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behavior of pesticides in plants

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A number of chemicals of diverse characteristics have arbitrarily been classed together on the basis of their use and given the descriptive name "pesticides." An unfortunate aura of mystery has developed about these chemicals. However, there is nothing unique or mysterious about the chemicals we refer to as "pesticides." Like other chemicals, they have properties which can be accurately measured; they obey all the laws of physics, chemistry, and biology.

Chemical and physical properties of a pesticide and interacting environmental factors determine the behavior of pesticides. Behavior in turn dictates the ultimate fate of the pesticide (*16*). To predict behavior, we need to measure the chemical and physical properties of the pesticide and the environment. With these data and the laws of physics, chemistry, and biology, we can attack the problem of predicting what happens to a chemical in the environment. Our freedom to continue using pesticides depends on our ability to understand and predict their behavior in the environment. In this paper I will consider the bases of chemical behavior and the behavior of pesticides in plants.

THE BASES OF CHEMICAL BEHAVIOR

The behavior of a chemical is its characteristic movement, persistence, and fate in the environment. The behavior of a chemical will determine its field effectiveness as well as its residue characteristics.

The absorption of pesticides by foliage will show how we can understand pesticide behavior by examining the interaction of physical and chemical properties with the environment. Absorption is the movement of chemicals from the surface to the interior of the leaf.

All aerial portions of the plant are covered by cuticle (*5*). The cuticle is continuous through stomates and into the stomatal chambers, and any chemical entering the aerial portions of the plant must pass through the cuticle. The cuticle is composed of plates and protuberances of wax imbedded in various layers of cutin, a mixture of polymers of dicarboxylic- and hydroxycarboxylic-acid esters.

The properties of the cuticle vary with environmental conditions and position on the plant (*6, 15, 17*). In general, the polarity of the cuticle increases towards the interior of the plant. The external cuticle contains much wax and is highly oxidized and polymerized. In the central portion of the cuticle, nearly continuous layers of wax plates may be imbedded in cutin. The interior cuticle has less wax and more pectinaceous material, and the epidermal cell walls are impregnated with a mixture of cutins and pectins.

The cuticle inside the stomatal chamber is more polar than the cuticle on the leaf surface, and the under leaf surface cuticle is more polar than the upper surface cuticle. Plants raised under mesic conditions show a thinner and more polar cuticle than similar plants raised under xeric conditions. The cutin has some affinity for water and under conditions which favor hydration may swell and force plates of wax apart (*7*).

Pesticide entry into a plant requires contact with the surface and compatibility with the cuticle (*4, 6, 12, 14*). Waxy projections and hairs may prevent good contact between leaf surface and spray solutions with high surface tension. Surfactants and emulsifiers may improve the leaf contact of aqueous spray solutions, and oil-soluble pesticides are frequently applied in diesel oil, a carrier with good leaf-contact properties.

The compatibility of pesticide and leaf cuticle depends on the interaction of their respective chemical and physical properties. The polarity of the cuticle and the pesticide are of primary importance.

The polarity of the cuticle increases from the waxy leaf surface toward pectins in cell walls and to the aqueous environment of the cell. The outer portion of the cuticle favors the entry of relatively nonpolar pesticides like 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane (DDT) or the long-chain alkyl esters of 2,4-dichlorophenoxyacetic acid (2,4-D). The inner portion of the cuticle favors passage of more polar compounds like 2,4-D acid but restricts the passage of lipophyllic compounds like DDT. Thus, DDT residues in plants are usually surface residues which can be removed with solvents which remove the outer cuticle.

The systemic action of 2,4-D requires a balance between absorption and translocation (*2*). Extensive absorption with no translocation gives ineffective vegetation control. The penetration of surface cuticle by 2,4-D increases with the size of the hydrocarbon portion of alkyl esters of 2,4-D, but at the same time herbicidal effectiveness reaches a maximum and then declines. The affinity of long-chain hydrocarbon esters for the lipid portions of the cuticle retards their entry into the aqueous portions of the plant and their subsequent transport to the site of action. However, long-chain glycol esters of 2,4-D have good absorption characteristics and are compatible with the aqueous environment of the plant. These latter esters have a proper balance of hydrophyllic and lipophyllic properties which helps make them effective systemic herbicides.

I have considered absorption in some detail, but it is only one facet of pesticide behavior in plants. In the following section, I will outline the mechanisms which determine the ultimate fate of chemicals in plants.

THE BEHAVIOR OF CHEMICALS IN PLANTS

The initial point of pesticide-plant contact depends on the method of application. Many herbicides and insecticides are applied as aerial sprays, and the foliage and stems are primary intercepting organs. Some chemicals are injected into or directed on the stems of larger plants. Roots are the principal absorbing organs for soil-applied pesticides.

Behavior of Pesticides on Aerial Portions of the Plant

Pesticides intercepted by aerial portions of the plant may undergo several processes:

1. *Absorption*, the uptake of chemical into the plant, is required for systemic chemical action; and the degree of absorption will dictate the effectiveness of treatments with systemic chemicals. The amount of absorption which is desirable, therefore, depends on the nature of the pesticide, its target, and its residue characteristics.

2. *Surface adsorption*, the physical or chemical binding of the chemical to the surface of the plant, is a form of storage. The extent of adsorption depends on the physical

and chemical properties of both the chemical and the leaf surface. Surface adsorption may inactivate pesticides since it prevents absorption of systemic chemicals and reduces insecticide contact action. It is important to realize, however, that surface adsorption is not final; it is an equilibrium reaction. Environmental factors define the equilibrium between *adsorbed* and *free* chemical, and a change in environmental conditions will alter the point of equilibrium. Any reduction in the amount of free chemical leads to a release of adsorbed chemical until equilibrium is reestablished.

