregistered Pesticide Residues

The intentional misuse of a pesticide is illegal and punishable by law.

The presence of unregistered pesticide residues, i.e., not registered for use on the specific crop, or an excess of a registered pesticide, both render the crop unmarketable. If either of these problems occurs, growers must analyze every aspect of their pest control program to determine the cause of the problem and to identify a strategy to prevent the problem from occurring again.

Illegal substance(s) may be present or legal residue(s) may be above tolerance for a number of reasons. There could have been overspray from careless application to a neighboring site or there could have been accidental drift from other application sites. A registered material may have been applied at too high a rate or it may have been applied too frequently. This could result in residue of an unapproved pesticide on the crop, or of approved pesticide but at too high a level.

Residues can accumulate in soil from previous applications to the site, from drift onto the site, run-off, leaching, irrigation water overspray, or from the deposition of contaminated soil particles carried by wind or water.

Producers of minor crops are at a distinct disadvantage because pesticides may not be registered for their particular crop. As discussed elsewhere, the cost of registering pesticides is very high. If manufacturers do not see an opportunity to recover this investment through sales, they may not choose to register a material for a minor crop for which sales of the product would be low. Growers of minor crops may not understand that a pesticide is not allowed on a minor crop when they use the same material on other crops on their farm. Nevertheless, the label is the law and growers must follow label directions at all times. In the U.S., funding is provided to IR-4 for research on minor crops so that pesticides can be registered for use.

Essential Records

There are a number of useful computer programs available to growers to help keep track of all pesticide applications. Pesticide label information is written in to the program. When growers enter information about an application, the program will alert them of any problems that may preclude them from making the specific application. The programs offer the additional advantage of preserving pesticide use records, which is required by law in most locations.

By U.S. federal law, record keeping is required for pesticides classified as Restricted Use Pesticides (RUP). Many states have additional requirements that exceed the federal law. They may require that records be kept for additional (not just RUP) products. Growers should check with the regulating agency within their state for specific information on what data are required. Recommendations below include the minimum requirements to meet the federal standard as well as best practices. They should be applied to all pesticides used, regardless of whether they are RUP.

Records must include the brand and product name; the EPA registration number; the total amount applied; size of the treated area; the crop, commodity, stored product or site to which the application was made; location of the application; month, day and year of the application; and the applicator's name and certification. A pesticide application record sheet also should contain crop data including the variety, planting date, product traceback code, etc. Weather conditions at the treatment site and date of the last equipment calibration should be noted.

Worker training also must be documented. Training records should include the name(s) of the individual(s) trained, their hire dates, date of training, the job title or description of duties, training topics and the institution responsible for conducting the training. A certificate signed by the trainer should be issued and kept on record.

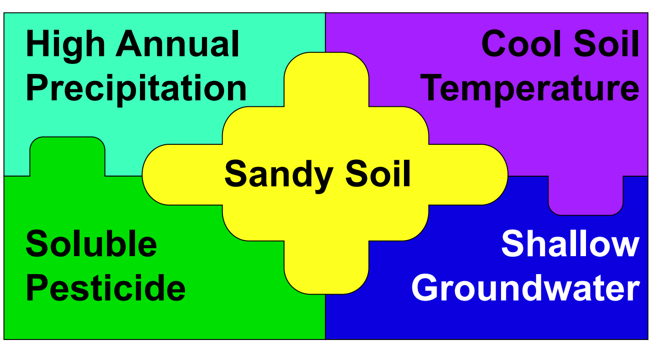
Protection of Water Sources

Water issues were introduced in Module 2. Protection of water sources is an extremely important concern that producers must consider as they develop their pest control programs.

Growers should identify all conditions on their farm that might make a water source vulnerable to contamination. Selection of pesticides should be postponed until a risk analysis has been conducted for the site. Such areas would include sandy soils, presence of sinkholes, wells, shallow groundwater or nearby surface waters that could be contaminated by run-off.

