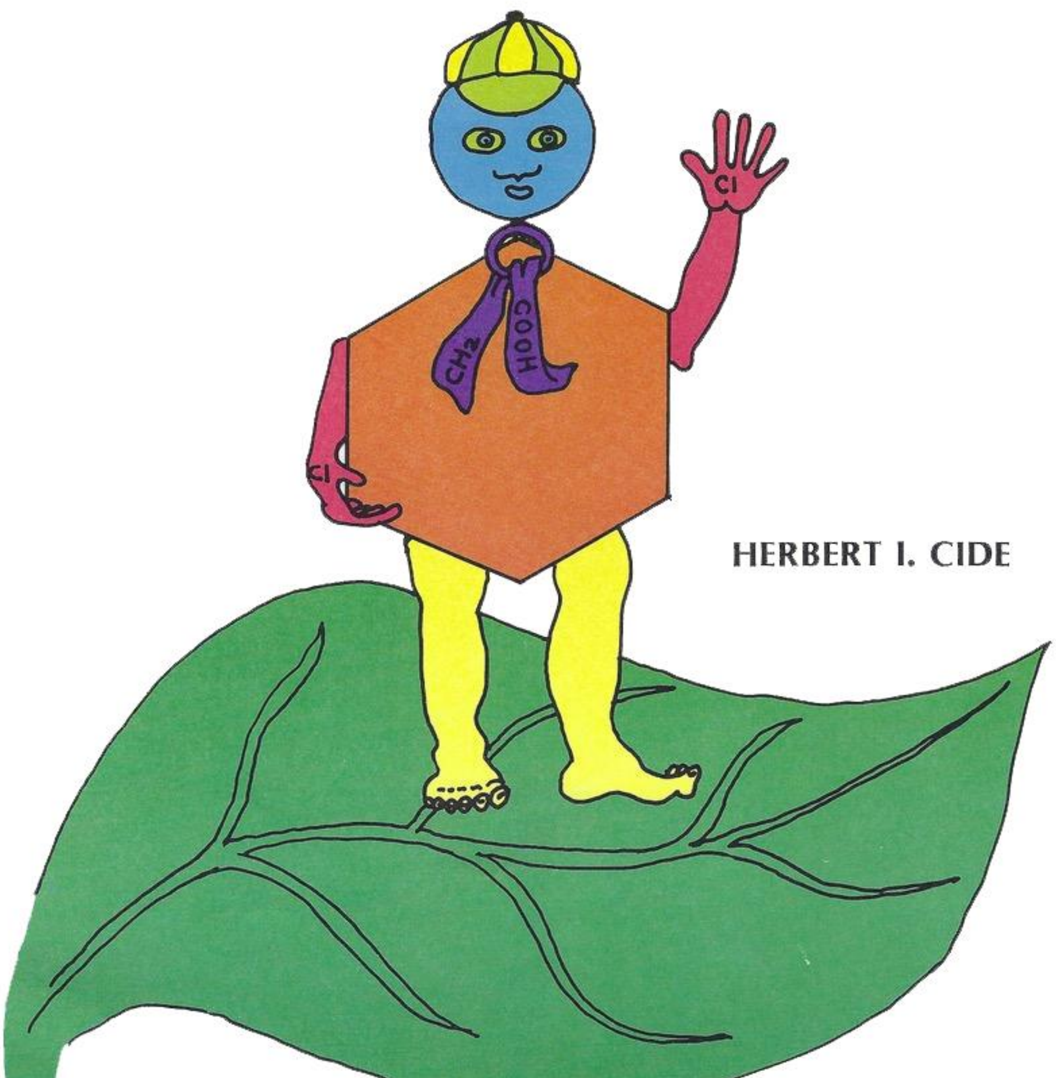
Colorado State University
Experiment Station
Fort Collins

Factors Affecting Herbicide Performance Starring: Herbert I. Cide

Bulletin 563S



HERBERT I. CIDE

INTRODUCTION

Weed control or weed science encompasses work on the selection of cultural, mechanical, biological, and chemical methods to best control weeds in crops and on noncrop land. Weed science involves far more than answering the difficult question of what chemical selectively kills weeds in a given crop. Frequently, a combination of methods is more effective and economical than any one method alone, and it is also more compatible with the maintenance of environmental quality. Nonchemical methods of weed control should not be considered as lesser or secondary methods.

One of the interesting things about weed control is that in contrast to other agricultural disciplines no method of weed control has ever been totally discarded. Older methods still have their place and are effectively combined with newer techniques. Enormous advances in weed control technology over the last few decades have been primarily due to the advent of herbicides for the selective control of weeds. A fact about weed control technology is that the use of herbicides constitutes one technique among many that can be employed. Herbicides are also the most important of the currently available weed control techniques. Weed control has taken on an entirely new aspect as new herbicides are continually added to the arsenal. New and better herbicides are being synthesized every day, and improvements in selectivity and environmental compatibility will continue for some time. If people are to employ these compounds to their fullest advantage and yet minimize potential dangers to the environment, they must understand the factors that affect their performance. That is, they must know something about those things which influence the selectivity of a herbicide and those environmental factors which are so important in determining the herbicide's efficiency in performing its delegated task.

A herbicide begins to interact with the environment at the moment of its application. It moves, is transported, acts, and is ultimately degraded in the environment. Interaction occurs in the atmosphere, in the soil, at the soil-atmosphere interface, and with plants and soil microorganisms. Perhaps the most critical phase that determines its ultimate effectiveness and selectivity involves those interactions from the moment the herbicide arrives at the plant surface until it reaches its site of phytotoxic activity. This bulletin describes, in general terms, the obstacles a herbicide molecule encounters between the time of release into the environment and the time it reaches its site of action. The environmental parameters affecting performance are included as well as comments on how the herbicides affect the environment. Because of the brevity of this bulletin, it is not possible to go into complete detail on each of these factors; much additional information is available. The bulletin attempts to give readers an understanding of the many factors involved and something of their interaction, but it does not attempt to completely describe each of the factors. Those interested in more complete information should consult one of the texts in the list of resource material included at the end of the bulletin.

In discussing the factors affecting herbicide performance one must make the initial assumption that the user has selected the proper herbicide for the task at hand. Herbicides are selective; but all herbicides are not selective in all crops, and not all herbicides kill all weeds. Therefore, the users of the herbicide must have defined the weed problem or the vegetation management situation in which they want to work. This means the users must know how to identify plants or gain the necessary assistance. People cannot solve a problem if they do not know what the problem is. Some herbicides work best when applied prior to planting and when incorporated into the soil. Examples include the use of Ro-Neet for preplant weed control in sugarbeets or the use of Eptam as a preplant herbicide for the control of weeds in seedling alfalfa. Other herbicides work well when applied postplant and incorporated. An example of this is Treflan or an Eptam-Treflan combination which is applied before a potato crop emerges and is incorporated into the soil. Still other herbicides work best when applied preemergence to the crop or to the weeds. Examples include the use of atrazine for weed control in corn or Lasso for weed control in corn and soybeans. In some situations herbicides only work when applied postemergence. Postemergence activity is not to be confused with contact activity, however, some herbicides like MSMA and Paraquat work postemergence because they must contact the plant foliage to be effective. Other herbicides like atrazine work postemergence, but the activity is delayed because the herbicide is dependent upon root uptake by the plant. Although many of the factors to be discussed in this bulletin are operative even when an incorrect herbicide has been chosen, the choice alone may influence the results rather than the factors discussed in this bulletin. One cannot overemphasize the importance of choosing the right herbicide and applying it at the right time.

SPRAYER CALIBRATION

Sprayer calibration is an extremely important step in any pesticide application. Yet it is the step most often estimated, forgotten, or totally ignored. Sprayers should be calibrated before every major spraying operation. This first essential step in any good program of chemical weed control must be combined with proper dosage and timing for best results.

When a herbicide is to be applied, regardless of the chemical or crop, similar questions arise: How much chemical should be added to the spray tank? How much water is being applied per acre? How many acres should a tank of spray solution cover? These questions are puzzling and the answers lie in calibration. For each spraying job it is necessary to know the exact amount of herbicide the sprayer applies. Too little usually gives poor weed control. If too much herbicide is applied, it wastes money, and possibly damages the crop. Excessive residues may make crops unsalable and soil unusable. Figure 1 shows the components of a good spraying system.

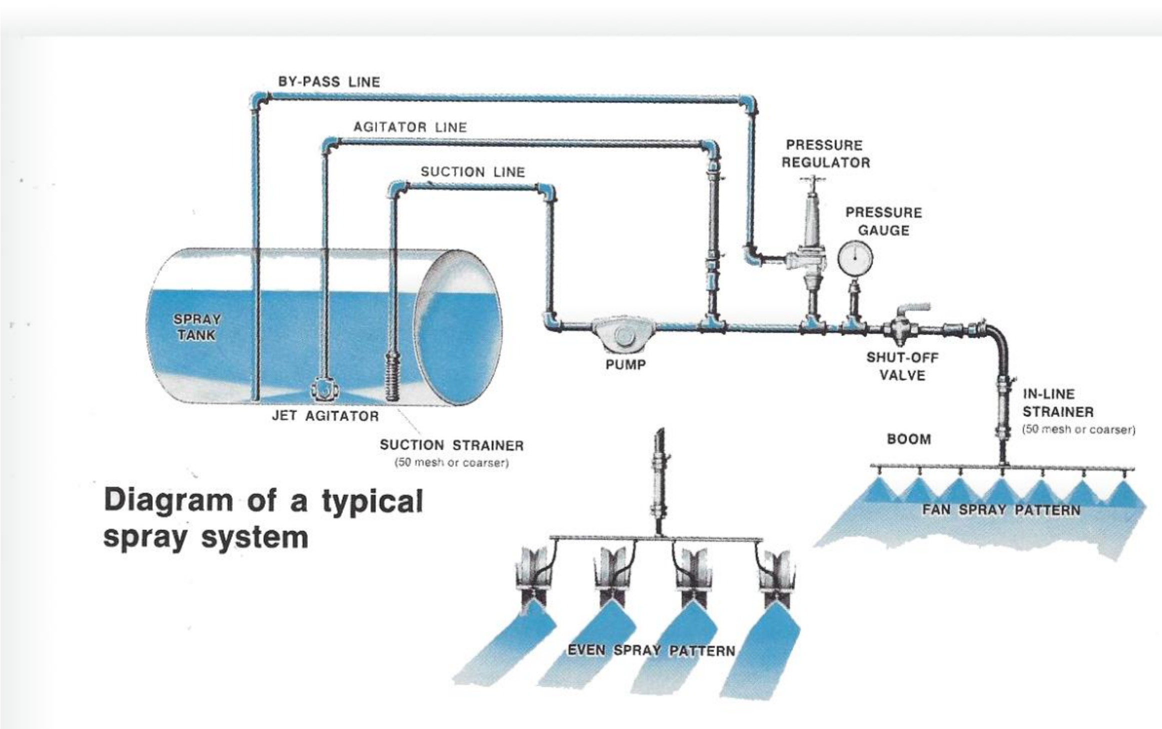


Figure 1. Diagram of a typical spray system. (Reproduced with permission — Ciba-Geigy Corp.)