3. *Volatilization*, the vaporization of intercepted chemicals back to the atmosphere, is not important for chemicals with a low vapor pressure or a high heat of vaporization. On the other hand, losses may be appreciable for compounds like ethyl N,N-dipropylthiolcarbamate (EPTC) or the isopropyl ester of 2,4-D. Volatilization moves the chemical from the site of action, thereby reducing treatment effectiveness. Although volatilization reduces chemical residues on the plant, it adds to the total load of atmospheric pollutants.

4. *Washoff* is the removal of surface residues by precipitation. The amount of chemical not absorbed, adsorbed, degraded, or lost through volatilization may be subjected to washoff. Washoff may carry pesticides in solution or suspension depending on their water solubilities. Washoff may reduce pesticide effectiveness and may lead to impact on nontarget species or water contamination. Chemicals washed to the soil may be leached to the root zone and absorbed by the plant.

5. *Degradation*--photochemical, chemical, or biological--of chemical residues on the plant surface is important in determining both efficacy of treatment and impact on environmental quality. Degradation of surface residues may reduce effectiveness by removing chemical from the site of action. On the other hand, degradation is the only mechanism which can reduce the total load of environmental pollutants. Absorption, adsorption, volatilization, and washoff only store or transport pesticides to other parts of the environment.

Behavior of Pesticides on Roots

Chemicals in the root zone are subjected to the same processes as chemicals intercepted by aerial portions of the plant. However, the degree to which a particular process operates may be quite different.

Water-soluble pesticides are readily absorbed by the roots and may be transported to other parts of the plant (*3*). Surface adsorption also occurs. Pesticide volatilization is relatively unimportant from root surfaces but may occur from the soil surface. Washoff does not occur, but leaching of chemicals from the root zone is an analogous process. Of course, photochemical degradation does not occur on roots, but chemical and biological degradation in the root zone is important.

Behavior of Pesticides Inside the Plant

The behavior of pesticides inside the plant is not important if absorption is limited. If large amounts are absorbed, however, internal behavior determines both effectiveness of treatment and internal residue (*11*).

Pesticides inside plants may also undergo several processes:

1. *Translocation,* the movement of chemicals in plants, may occur toward the top of the plant in both the xylem (water transport tissue) and phloem (photosynthate transport tissue); but translocation toward the roots occurs only in the phloem (*9, 1*). Lateral transport is limited. Translocation is important because the fate of chemicals may vary in different plant parts. Pesticides absorbed by foliage but not translocated to other plant parts may be lost in leaf fall, while pesticides transported to the roots may be exuded into the soil (*13*). Generally, pesticide mobility and water solubility are positively correlated.

2. *Storage,* the chemical or physical binding of pesticides to plant constituents, may occur in any part of the plant. Largest amounts are frequently found close to the point of absorption, in storage cells adjacent to the paths of translocation, and in areas of intense metabolic activity. Pesticide storage may be active or passive. Active storage is pesticide accumulation against a concentration gradient and requires expenditure of metabolic energy. Pesticides may be passively adsorbed to structural components of plants. Both active and passive storage are reversible, and pesticides may be released and translocated to other parts of the plant as conditions in the plant change.

3. *Metabolism,* which alters pesticide structure, may result in detoxication or activation and may occur anywhere in the plant. Metabolism of herbicides is nearly always a detoxication process for the plant, but the products may be biologically active in other systems and, therefore, still important as residues (*12*). The phenoxybutyric herbicides are an exception (*10*). They are inactive as herbicides, but their herbicidally active acetic acid derivatives are produced through beta-oxidation of the butyric side chain. Insecticides are also metabolized in plants. Although insecticides and their metabolites are generally not active in plants, they are frequently quite toxic to other organisms.

4. *Exudation* is the exit of pesticides from the interior of the plant. Volatile pesticides and metabolites may leave the plant as vapors through the stomates (pores in the leaves). Some herbicides like 2,4-D, 2-methoxy-3, 6-dichlorobenzoic acid (dicamba) or 4-amino-3,5,6-trichloropicolinic acid (picloram) are exuded from the roots (*8*). In contrast with animals, fish, and birds, however, exudation of pesticides from plants is not extensive.

CONCLUSIONS

The behavior of a pesticide determines its fate in all parts of the environment including plants. Pesticides in plants may be absorbed, stored, metabolized, and/or released to the environment. These processes determine both the pesticide's impact on the plant and its residue characteristics.

The behavior of a chemical results from the interaction between the properties of the compound and the environment. The environment has many components, and a chemical may interact with any or all of them. The chemical behavior we observe in the field is an integration of many single interactions.

Scientists can accurately measure both the chemical properties and the environmental factors which interact to produce behavior. The results of some simple interactions can be predicted. However, the field of chemodynamics has not yet attained the sophistication necessary to quantify the multiple interactions which may occur between chemicals and their environment.

It will be difficult to derive a single predictive equation which includes the important primary and secondary interactions which produce chemical behavior, but such an equation is needed. I believe a better understanding of the behavior of chemicals in organisms will lead to greater pesticide effectiveness and, in turn, to fewer hazards connected with their use. Pesticides will remain available to man only if he can learn to use them with greatest effectiveness on target organisms and minimum impact on the remainder of the environment.

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