Management of run-off was addressed in Module 2. Unless the label directs you to do so, do not apply pesticides to bare ground and do not apply before a rain event. Both practices can lead to contamination of surface water and/or water used for irrigation. The use of contaminated water for irrigation or for mixing pesticides can lead to illegal residues.

The following graphic shows several of the factors that contribute to the risk for leaching of pesticides into groundwater. If several of these conditions exist in the field and the grower concludes that the site is vulnerable to leaching it would be prudent to consider products and methods of application that would reduce this risk.



Pesticide Carryover and Resistance

Pesticide carryover simply means that some amount of pesticide remains on the site after the crop cycle is completed. If the same crop is planted continuously and if the same pesticides are used repeatedly, residues may eventually build up in the soil. These residues can be absorbed by the crop and the additive effect of applying additional pesticide can result in residues in the plant that are over the tolerance level.

Rotational crops may not have a tolerance for the pesticide(s) used for previous crops. To avoid illegal residues, growers should check the label for restrictions against planting certain crops into previously treated soil. Wait the proper length of time, as specified on the label, before planting rotational crops if a risk of contamination exists.

Pesticide resistance can occur when a pest population has been repeatedly exposed to the same pesticide. Sensitive individual pests are killed by each subsequent application of the pesticide, leaving only individuals with behavioral or physiological resistance to the material. These resistant pests reproduce and pass the resistant genes to the next generation. Over a period of time the pesticide loses its effectiveness for pest control.

Once resistance has begun to develop, it takes more and more of the pesticide to achieve the same level of control. In response, growers may raise the application rate or increase the number of applications. Either of these choices can result in the presence of residues above tolerance.

Integrated Pest Management (IPM) programs were discussed earlier and are strongly recommended. Under IPM, crops are evaluated by the knowledgeable grower or professional scouts who determine the population of pests and make recommendations for pesticide application based on pest pressure, as opposed to the arbitrary application of pesticides on a calendar schedule. Non-chemical control measures also may be appropriate. IPM can help growers reduce costs and residues, and avoid the development of resistance.

Pre-harvest Interval (PHI)

The time that passes between a pesticide application and harvest is known as the pre-harvest interval (PHI). Pesticide labels usually are quite specific about the PHI requirement. A PHI is necessary to allow time for biotransformation processes within the plant to reduce pesticide levels to within tolerance.

The PHI varies depending on the crop, the portion of the crop that is consumed (root, fruit, etc.), the intended use of the crop (human food vs. animal food), the application rate, soil type and climate. The important point for the grower to remember is to follow the label directions because all of these factors were taken into account when the label was written.

Drift

Drift refers to pesticide movement in the air. Vapor drift occurs with some products that volatilize during warm conditions (typically above 85°F) and are carried off-site by the air flow. If a product is known to volatilize, the label will specify a cutoff temperature above which the product should not be applied.

The more common type of drift is when very fine particles of liquid spray material are carried by the wind. Drift of some pesticides, such as herbicides, can seriously damage nearby crops. Drift of pesticides with high toxicity to humans may pose health risks to field workers as well as to those in nearby residential areas. Although it is thought that most drift incidents do not generally pose a threat of chronic health effects, it may occasionally be a valid concern. Schools, hospitals and nursing homes are particularly sensitive areas. In any case, drift of any material does present the risk of illegal residues on nearby crops.

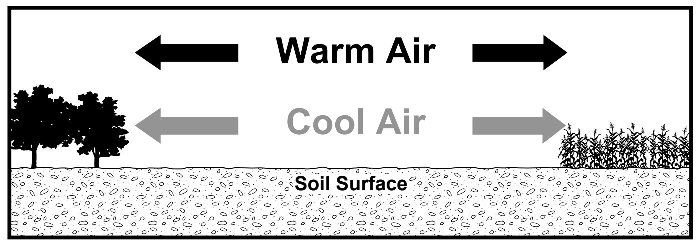
Pesticide applicators should be aware of wind speed and direction. Wind gauges are relatively inexpensive and are very useful for measuring conditions at the field site if the applicator has any doubts about the risk of drift. Wind may also carry soil particles to which the pesticide is adsorbed. If there is any doubt about the risk of wind drift, then spraying should be postponed until conditions improve.