The adjustable factors which determine application rate are:

1. SPEED: Forward speed should be held constant and is usually in the range of 2 to 5 miles per hour for ground spraying.
2. PRESSURE: It should be held constant in the range of 30 to 60 pounds per square inch. Higher pressures produce smaller droplets and increase the drift hazard.
3. NOZZLE SIZE AND TYPE: At constant pressure the larger nozzle orifice usually delivers a greater amount of pesticide to a given area. The shape of the orifice determines the spray pattern. Accurate calibration is difficult if nozzles are worn as they can be by abrasive material such as wettable powders. Brass nozzles are the most durable nozzle material. They should be replaced every year if one sprays 50 to 100 acres per year and uses wettable powders.
4. HERBICIDE CONCENTRATION: The viscosity or thickness of the spray mixture is an important consideration often influenced by the type of herbicide and its concentration. Generally, wettable powder suspensions have a higher viscosity than water and oil base solutions. Hence, if one calibrates with water and applies a wettable powder suspension, the amount of herbicide per acre may be lower than expected. Calibration should include wetting agents, oils, and other adjuvants if possible.
5. BOOM HEIGHT: The height of the boom is not often adjusted but should be considered when calibrating the sprayer. Improper height adjustment affects the nozzle pattern overlap and can change the rate of application. Height is of great importance in band application because it determines the band width.

Because it is necessary to change the rate of application for different tasks, a complete crop sprayer is equipped with a pressure regulator and exchangeable nozzle tips.

FACTORS AFFECTING PERFORMANCE OF FOLIAR HERBICIDES

What this bulletin deals with are those factors which influence the performance of a properly selected and applied herbicide from the time it leaves the spray nozzle tip until it reaches some site of action in the plant. It is important to realize than many factors can influence the herbicide and its resultant activity once it is released into the environment. The character being used to illustrate those factors and how they work is dubbed Herbert. Herbert is visualized to represent some of the components of a herbicide molecule. He probably most closely represents that common herbicide 2,-D. But in this bulletin he represents all herbicides, and he is used to show the many things that can affect his travels from nozzle tip to the interior of the plant and a site of action. These are listed below and are discussed individually.

Factors affecting Performance of Foliar herbicides

1. Reaching the target plant
    a. Drift
    b. Volatility
2. Retention by the plant
    a. Plant properties
    b. Characteristics of spray solution
3. Weather

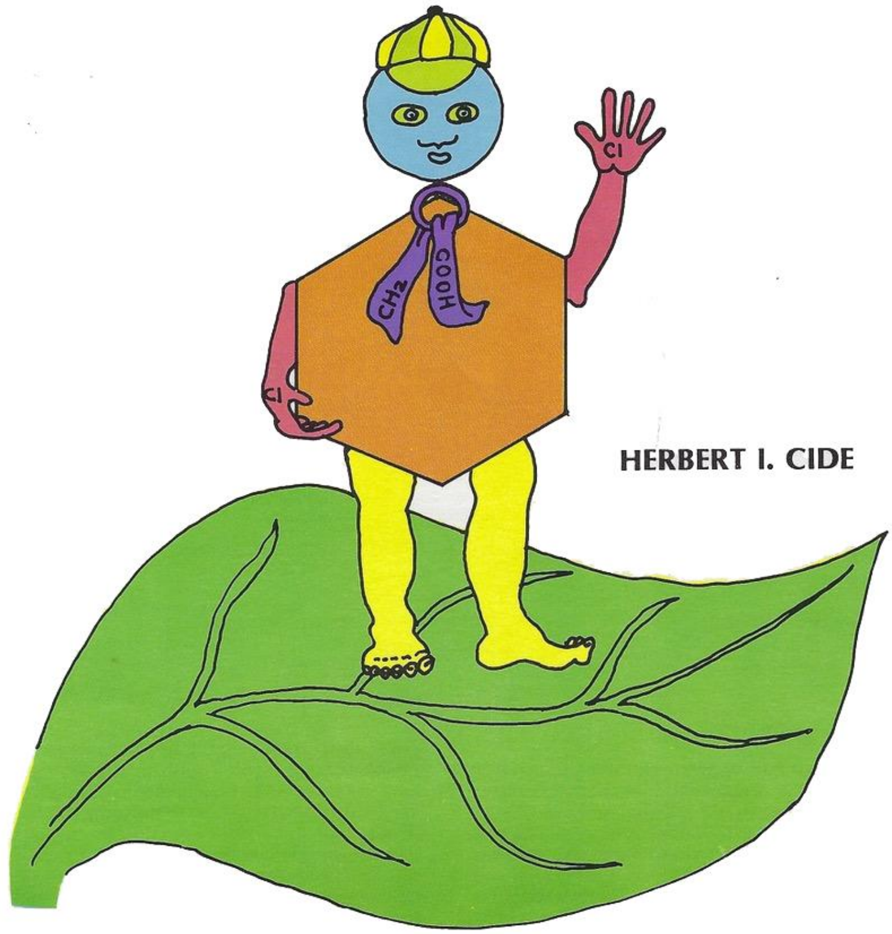


Figure 2. Herbert I. Cide

Reaching the Target Plant – Drift

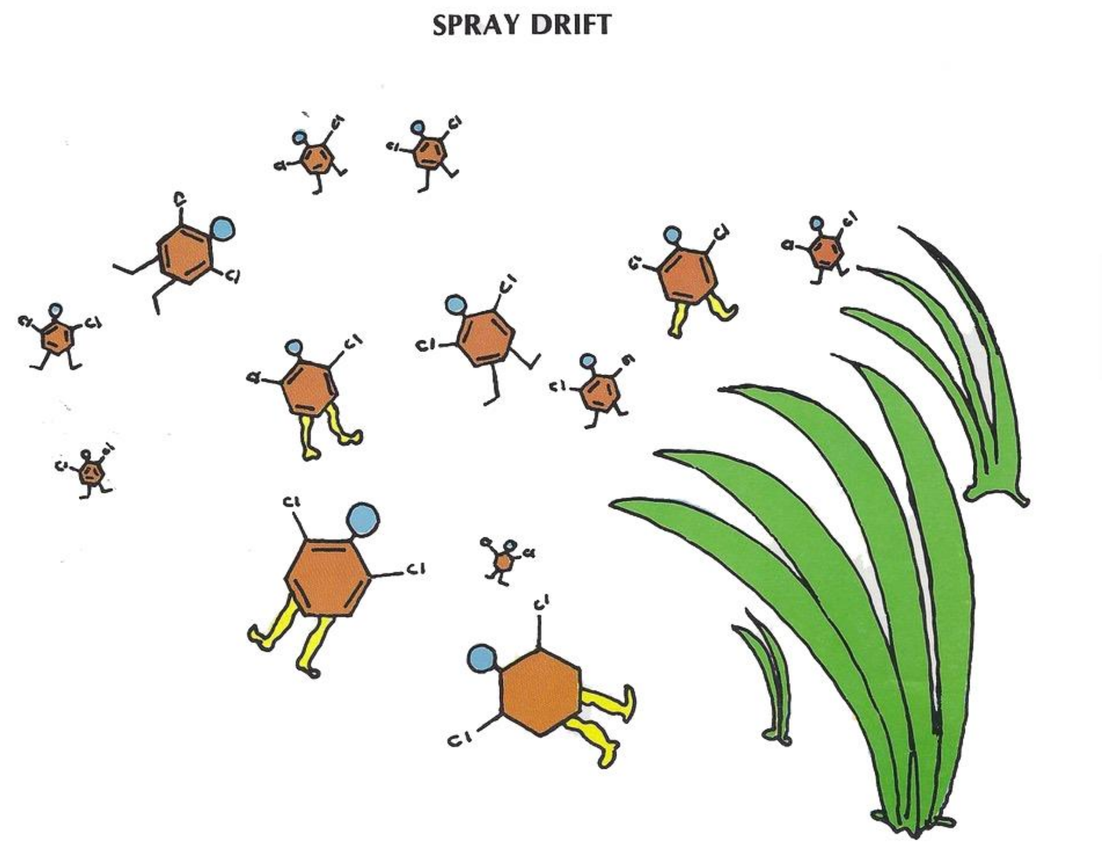


Figure 3. Spray Drift. Movement as liquid droplets.

The first thing that can happen to Herbert is that he can move as a liquid droplet and miss the target plant. This is known as spray drift and is a common occurrence with very small spray particles. Drift is influenced by the pressure of release, the surface tension of the droplet, nozzle orifice diameter and how much it breaks up the particles, the amount of wind, and the height above the ground where the spray is released. Most nozzles permit recovery of about 70 percent of the total spray volume in an area 1,000 feet from the point of release. Obviously this is affected by the plant cover in the area. If there is heavy plant cover, drift is reduced; but in a preemergent situation with no plant cover, drift could be a very important factor. Uniform droplets ½ to 1 millimeter in size deliver a spray with very little drift. However, some spray particles are always smaller than this and they can drift several miles. Spray drift is usually the greatest from aerial applications. The sprayer in this case is operated at a greater distance from the surface being sprayed compared to a ground rig, and it produces turbulent air which enhances or increases the possibility of drift. It is possible to modify the herbicide formulation with thickening agents or invert emulsions which significantly reduce drift.

Reaching the Target Plant – Volatility

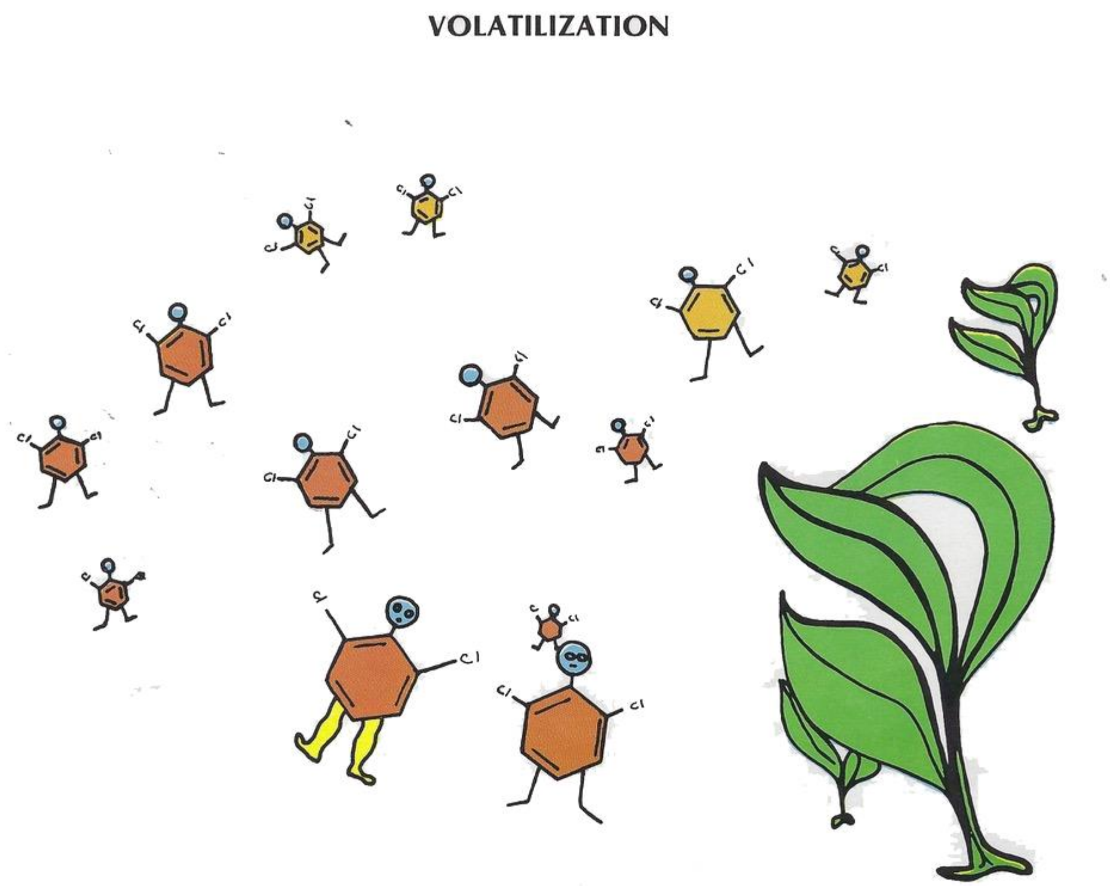


Figure 4. Volatilization. Movement as a gas.