The viscosity, or "thickness," of the formulation affects its ability to drift. Invert emulsions are thick and present low risk of drift. Water-based formulations are affected not only by wind, but by temperature and humidity, which influence the rate of evaporation that can occur.

Droplet size at the nozzle discharge highly influences the potential for drift. Larger droplets are less likely to drift than smaller droplets so nozzles with larger orifices are preferred. It is prudent for growers to determine the largest droplet size that still gives good pest control. Apply at the lowest possible pressure and lower the boom to reduce the distance that the droplet must fall before striking the target. Equipment manufacturers have charts available that show droplet size based on nozzle orifice and pressure. Check the pesticide label for any specific restrictions regarding volume requirements and concerns for aerial application.

Weather also is a factor. At higher temperatures large droplets evaporate quickly to smaller droplets. This process is slowed by higher humidity.

Temperature inversions can result in long distance drift. An inversion forms when air at the ground level has cooled and warmer air holding the pesticide has risen above the field as indicated in the photo. Inversions usually develop at dusk and can continue through the night. The warm air layer can drift for a long distance before the inversion ceases when the ground warms in the morning, depositing the pesticide on a distant location.



Growers should consider the use of a drift control adjuvant. Adjuvants change the viscosity of the spray mix so that it is less likely to drift. There is some disagreement among experts about the effectiveness of adjuvant and if the products function well. Growers should ask advice from a nonbiased source, such as an Extension Specialist, and conduct their own evaluation.

Mixing Pesticides

The four major concerns for mixing pesticides are protection of the crop, the water source, the soil and the workers. Always mix pesticides to the concentration specified by the label for the crop. Do not mix and load pesticides near surface water, wells or drains. Do not mix at the same location each time unless you have a properly constructed mixing and loading site. When filling tanks, be sure to maintain an air gap between the water supply and the level of the mixture. Back flow devices should be installed in the water supply line and must be tested regularly to ensure that they function effectively. Stay with the tank while it is being filled and never leave the area unattended. Spills can occur from an overfilled tank or from an accident like a broken hose, resulting in contamination of the loading area and possible run-off into water sources or nearby fields. Workers should adhere to safe handling guidelines.

Application Method

Apply products only by the methods allowed on the pesticide label. These instructions are designed to ensure proper coverage and avoid overapplication, which could result in excess residues.

Maintain application equipment in good working order. This can prevent overapplication through leaky nozzles or connections and prevent major leaks or spills from burst lines.

Calibrate your equipment properly after any change in set-up or whenever you change products. Maintaining and calibrating equipment helps to ensure good coverage while minimizing the likelihood of drift, achieve labeled rate for product delivery to maximize pest control, and avoid overapplication and prevent off-target deposition. Operate the sprayer at a constant speed to which it has been calibrated.

Follow all directions on the pesticide label. In the U.S. each pesticide is labeled in accordance with specific instructions and they are a matter of law. The label specifies site or crop; application method; type of equipment; application rate depending on the pest or soil type; the timing of application according to season; pest stage or crop stage; number of applications allowed per season; pre-harvest interval; and safety precautions for humans, wildlife, and the environment.

Take protective measures for sensitive areas. Follow restrictions for different soil types or geologic regions. For example, a pesticide might not be registered for application to sandy soils or geologic formations such as karsts with direct conduit to groundwater. Observe setbacks from surface water, wells or other sensitive areas. Use barrier strips with noncrop cover to help prevent run-off and when appropriate use an untreated strip as a buffer zone.

Be aware of any rules regarding the feeding of the crop to animals. Culled fruits and vegetables from the packinghouse often are disposed of by feeding to domestic animals. Animals produced for human consumption must not have residue levels above tolerance. Read the label and be aware of feeding restrictions.

Conclusion

The label is the law. Adherence to label directions will help ensure that tolerance levels are not exceeded and provide the grower and applicator a measure of protection against liability. Following proper handling practices will reduce the risk of contaminating the environment and injuring workers.

Summary

Growers must be aware of handling practices that provide the best efficacy for the product while avoiding injury to people, animals and the environment. Intentional misuse of a pesticide is illegal and is punishable by law.

If an excessive residue is discovered, growers must investigate the source of the residue and take steps to prevent a reoccurrence.

Protection of water sources is a major concern for Best Management Practices programs.

Pesticide carryover means that some pesticide remains in the soil after completion of the crop cycle. Ideally, growers would manage their production so that no carryover exists.

Pesticide resistance can occur when a pest has been repeatedly exposed to the same pesticide or a class of pesticides with the same mode of action.

Integrated Pest Management (IPM) programs can minimize pesticide use, carryover, resistance and residues.

The pre-harvest interval is the time that must pass between application of the pesticide and harvest of the crop to allow residues to degrade to the expected level.

Drift is the undesirable movement of pesticides in the air to nontarget locations. Growers should be aware of conditions that favor drift and design their pest management programs to avoid it.

Pesticides must be mixed in a manner that avoids contamination of the environment, injury to workers or overapplication to the crop.

Pesticide application equipment should be maintained in good condition.

The label is the law.

Introduction

Most countries that are major producers of fruits and vegetables have official standards to protect workers, such as the U.S. Worker Protection Standards (WPS) for the handling of pesticides. Such standards provide for specific protections to be provided by employers to pesticide handlers and field workers who may be exposed to residues. Adherence to these standards is required by law. Copies of the WPS training materials are available online from the websites of many land-grant universities.

This Module provides an overview of the potential risks to human health through exposure to pesticides as well as best practices to minimize exposure.

Pathways of Human Exposure

There are three routes of entry of pesticides into the human body: oral, or through the mouth; by inhalation, or through the lungs; and dermal, or through the skin. Oral exposure is most likely to occur if the worker eats or smokes during the handling of pesticides or does not wash hands properly after handling. Inhalation of fumes can occur during mixing or by entering improperly ventilated storage areas. Skin contact accounts for most exposure—up to 97% of all body exposure is by this route.

Different parts of the skin absorb pesticides with different efficiencies. Studies investigating how fast pesticides penetrated various body areas of volunteers have shown that the groin or genital area absorbs pesticides fastest; the scalp, forehead and ear canal absorb pesticides moderately fast, and the feet, hands and forearms absorb pesticides relatively slowly. However, it must be noted that the hands and forearms are often subject to the most exposure throughout the work day and that pesticides left on these areas will eventually penetrate through the skin.

The most common exposure scenarios for pesticide applicators are during mixing or loading of the concentrated material; by spills, leaks or improper cleaning and maintenance of equipment; during application; by recontamination through the use of leather items such as gloves, shoes, belts or bands inside hats that cannot be decontaminated, or by the reuse of contaminated protective equipment.

Pesticides may also be carried into the home and contaminate other people. Workers can carry the pesticide into their homes on their shoes, clothing or protective equipment that should have been removed before going home. Workers should wash thoroughly before greeting family members. Clothing worn while handling pesticides, including protective clothing and gear, should always be washed separately from household items.

Pesticide drift may enter homes through open windows or doors. Pesticides should never be stored within the home and empty containers should not be reused for a household purpose. Poisonings and deaths within homes have occurred through several of the practices mentioned here.

Potential Adverse Effects of Pesticide Exposure

Pesticide poisoning is categorized as either acute, chronic (delayed) or allergic.