Herbert can also volatilize which in the chemist's terminology is a change of state. He changes from a liquid droplet to a gaseous form shown in Figure 4 by how he is fading out as he moves away from the site of release. Volatilization is undoubtedly responsible for herbicide loss, and it is the reason that herbicides like Eptam, Treflan, and Fargo have to be incorporated. Volatilization can occur after release of the herbicide from the sprayer as it travels through the air or after it has hit the plant foliage. The physical and chemical properties of the herbicide, the same properties of the plant surface, and the temperature of the air influence the rate of volatilization. Volatilization increases as air temperature and the temperature of the plant surface increase. Adsorption of the herbicides to plant or soil surfaces and consequent penetration reduce or eliminate vapor losses.

Retention by the Plant – Plant Properties

The ability of Herbert to perform his assigned task can depend on the morphology (shape of the plant) and chemical variations of the plant surfaces. Large, broad leaves disposed parallel to the soil surface present a much easier target for Herbert to hit. He is more liable to land upon them and remain there than he is on a grass type leaf which is often disposed perpendicular to the soil surface.

The location of growing points or meristematic areas in a plant may determine the selectivity of a herbicide. In grass type plants or monocots, the growing points are usually at the base of the plant and therefore protected from contact herbicides by the surrounding leaves. In other plants, the growing points are actually below the surface of the soil. In contrast to grasses, broadleaf plants have exposed growing points as shown in Figure 6. Herbert can often seek out these growing points which are located at the tips of the shoots or in the leaf axils. Because of their exposure, Herbert can contact them readily, gain access, and thereby facilitate action.

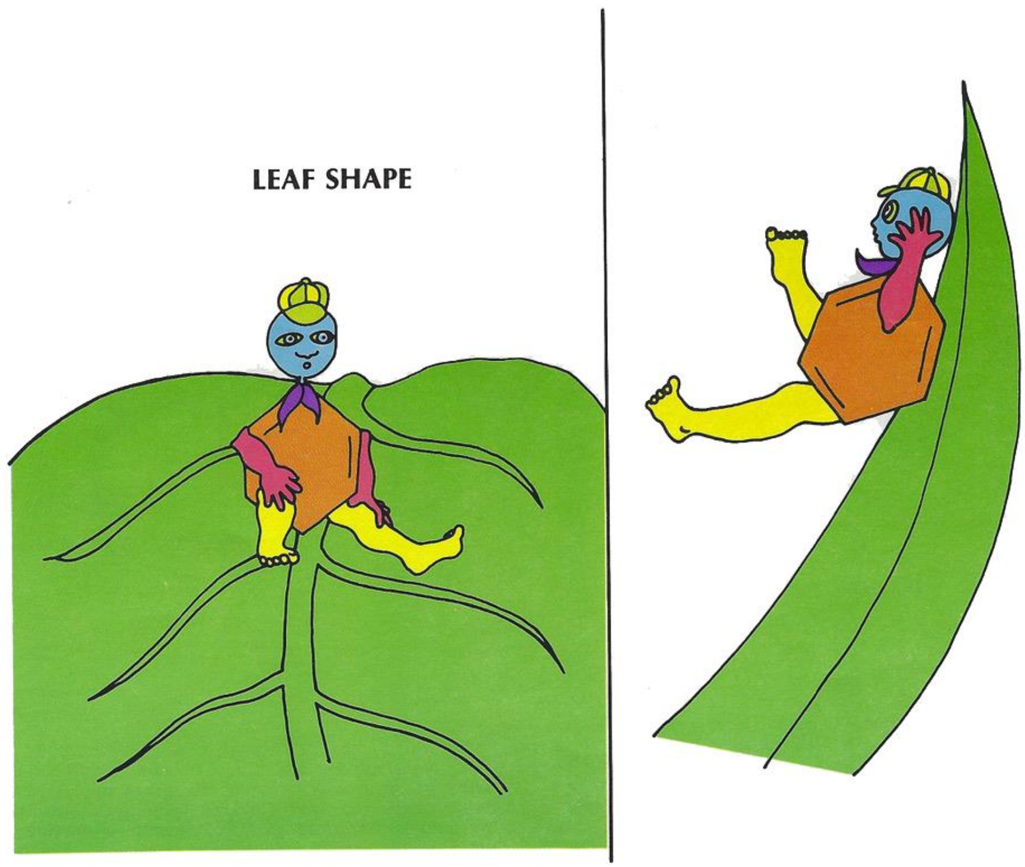


Figure 5. Leaf morphology.

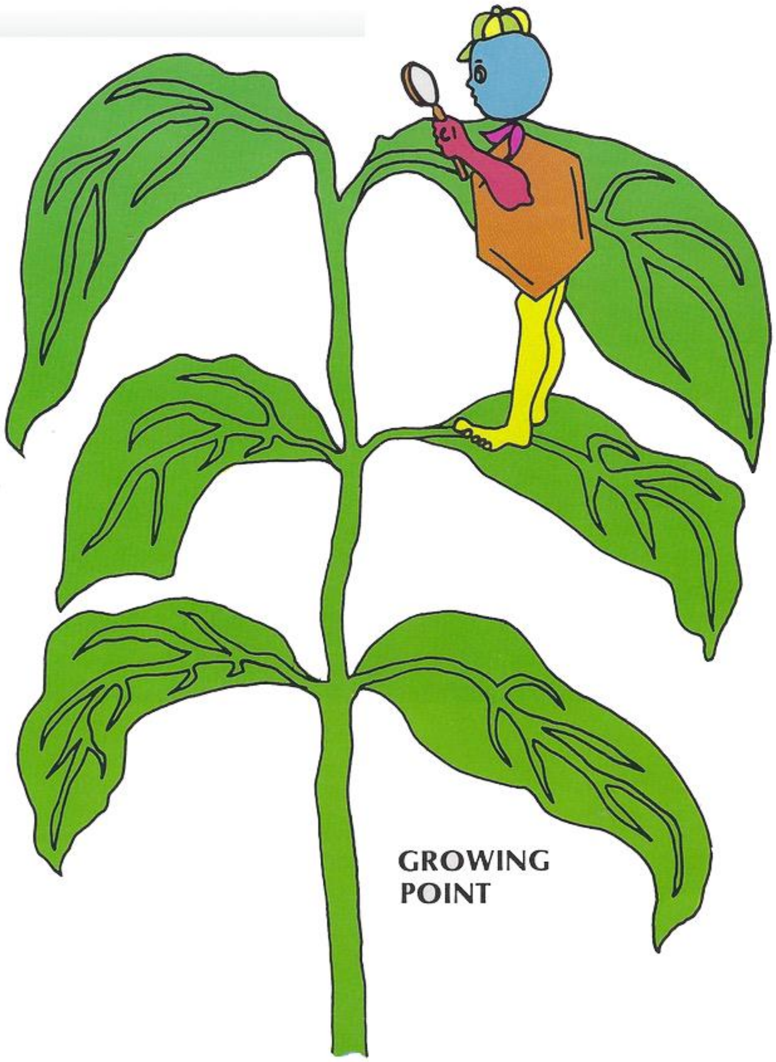


Figure 6. Location of growing point.

One of the very important factors in determining selectivity and performance is the nature of the leaf surface. Often, as shown in Figure 7, leaves have hairy surfaces which prevent intimate contact of spray droplets and leaf surface. Weeds such as velvetleaf, crabgrass, and some mallow species are quite hairy. Sometimes a hairy surface can become saturated with liquid and actually promote herbicidal injury because the hairiness prevents evaporation of the liquid.

Because the leaf is the principal entry portal for herbicides, it is important to understand something about its structure and function. Leaves are commonly studied in cross section, and the tissues of the leaves may be classified as epidermis, mesophyll, and vascular. In terms of herbicide entry, it is the thin epidermal layer which is most important. This layer can be regarded as the first hurdle the herbicide must cross in entering the plant. The epidermis is present on the upper and lower leaf surfaces, and it consists of a single layer of interlocked cells that contain no chloroplasts. The epidermis is covered by the cuticle which in turn is often layered with cuticular or epicuticular waxes. These (shown diagrammatically in Figure 8) constitute a varnish-like layer or film that retards the movement of water and gases in and out of the leaf.

Almost all leaves have cuticles and they represent a formidable barrier to the penetration of herbicides, yet many herbicides are able to accomplish it. The presence or absence of a surface active agent in a foliar herbicide formulation can often be the difference between little or no selectivity and some selectivity. Thus, these surface active agents or surfactants influence the ability of the formulation, and thus the compound, to penetrate foliage. Water is not compatible with many plant surfaces especially those with thick or especially waxy cuticles. Surfactants lower the surface tension of water systems increasing their spreadability and thus wettability. Thus, they aid penetration. Plants with thick, waxy cuticles absorb less herbicide than plants with thin, nonwaxy cuticles. Plant leaves growing in the shade have a thinner cuticle than those in full sunlight, and young leaves have thinner cuticles than old ones. This is one of the principal reasons that young plants are more susceptible to herbicides than old plants.

LEAF SURFACE

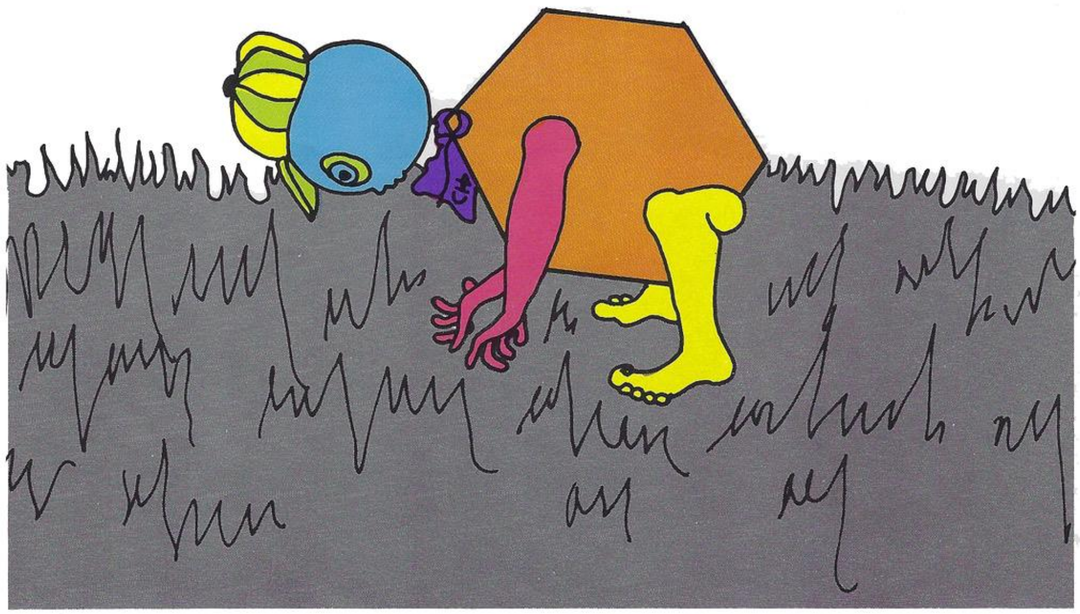
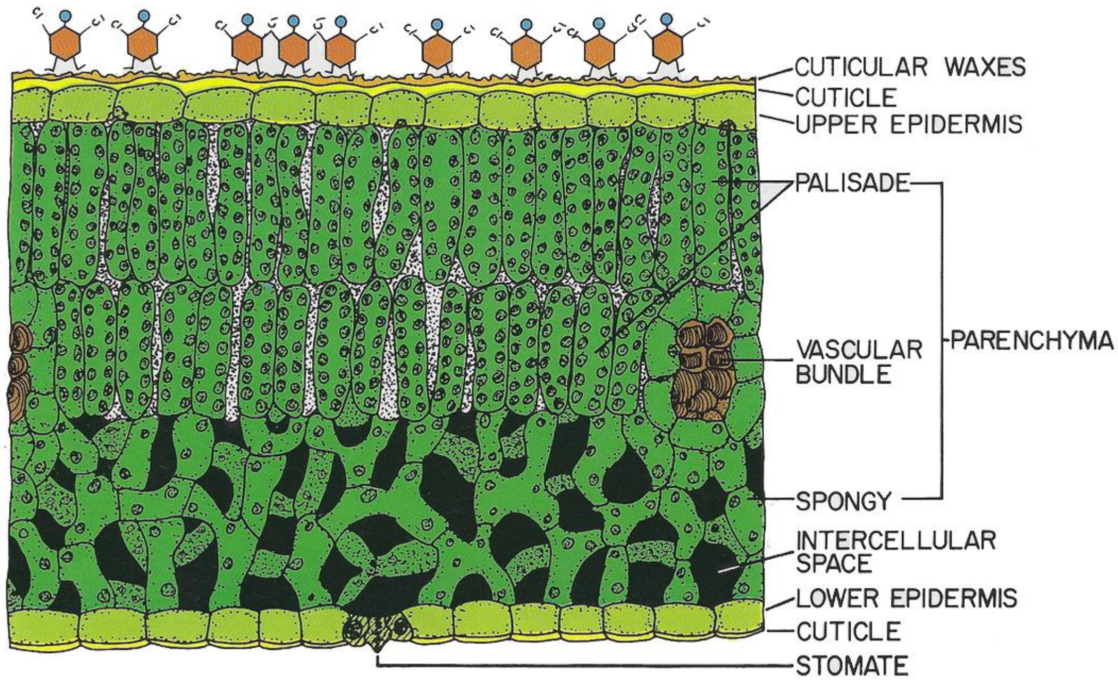


Figure 7. The nature of the leaf surface — hairiness.



LEAF CROSS SECTION

Figure 8. Diagrammatic representation of plant leaf and cuticle.

Herbert can also penetrate through stomata. Although direct absorption by the leaf surface is the most common route of entry, the spray material or its volatile fumes can penetrate stomata. Even in this case, the herbicide must still penetrate the cuticle present in the substomatal chamber. It is often less thick than that of the leaf surface. The stomata vary in number, location, and size among different plant species, and they can be located on the upper and lower surface or only on the lower surface. There may be as much as tenfold variation among species in the number of stomata. Plants with many large stomata on the upper leaf surface are often more readily killed by herbicides than those with few or no stomata.

Another barrier to entry through the stomatal opening is the surface tension of the herbicide. It is possible for the liquid droplet to bridge the stomatal opening and actually not enter it at all. Often the stomata are not open at the time the herbicide is applied. They close during the heat of the day and open when it is cool in the morning or evening. Thus, this route of access may be closed at the time of herbicide application. To best achieve stomatal penetration a herbicidal spray must have low surface tension and high wetting power.

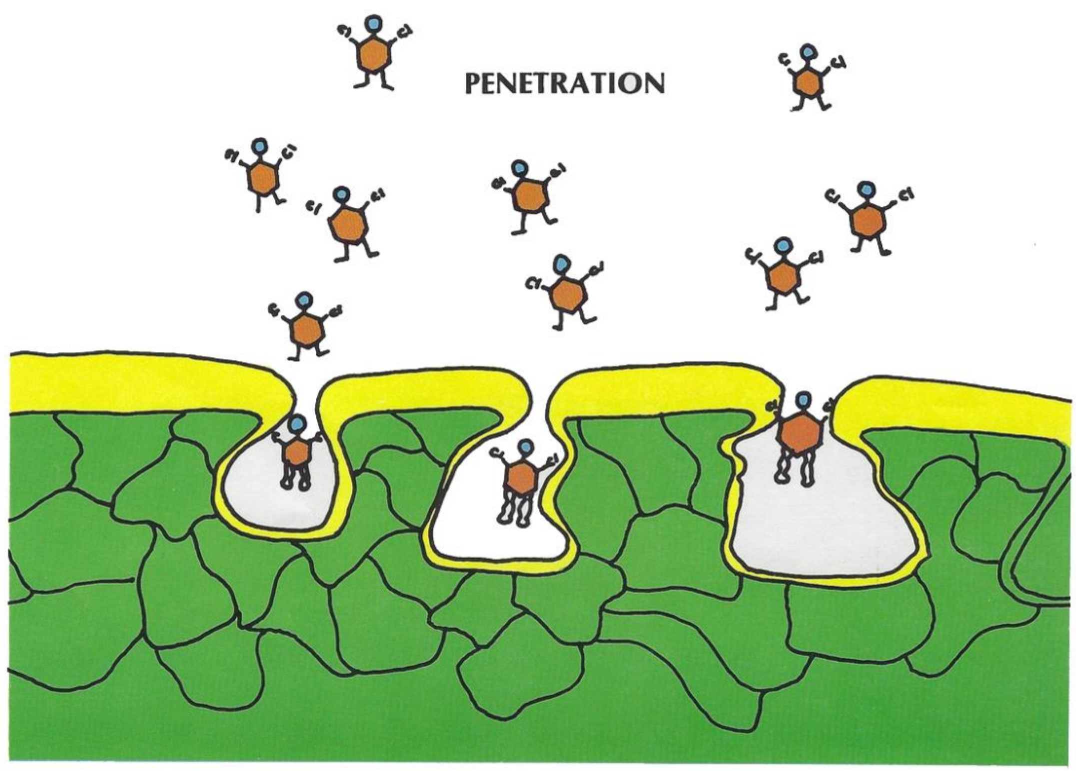


Figure 9. Stomatal penetration.

The Role of Formulation

The spray solution and its formulation are very important aspects of selectivity and performance. A spray solution with little or no surfactant may just bubble up on the cuticular surface as water does on a newly waxed car (Figure 10a). In this case there is less opportunity for Herbert to achieve maximum contact with the cuticular surface. There is very limited contact between the liquid and the surface of the plant. On the other hand, a spray solution with surfactant or surface active agent, which spreads out the water droplet, increases its coverage and wettability (Figure 10b). Therefore, Herbert has a much greater area of surface contact and a greater chance for penetration.

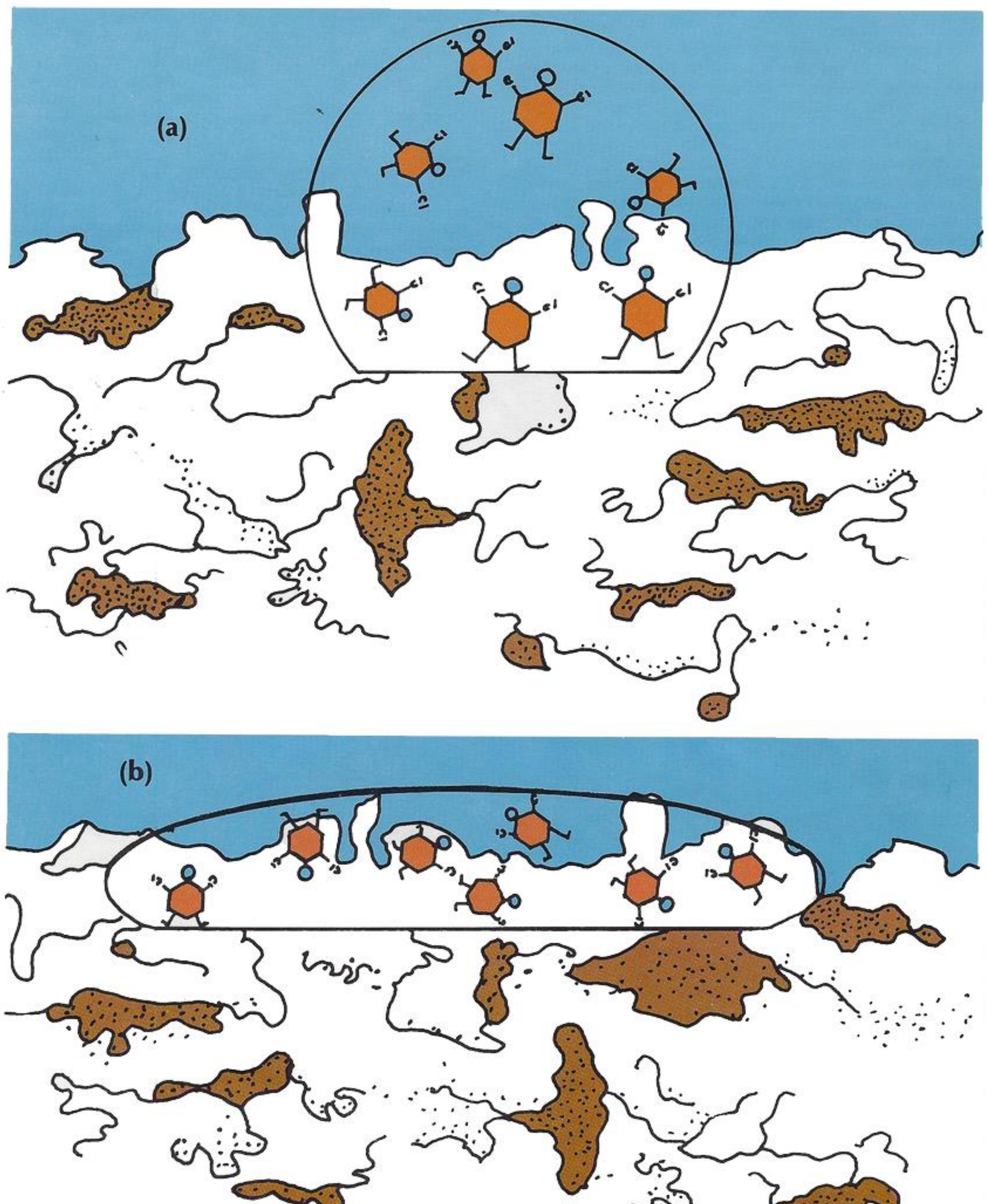


Figure 10. Spray droplets on the cuticular surface.