Acute poisoning is defined as the occurrence of symptoms within 24-48 hours after exposure. Symptoms can occur almost immediately if the subject is exposed to a very high concentration or if the pesticide is extremely toxic.

In research studies with acute poisoning, scientists often use the terms LD_{50} (Lethal Dose 50%) and LC_{50} (Lethal Concentration 50%). Since genetic makeup influences how animals, including humans, respond to a toxic substance, the average dose to cause death is used as the best estimate. Thus, the LD_{50} identifies the dose found to be lethal for 50% of the test animals. Similarly, the LC_{50} identifies the concentration in the air or water that would be lethal for 50% of the test animals.

LD_{50} and LC_{50} are standard measures in toxicological studies and provide an estimate of the relative acute toxicity of different pesticides through different routes of exposure. LD_{50} and LC_{50} are presented in terms of mg pesticide per kg body weight. Therefore, a pesticide with low LD_{50} and LC_{50} is more toxic than a pesticide with high LD_{50} and LC_{50}.

Chronic, or delayed, effects occur when a subject is repeatedly exposed to a pesticide over a long period of time. The likelihood of causing chronic effects is estimated by the maximum allowable dose in a subject's lifetime. It is important to understand that the LD_{50} and LC_{50} measure acute effects and do not provide an estimate of the likelihood of having a chronic effect. A pesticide with a high LD_{50} (low acute toxicity) may have the potential to cause chronic effects and, conversely, a pesticide with a low LD_{50} (high acute toxicity) may not be associated with any chronic effects.

Allergic effects are more idiosyncratic and may be more difficult to characterize. Typically the first exposure sensitizes the subject to the foreign substance. Additional exposures cause the subject to begin to exhibit allergic symptoms, which can be expressed in a variety of ways, such as skin rashes or chronic respiratory conditions. Having an allergic reaction to a pesticide does not indicate any greater likelihood of having either an acute effect or a chronic effect from the pesticide. Individuals exhibiting allergic responses to a pesticide must either increase their level of personal protective equipment (PPE) and their handling precautions or stop using the particular pesticide as well as any other pesticides in the same class of chemicals that causes the reaction.

Practices that minimize exposure to pesticides will minimize the likelihood of having any adverse response, acute, chronic or allergic, to a pesticide.

Personal Protective Equipment (PPE)

Personal protective equipment (PPE), as the name implies, is used specifically for the protection of the worker. Appropriate use of PPE can dramatically reduce the risk of exposure.

All clothing items worn during pesticide handling are PPE and it is assumed that they are contaminated after handling. Always wear long pants, a long-sleeved shirt, socks, shoes and/or boots, and chemical resistant gloves while handling pesticides. Wear a hat if spraying above the head.

Wear any additional PPE required by the pesticide label, such as goggles or a respirator. Note that a dust mask is ***not*** a respirator and does not prevent the inhalation of pesticides. When mixing or loading concentrated pesticides, wear a chemical-resistant apron. Do not wear any leather items during handling, as leather cannot be effectively cleaned or decontaminated and re-exposure will continue to occur. If leather shoes or boots are worn, it is particularly important to wear chemical-resistant boots over them while mixing, loading or applying pesticides or while walking through treated areas.

Do not wear PPE for tasks other than handling pesticides. Wash PPE separately from the family laundry in hot water with detergent. Dry the garments by hanging outdoors or in a drying machine, as sunlight and heat both help to break down pesticide residues. After PPE is properly cleaned, store it separately from other clothing. If PPE cannot be cleaned right away, store it in a plastic bag and keep it separated from household laundry or other clothes.

Heat Stress

The risk of heat stress increases while wearing PPE. Workers can avoid heat stress by taking appropriate breaks and wearing a lightweight hat with a brim to avoid direct exposure to sunlight. Drink plenty of water but remember to wash hands before drinking.

The symptoms of heat stress are similar to the symptoms of overexposure to organophosphate or carbamate pesticides. Workers and supervisors should know the different symptoms for heat stress and pesticide poisoning so that anyone who exhibits symptoms can be treated promptly. Any time that a worker is in serious distress, medical attention should be provided without delay. Farm workers, supervisors and managers are not medical professionals and should seek assistance from trained professionals. The similarities and differences with pesticide exposure and heat stress are summarized in the following Table.

Symptom Comparison

Pesticide Exposure	Heat Stress
• Sweating • Headache • Fatigue • Most membranes normal • Slower pulse • Nausea and diarrhea • Small or normal pupils • CNS depression – Coordination loss – Confusion – Coma	• Sweating • Headache • Fatigue • **Dry membranes** • **Faster pulse** • **Nausea only** • **Dilated pupils** • CNS depression – Coordination loss – Confusion – Fainting

Factors Affecting the Human Response to Exposure

A person's response to pesticide exposure depends on a number of factors. The schedule and duration of exposure are significant. Long or frequent exposures may overwhelm the body's biotransformation capabilities and cause acute poisoning. Short exposures followed by periods of nonexposure can allow the body time to metabolize the pesticide to a level that is below that causing a toxic response, which is termed the toxic effect threshold.

Human nutrition also is a factor. Proper diet is necessary to maintain adequate levels of biotransformation enzymes. Consumption of foods that are high in antioxidants is believed to provide some protection against the action of many toxic substances. In the body antioxidants are scavengers of free radicals that cause injury to cells.

Size, age and gender of the person all impact the response to pesticide exposure. Larger individuals can safely absorb and metabolize larger doses than a smaller person. Infants and elderly people may have lower levels of biotransformation enzymes and be more susceptible to injury from exposure. Finally, male and female hormones both affect biotransformation pathways in manners that are not well defined. For some substances, women are more likely to exhibit an adverse effect, while in other cases men are more likely.

Smoking or chewing tobacco or other leaves has several negative consequences. It can serve as a means of direct ingestion of the pesticide if the hands are not washed before smoking or chewing. Further, it predisposes the individual to respiratory illness, which can have a synergistic negative effect when pesticides enter the body.

Consumption of alcohol also has negative effects. Excessive alcohol use decreases or can permanently impair liver function, which decreases the body's capacity for metabolizing other chemicals. It is impossible to test all combinations of alcohol and pesticides for their effect on the body. Understanding that the combination can result in a more severe negative consequence allows individuals to make decisions about personal behavior that decrease their risks.

Drugs, whether they are over-the-counter, prescription or illegal "recreational" drugs, all may compete for the same biotransformation enzymes as pesticides. Drug use may result in increased toxicity of the pesticide, increased toxicity of the drug or inactivation of the drug by the pesticide. Interactions may be additive, synergistic or antagonistic. As is the case with alcohol, it is impossible to test the effects of all drug-pesticide combinations.

Personal hygiene practices of the individual are critical. Workers should wash their hands before eating, drinking or smoking to prevent the transfer of residues through the mouth. They also should wash before using the toilet to prevent the transfer to the highly absorptive genital areas of the body. Workers should shower at the end of the day and always put on clean clothing to begin the work day. Clothing and shoes that may be contaminated from the previous day's work should never be reused without cleaning.

Good pesticide handling practices minimize exposure, help prevent accidents, and reduce the likelihood of adverse effects. Applicators should take care not to walk or drive through spray. They should take extra precautions, such as wearing a chemical-resistant apron, goggles, and respirator or a full face mask while mixing and loading because these activities pose the highest likelihood of exposure.

Treated areas should be posted with appropriate signage and no one should be allowed to enter treated areas before the reentry time specified on the label unless the worker has been specifically trained and properly equipped and the label allows such reentry. The label for some pesticides does allow early reentry but only if specified conditions are met for PPE and worker training.