The Role of Weather

A question that one frequently encounters from a user of herbicides is what is the influence of weather; that is, rain, snow, cold, hot dry, wet, etc.. Figure 11 depicts two environmental conditions that can ensue after a herbicide has been applied. If a very hot sun comes out immediately after application or even during application, as opposed to it being a gray cloudy day, what effect does this have on the ability of Herbert to penetrate the leaf and perform his assigned task? It is known that herbicides like 2,4-D when formulated as the ester are more fat soluble than water soluble. Therefore, on a very warm day the cuticles of leaves are soft and perhaps more readily available for access by a fat soluble compound such as 2,4-D ester. So, in that case, a very warm day aids penetration and activity. It is also known that for a herbicide like MSMA the heat of the day enhances performance. The ability of MSMA to control weeds increases as temperature increases. The warmer it is, the better the activity. For other noncontact herbicides or soil active herbicides, the temperature at the time of application may be much less of a factor. Temperature also influences the rate of metabolism or the physiological activity of the plant. If a plant is rapidly metabolizing and working hard to grow and produce food, it is in a state amenable to rapid herbicide translocation and this enhances activity.

The other side of Figure 11 shows the case where Herbert is rained upon shortly after application. With a herbicide like 2,4-D, penetration occurs within a matter of hours after application so rain does not have as great an effect on activity. On the other hand, atrazine penetrates foliage poorly and rain tends to wash it off even if it rains as many as seven days after application. The best recommendation for foliar herbicides probably is that herbicides should be applied on warm, sunny days with little chance of rain within twenty-four after application. However, the activity of some soil-applied herbicides may be enhanced by a light rain shortly after application to help move them into the upper soil layers. It is also known that photodecomposition or breakdown by light occurs with many herbicides, especially those with nitrogen and cargon in a ring structure. In this case, a sunny day may not be the best day to apply them because of the likelihood of photodegradation (see Figure 17). This is not considered to be a serious drawback for the use of herbicides in the field, but it is a known method of decomposition.

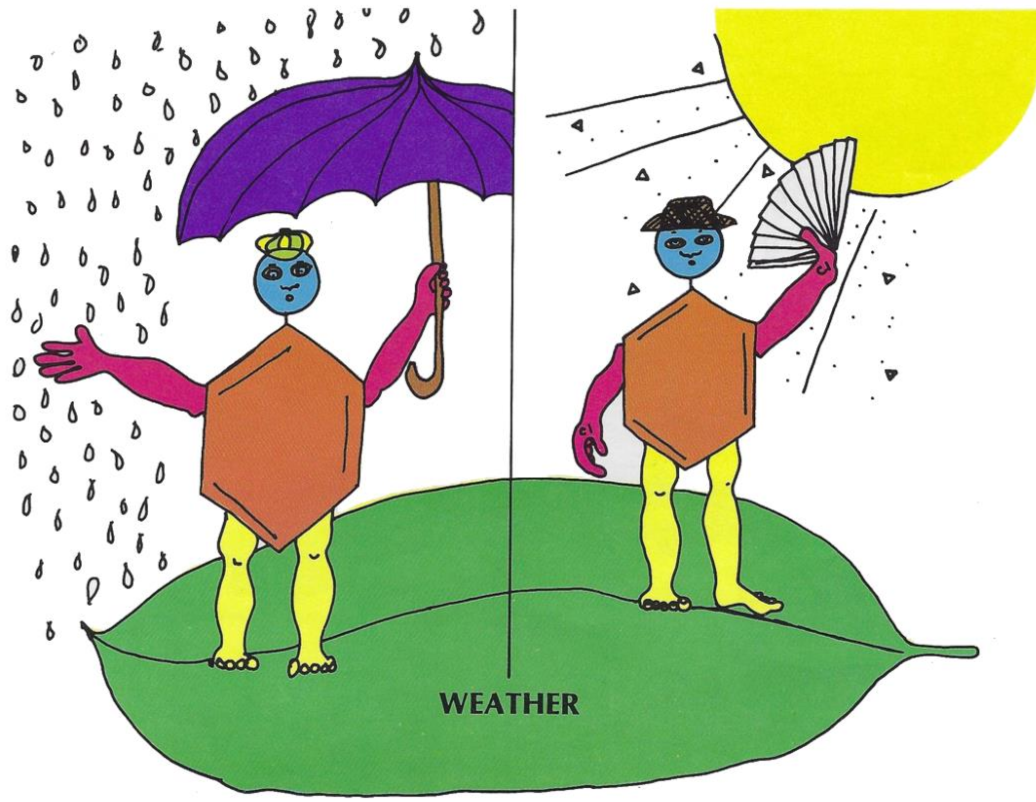


Figure 11. The influence of weather on Herbert I. Cide.

ABSORPTION OR FOLIAR UPTAKE

Once Herbert has surmounted the barriers of drift and volatility, he reaches the leaf surface and contacts the cuticle where several things may happen to him. First of all, he may be adsorbed or in some way stuck to the cuticle (Figure 12), thus eliminating his activity.

Herbert can also get stuck (adsorbed) or partially embedded in the cuticle and not be able to volatilize off the surface nor be able to penetrate beneath the cuticle.

And in the third case, Herbert can actually work his way through the cuticle and into the plant.

Figure 12. Adsorption of Herbert I. Cide to the cuticle.

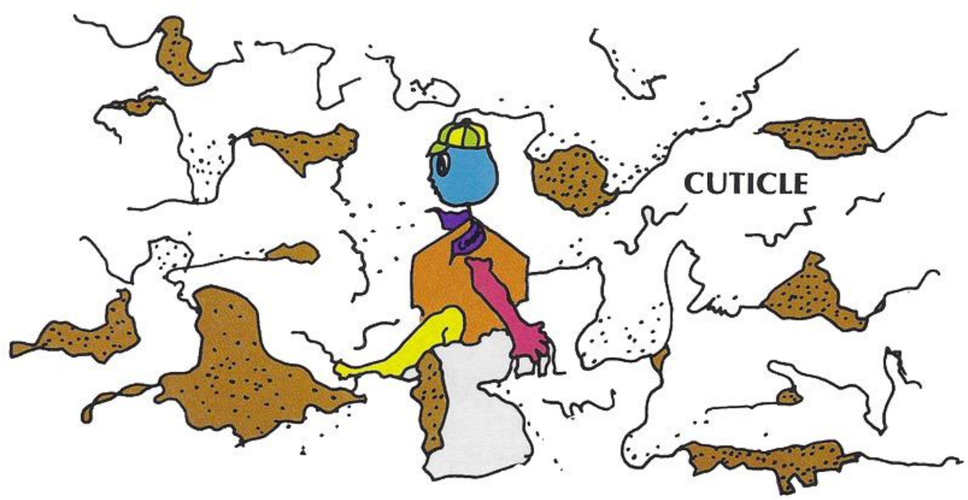


Figure 13. Adsorption or immobilization of Herbert I. Cide in the cuticle.

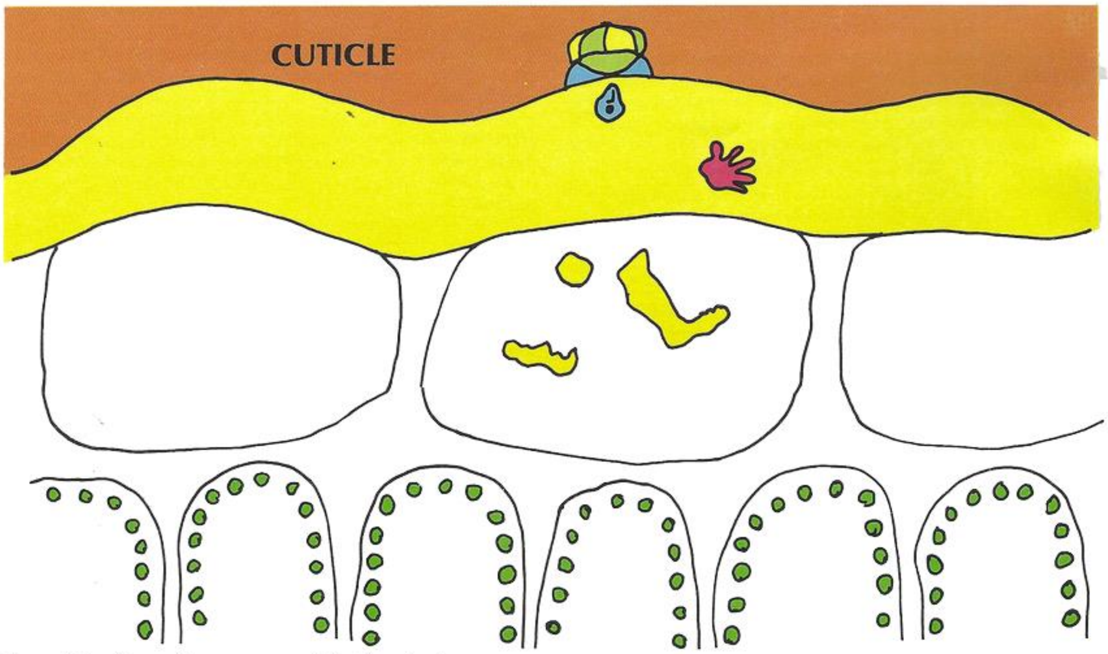


Figure 14. Absorption or passage into the plant.

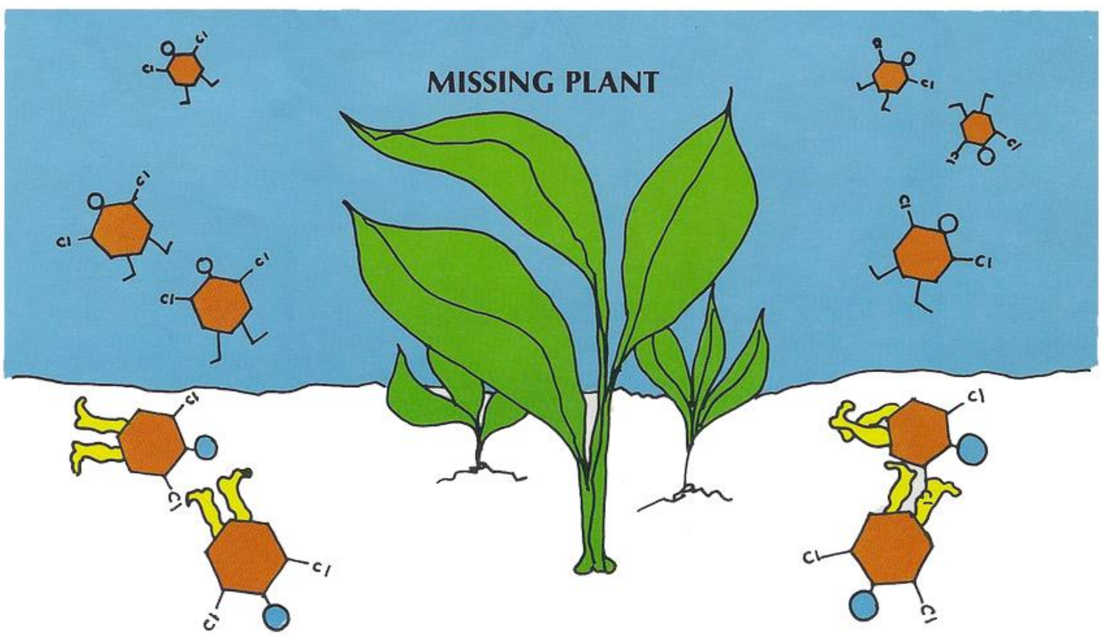


Figure 15. Herbert I. Cide often misses the plant or is applied directly on the soil.

FACTORS AFFECTING PERFORMANCE OF SOIL HERBICIDES

Some of the herbicides applied are directed at the soil without attempting to hit plant foliage. Because many herbicides are applied as broadcast sprays, the droplets hit the soil and actually miss the plant foliage; so the fate of the herbicide in the soil becomes of great importance in determining its performance and environmental impact. Several factors which influence the performance of herbicides in the soil are listed below:

Factors Affecting Performance of Soil Herbicides

1. Volatility
2. Photodecomposition
3. Selective Placement
4. Leaching
5. Adsorption
6. Decomposition of Herbert

Volatility

Volatility has already been discussed under the section on foliar-applied herbicides. When herbicides hit the soil surface the likelihood of volatility is still there. One should remember that this is a matter of change of state of liquid to gas. Herbicides can easily volatilize off the soil surface and then move away from the target area, or their activity can be completely lost.

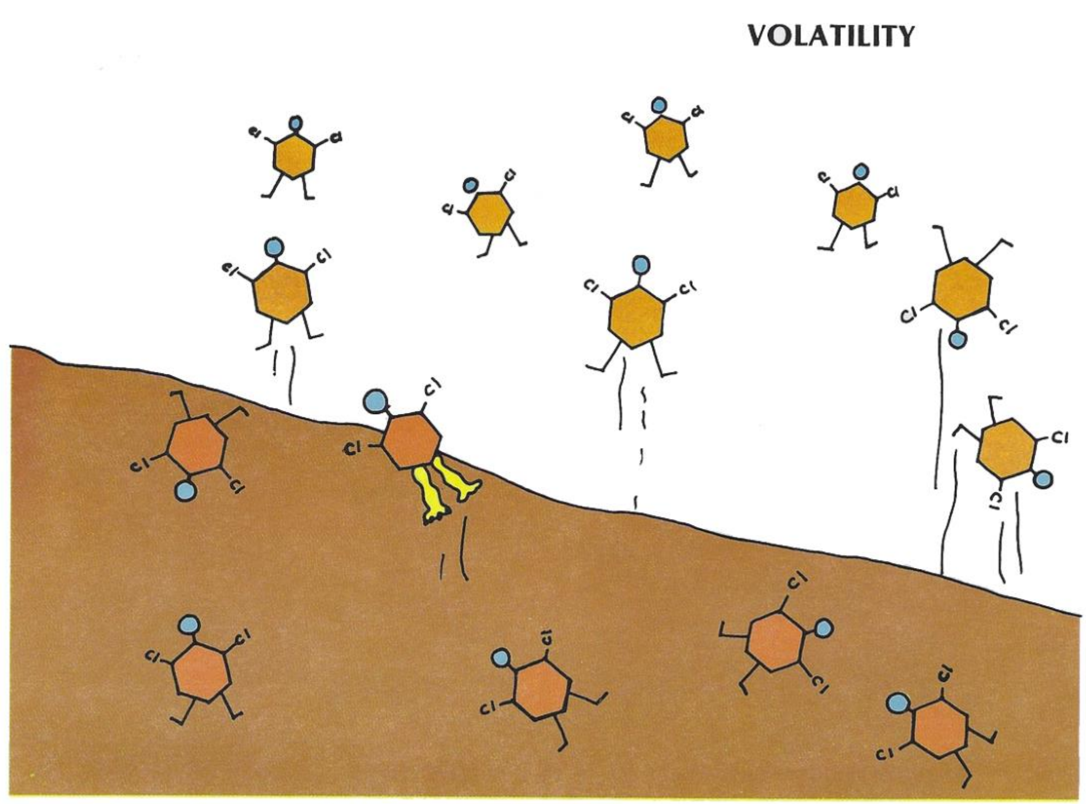
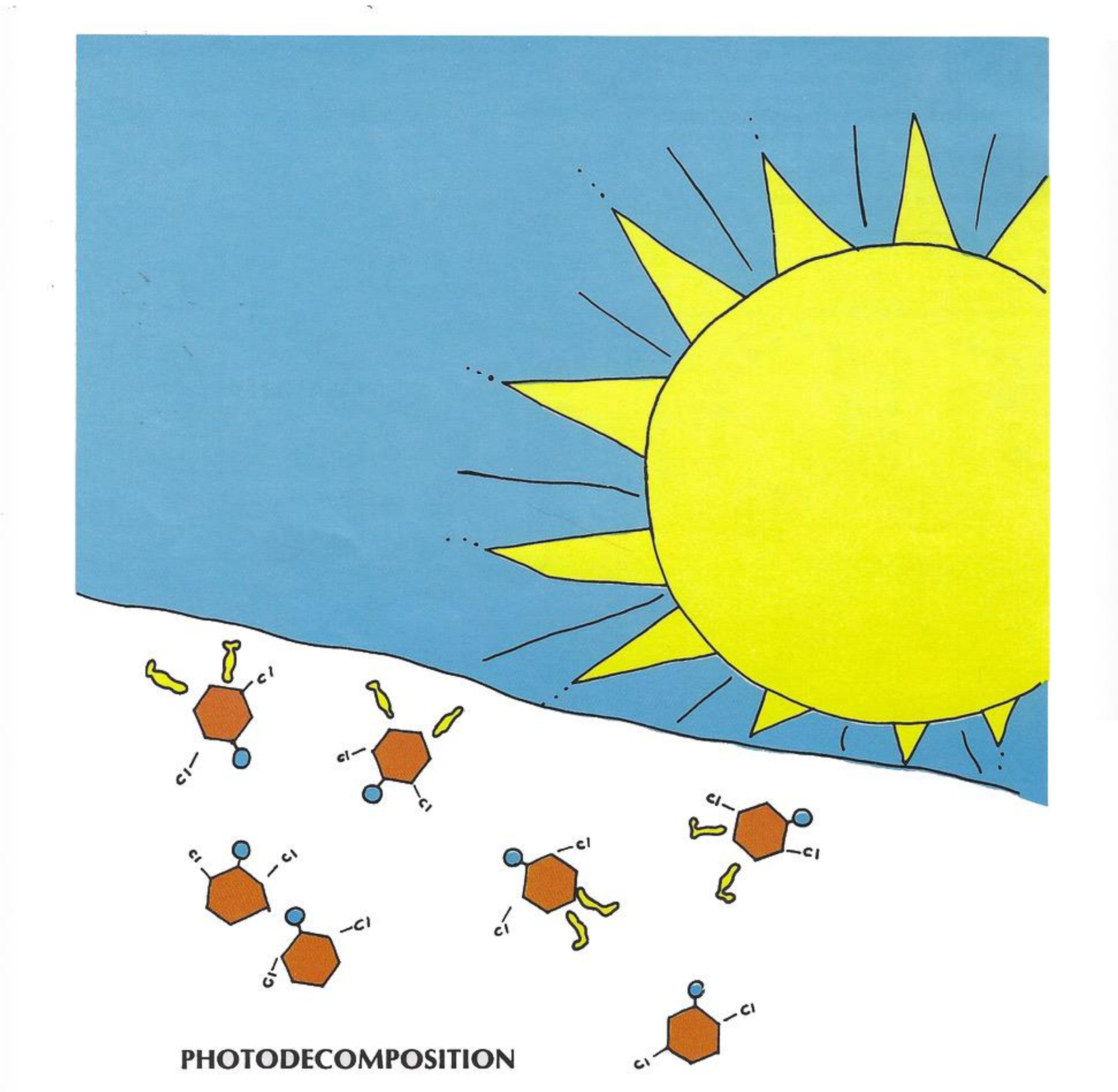


Figure 16. Volatilization of Herbert I. Cide from the soil surface.

Photodecomposition

Photodecomposition can also occur on the soil surface. This is the decomposition and actual destruction of the molecule due to the action of sunlight. Although photodecomposition has not been conclusively demonstrated for many herbicides in field studies, it has been shown in the laboratory. It is reasonable to assume that the phenomenon does occur on soil and in the air and is important as a destructive mechanism.



Selective Placement

One can also achieve selectivity in the soil by selective placement of the herbicide. If the weed or the crop is shallow or deep rooted, the herbicide can be placed to take advantage of this knowledge. For instance, if in Figure 18 the weed is shallow rooted, one could incorporate the herbicide lightly to get it in the area where the weed roots are and where uptake is most likely. On the other hand, if the crop is shallow rooted and the weed deep rooted, one can apply the herbicide and incorporate it or use water to leach it down into the area where the weed roots are. The crop roots are thus, not able to take it up. Selective placement can also be achieved by selectively shielding the crop from the spray or by placing nozzles so that no herbicide contacts the crop. The latter method is most often accomplished by using drop nozzles between the rows when the crop is taller than the weeds.