Protection of Sensitive Species Other than Humans

Although this Module is dedicated to human exposure, it is important to mention other sensitive species in the environment. There has been widespread publicity about the possible reduction in bee populations due to pesticide use, and other species are also susceptible to certain pesticides. Pesticide application may cause direct kill, reduction of habitat or reduction in fertility of the species, all of which lead to an overall reduction in the population.

Growers should be aware of sensitive local conditions or populations. This includes nearby crops, endangered species, parasites and predators that contribute to biological control, and pollinators including bees. If pesticide application is necessary, protective measures should be taken such as applying at a time of day when sensitive species are not present or establishing untreated refuges.

Storage and Disposal of Pesticides

Improper handling, storage and disposal of pesticides, or use of empty containers have many negative consequences. Poor handling leading to cross contamination of pesticides can result in the generation of illegal residues when the product is applied. Contamination of the environment and endangerment of humans and other animals also is a serious concern.

Store all pesticide products with the label intact, attached to the container and legible. Herbicides should be stored away from all other pesticides or fertilizers. Leakage or spillage of herbicide into other products can result in illegal residues or it can kill crops directly.

Pesticides should be stored in a secure location that is away from foods and food containers. The storage facility should have proper signage, good lighting and ventilation, a roof to avoid exposure to rain or sun, a fence to keep out animals and a lock to keep out children and other unauthorized persons. Ideally, the pesticides would be stored in a building with a concrete floor so that spills could be contained. Storage should not be in an open area. Products should not be exposed to extreme temperatures. Freezing can damage some pesticides and destroy their usefulness.

Excess or leftover pesticide mixtures must be disposed of properly. The preferred method is to apply the material according to label directions on a registered crop or site at the recommended rate. Another option is disposal at a hazardous waste site, which can be very expensive. Any other disposal method can result in the negative consequences mentioned previously.

Empty containers should first be cleaned according to recommended procedures on the label. They may then be disposed of in a suitable landfill unless the label allows for other disposal methods. As emphasized previously, empty containers should never be reused for other purposes. This can be a major source of pesticide poisoning.

A typical practice for the decontamination of a container with a liquid formulation would be to rinse the container immediately after it is emptied into the spray tank. Fill the container to about ¼ of its capacity with the proper diluent, which usually is water or oil. Replace the closure (lid, cap, plug, etc.) and rotate the container a few times. Add the rinsate to the spray tank and repeat the procedure two more times. When the rinsing is completed puncture the top and the bottom of the container to prevent its reuse.

For containers holding dry formulations, empty the contents into the tank while shaking vigorously to remove as much residue as possible. Take care not to inhale the dust and try to ensure that dust does not escape to the surrounding area. After the container is emptied, open both ends to help remove any additional residue into the tank and to prevent reuse.

Conclusion

The health and safety of workers is far more important than the value of the pesticide or the crop. Managers and supervisors have legal and ethical obligations to follow the law and to take all reasonable steps to protect personnel.

Summary

Most countries that are significant producers of fruits and vegetables have Worker Protection Standards (WPS) that are designed to promote the heath and safety of personnel.

The three pathways for pesticides to enter the body are oral, by inhalation and dermal. Up to 97% of all exposure is through the skin.

Personal protective equipment (PPE) includes all clothing and specialized equipment used to protect the worker from exposure.

Heat stress has similar symptoms to pesticide poisoning. Managers, supervisors and other workers should be aware of the symptoms and understand the practices that help prevent their occurrence.

The adverse effects of pesticide exposure are categorized by researchers and medical professionals as acute, chronic or allergic.

A person's response to pesticide exposure is affected by the schedule and duration of exposure and the person's nutritional condition; size; age; gender; consumption of tobacco, alcohol, or drugs; and personal hygiene.

Growers should be attentive not only to the protection of people but also to the protection of other sensitive species such as bees.

Pesticides should be stored in a suitable area that protects them from the environment and prevents access by children or other unauthorized persons.

Leftover pesticides should be disposed of in accordance with label directions.

Empty containers should be properly cleaned before disposal and should never be reused.