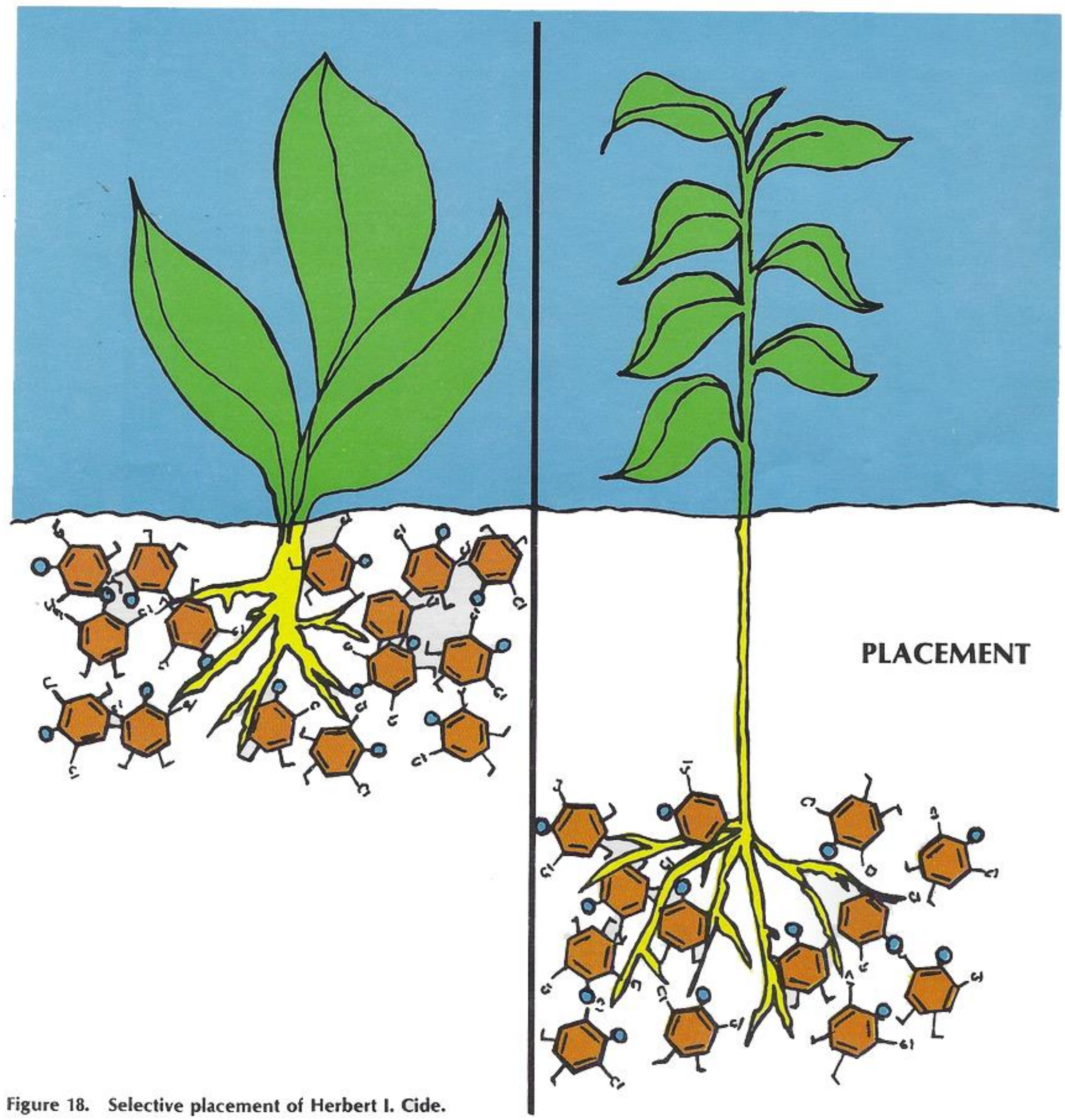


Figure 18. Selective placement of Herbert I. Cide.

Leaching

Another aspect of the fate of herbicides in soil is their leachability. This is defined as the movement of herbicides due to the action of water (Figure 19). Leaching of herbicides is of environmental concern because of the possibility of ground water contamination. It is usually considered to be movement down in the soil profile, although there are cases where the herbicide has actually been leached in an upward direction in a furrow irrigated crop or where subirrigation occurs. The herbicide can be leached down into a zone of action or out of the zone of action. The leachability of the herbicide is directly related to its water solubility, the amount of water moving in the soil profile, and its adsorption.

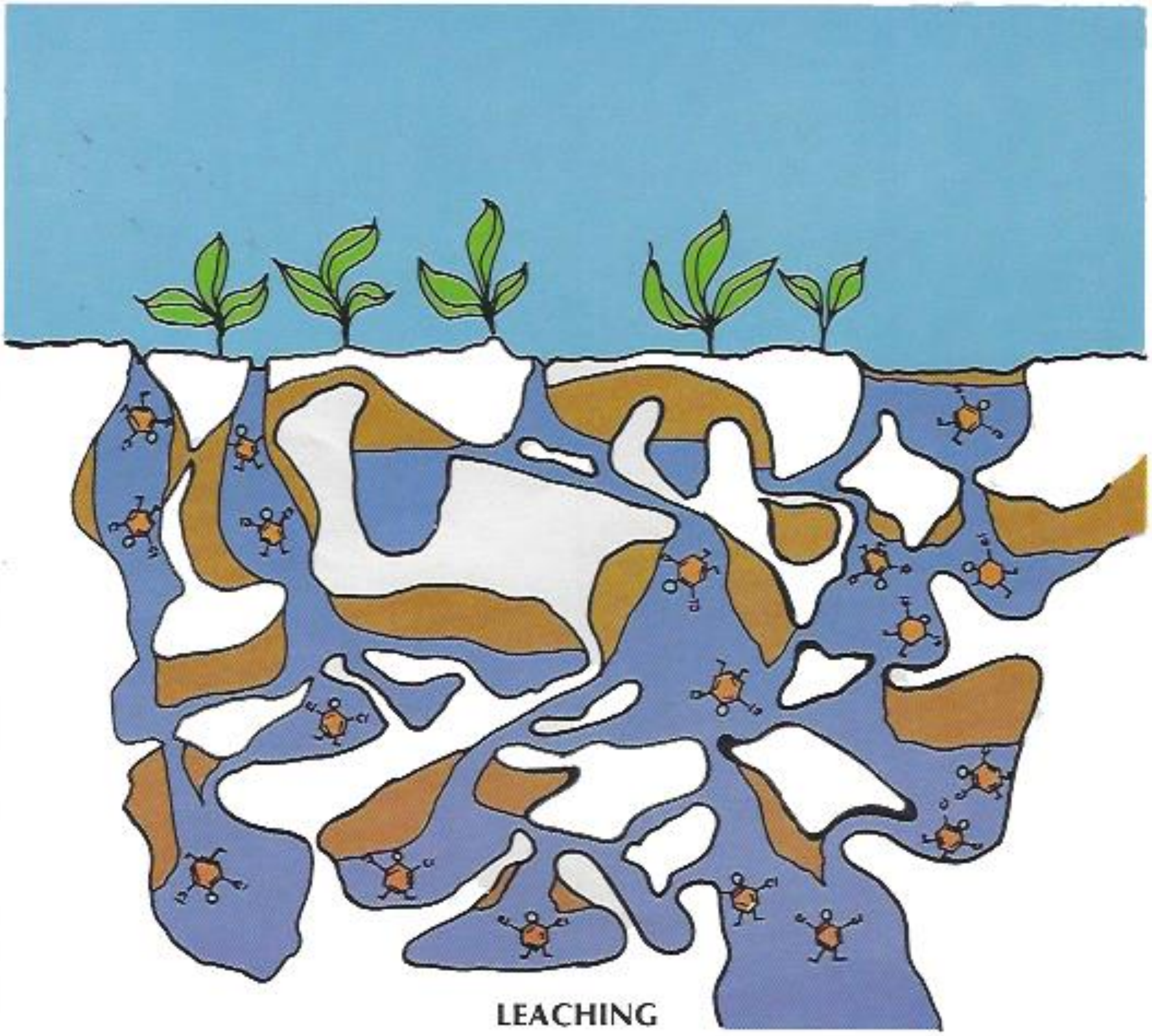


Figure 19. Herbert I. Cide being leached.

Adsorption

Adsorption is the process of accumulation at an interface, and in this case the interfaces of concern are the clay and organic matter colloidal surfaces. These surfaces through their cation exchange ability or physical attraction can concentrate herbicides and remove them from the soluble state which is usually considered to be the state from which plants take them up. Adsorption is one of the most important mechanisms for the reduction n of the concentration of herbicide in the soil. Herbert cannot entirely escape being adsorbed, but hopefully enough molecules remain in solution or the "desorbed" state for soil activity to occur. Some herbicides like MSMA and Paraquat are absorbed quickly and extensively and have no soil activity. That is, because of adsorption, some herbicides are only active on plant foliage. Adsorption also plays an important role in leaching. Dalapon and Trysben are not adsorbed by soil colloids and leach readily.

Figure 20. Adsorption of Herbert I. Cide on soil colloids.

Decomposition

Two other systems are operative in the soil and serve to destroy the herbicide molecule.

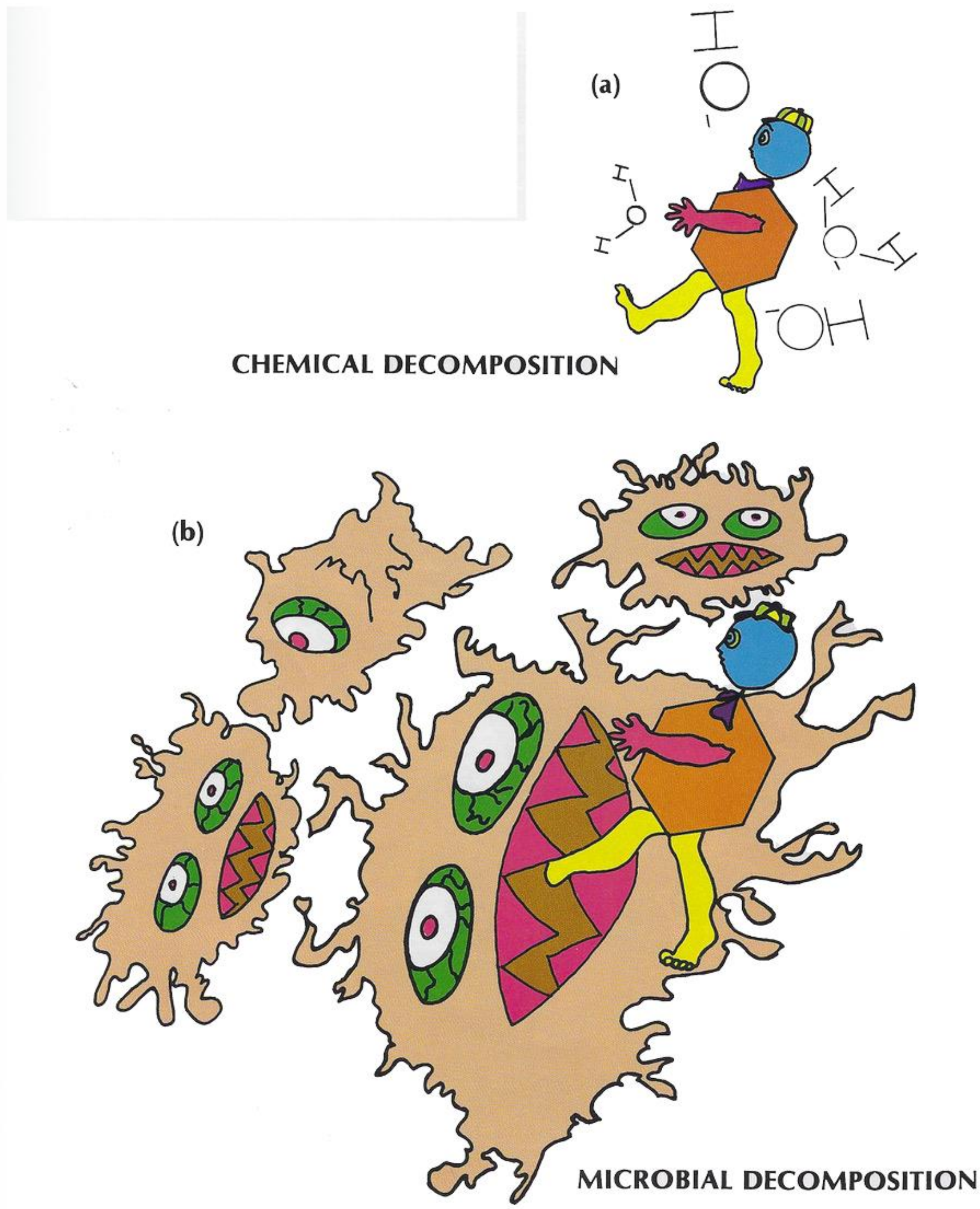


Figure 21. Chemical (a) and microbial (b) decomposition of Herbert I. Cide.

One of these is chemical decomposition. This is action that usually takes place in the soil solution and may involve hydrolysis (attack by water) or hydroxylation (attack by OH ions). The end result is a loss of the original molecular structure and usually a loss of phytotoxic activity.

Another destructive process which occurs in the soil is microbial decomposition. The bacteria, fungi, and actinomycetes in the soil all participate. Microbial degradation is the most important process for the destruction of pesticide molecules of all kinds in the soil.

Herbicides in the soil do not just rot or disintegrate. They are broken down by active chemical processes, many of which are mediated by living organisms – the soil microorganisms. The fungi and bacteria are of key importance for the degradation of herbicides. Herbicide molecules in the soil solution are subject to microbial attack. Many of these herbicide molecules provide an energy source from which microorganisms derive the energy necessary for their lives. One should know that in most cases the decomposition of herbicides is not a singular process but is one that occurs as an incidental adjunct to microbial degradation of organic matter. Microbial losses are usually enhanced by conditions favoring microbial growth such as warm, moist, aerobic soil. The rate of microbial decomposition varies from weeks for compounds such as 2,4-D or Sutan up to a month or longer for compounds such as Eptam and Lasso. Other compounds may take six months or more to degrade. Among these are Pyramin, diuron, and some of the triazines. Other compounds may take a year or more to degrade. Among these are Tordon, Trysben, and Banvel-D. In each case, microbial activity is important.

ROOT UPTAKE

If Herbert surmounts all of the obstacles in the way of absorption via the root and the soil, he presents himself at the root-soil interface for entry. Here the problems are perhaps somewhat less than they are at the foliar-air interface because the cuticular barrier is not present. But the process of getting to the root-soil interface is more complex than the foliar route. When Herbert gets there he still must enter the plant, and he does so along with the water and nutrient stream entering the plant through the root. The easiest route of entry is through the small root hairs rather than through the major part of the root.

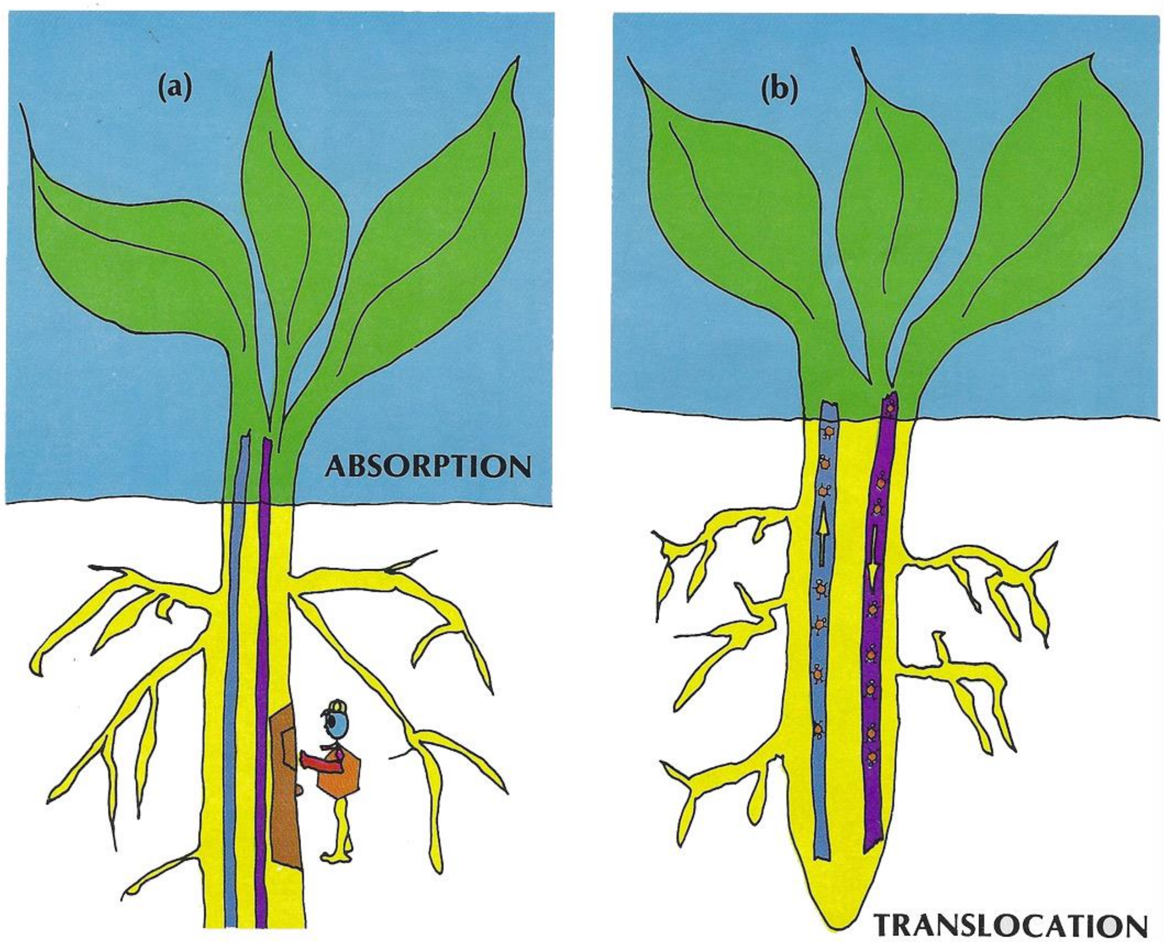


Figure 22. Absorption (a) and translocation (b) of Herbert I. Cide.

When Herbert enters the plant, he is translocated, whether entry was via the foliage or the root, to some site of action in the plant. He moves up in the xylem with the water and down in the phloem with the photosynthetic products to some site of biochemical importance to the plant. These sites are most often housed in the cells of the plant; thus, Herbert must work his way to the cells where he finally exerts his phytotoxic activity.

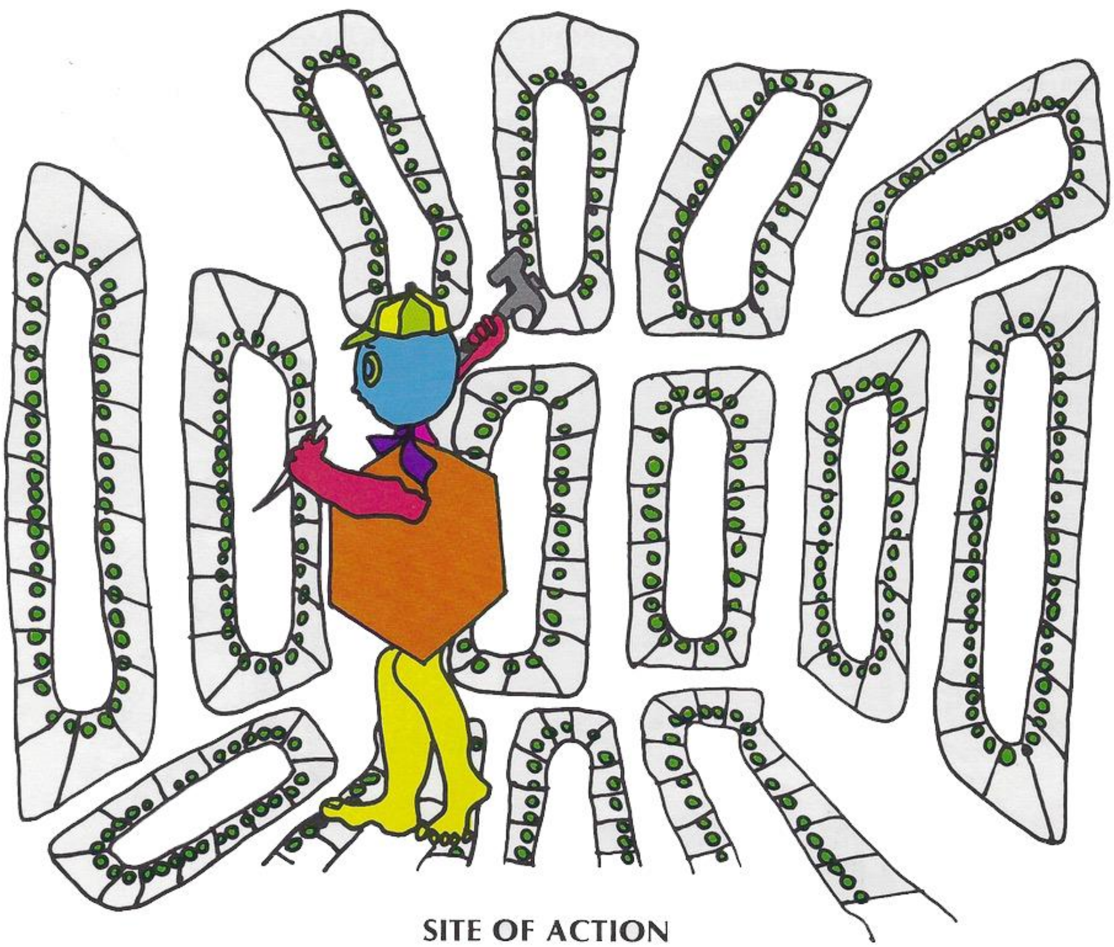


Figure 23. Herbert I. Cide at the cellular site of action.

SUMMARY

The manner in which herbicides alter growth and composition of plants after application and penetration to sites of action is a matter of great complexity. Numerous explanations have been suggested. The preceding has elucidated some of the important factors affecting the ability of herbicides to perform their assigned tasks. For further discussion you may consult chapters in one or more of the following texts on weed control and herbicide selectivity.

REFERENCES

List of references for further study of factors affecting herbicide performance includes:

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INDEX OF HERBICIDES MENTIONED IN TEXT

Trade name	Common name	Chemical name
Aatrex	atrazine	2-chloro-4-(ethylamino)-6a-(isopropylamino)-*s*-triazine
Banvel-D	dicamba	3,6-dichloro-o-anisic acid
Dowpon	dalapon	2,2-dichloropropionic acid
Eptam	EPTC	S-ethyl dipropylthiocarbamate
Far-go	triallate	S-(2,3,3-trichloroallyl)diisopropylthiocarbamate
Karmex	diuron	3-(3,4-dichlorophenyl)-1,1-dimethylurea
Lasso	alachlor	2-chloro-2',6'-diethyl-*N*(methoxymethyl)acetanilide
Paraquat	Paraquat	1,1'-dimethyl-4,'bipyridinium ion
Pyramin	pyrazon	5-amino-4-chloro-2-phenyl-3(2H)-pyridazinone
Ro-Neet	cycloate	S-ethyl *N*-ethlthiocyclohexanecarbamate
Sutan	butylate	S-ethyl diisobutylthiocarbamate
Tordon	picloram	4-amino-3,5,6-trichloropicolinic acid
Several names	MSMA	Monosodium methanearsonate
Treflan	trifluralin	a,a,a-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine
Trysben	2,3,6-TBA	2,3,6-trichlorobenzoic acid
2,4-D	2,4-D	(2,4-dichlorophenoxy)acetic acid