FOREST, RIGHTS-OF-WAY AND INDUSTRIAL HERBICIDES

(FNR-73)
(Revised 10/25/01)

Harvey A. Holt
Department of Forestry and Natural Resources
Purdue University
West Lafayette, Indiana 47907

Effective weed control can be accomplished by combining the desired characteristics of selected herbicides, assuming there are no incompatibilities or label restrictions. The use and application of a herbicide depends on the characteristics of the active ingredient, including: 1) foliage-absorbed or root-absorbed, 2) contact or translocated, 3) selective or nonselective, and 4) persistent or nonpersistent.

HERBICIDE TERMS

Foliage-Absorbed or Root-Absorbed

Foliage-absorbed herbicides enter the plant through the leaves (postemergence). Root-absorbed herbicides enter the plant through the roots. Root-absorbed herbicides are generally most effective when applied before the weeds emerge (preemergence). Root-absorbed herbicides are often applied in combination with a herbicide having postemergence activity. Some herbicides are absorbed by both the foliage and the roots. Herbicide formulation or method of application determines whether the herbicide is taken up by the foliage or the roots. Examples: (foliage-absorbed) 2,4-D, dicamba (Banvel, Vanquish), diquat (Diquat Herbicide-H/A), glyphosate (Accord, Rodeo, Roundup Pro), hexazinone (Velpar), imazapyr (Arsenal), picloram (Tordon), triclopyr (Garlon); (root-absorbed) bromacil (Hyvar), diuron, hexazinone (Velpar), imazapyr (Arsenal), picloram (Tordon), prometon (Pramitol), simazine, tebuthiuron (Spike).

Contact or Translocated (Systemic)

A contact herbicide kills only the green portion of the plants that it contacts; the herbicide does not move (translocate) within the plant. Good coverage is necessary. A contact herbicide is usually nonselective. Contact herbicides are effective in controlling annual weeds but provide only temporary suppression of perennial vegetation. Herbicides that are translocated move throughout the plant, whether they are absorbed by the foliage or roots. Since perennial plants will resprout from persistent root systems, translocated herbicides are especially useful for controlling perennial weeds because they will move into the roots. Examples: (contact) cacodylic acid, diquat (Diquat Herbicide-H/A), oxyfluorfen (Goal); (translocated) 2,4-D, clopyralid (Transline), dicamba (Banvel, Vanquish), dichlorprop (Weedone 2,4-DP), diuron, glyphosate (Accord, Rodeo, Roundup Pro), imazapyr (Arsenal), picloram (Tordon), simazine, sulfometuron methyl (Oust), tebuthiuron (Spike), triclopyr (Garlon).

Selective or Nonselective

Selective herbicides control only certain types of plants. When applied to mixed vegetation, some plant types (species) will be noticeably unaffected. Nonselective herbicides will generally control most weed species. Some herbicides are selective because of the plant's inherent ability to resist the herbicide effect. However, selectivity is most often determined by rate of application. Timing, method of application, and herbicide placement can also accomplish selectivity. Examples: (selective - broadleaf control) clopyralid (Transline), 2,4-D, dicamba (Banvel, Vanquish), dichlorprop (Weedone 2,4-DP), picloram (Tordon), triclopyr (Garlon); (selective - grass control) fluazifop-butyl (Fusilade), sethoxydim (Poast); (nonselective) bromacil (Hyvar), diquat (Diquat Herbicide-H/A), diuron, glyphosate (Accord, Rodeo, Roundup Pro), imazapyr (Arsenal), sulfometuron methyl (Oust), tebuthiuron (Spike).

Persistent or Nonpersistent

Persistent herbicides remain active in the environment for an extended period of time. Nonpersistent herbicides are relatively short-lived in the environment. The degree of persistence is greatly influenced by temperature, moisture, soil type, and rate of application. Persistence is generally used in the context of residual soil activity. Examples: (persistent) bromacil (Hyvar), imazapyr (Arsenal), picloram (Tordon), sulfometuron methyl (Oust), tebuthiuron (Spike); (nonpersistent) 2,4-D, diquat (Diquat Herbicide-H/A), glyphosate (Accord, Rodeo, Roundup Pro).

MODES OF ACTION

I. Herbicides causing injury to new growth and generally move from leaves to roots

Auxin growth regulator:
- Phenoxy acetic acid
  - 2,4-D (several brand names)
- Phenoxy propionic acid
  - dichlorprop (Weedone 2,4-DP)
- Benzoic acid
  - dicamba (Banvel, Vanquish)
- Picolinic acid and related compound
  - clopyralid (Transline, Stinger)
  - fluroxypyr (Vista)
  - picloram (Tordon, Pathway)
  - triclopyr (Garlon, Pathfinder)

Inhibit amino acid synthesis, nonpersistent:
- glyphosate (Accord, Rodeo, Roundup Pro and others)
- sulfosate (Touchdown)

Inhibit amino acid synthesis, persistent:
- Sulfonyl urea
  - chlorsulfuron (Telar)
  - metsulfuron methyl (Escort)
  - sulfometuron methyl (Oust)
- Imidazolinone
  - imazapyr (Arsenal, Chopper, Stalker)

Light activated by carotenoids:
- Diphenyl ether
  - oxyfluorfen (Goal)
- Other
  - oxadiazon (Ronstar)

II. Herbicides causing injury to established growth and generally move from the roots to the growing points (leaves)

Photosynthetic inhibitor:
- Chloro-s-triazine
  - atrazine (several brand names)
  - simazine (several brand names)
- Methoxy-s-triazine
  - prometon (Pramitol)
- Other triazine
  - hexazinone (Velpar, Pronone)

- Substituted urea
  - diuron (several brand names)
  - tebuthiuron (Spike)
- Uracil
  - bromacil (Hyvar)

Pigment Inhibitor
- Pyridazinone
  - norflurazon (Predict)

III. Herbicides causing localized injury with little or no movement within the plant

Cell membrane disruptors:
- diquat (Diquat Herbicide-H/A)
- glufosinate (Finale)

IV. Herbicides applied to the soil to inhibit root development of emerging seedlings

Mitotic disrupter:
- Dinitroaniline
  - oryzalin (Surflan)
  - pendimethalin (Pendulum)
  - prodiamine (Endurance)
- Others
  - DCPA (Dacthal)
  - pronamide (Kerb)

Inhibit root growth of germinating seedlings:
- napropamide (Devrinol)

V. Inhibit bud development

Inhibit bud development:
- fosamine (Krenite)

VI. Grass specific herbicides

Inhibit lipid biosynthesis
- fluazifop-butyl (Fusilade)
- sethoxydim (Poast)

VII. Miscellaneous

Modes of action not clear:
- Organic arsenicals
  - cacodylic acid (several brand names)
  - MSMA (several brand names)

Many more products are available. Most of these products are mixtures of the active ingredients above. Pre-mixed and tank-mixed combinations offer convenience and utilize the desired characteristics of each component.

CHARACTERISTICS

The following are some of the common characteristics of auxin growth regulator herbicides [clopyralid (Transline, Stinger), 2,4-D, dicamba (Banvel, Vanquish) dichlorprop (Weedone 2,4-DP), fluroxypyr (Vista), picloram (Tordon, Pathway), and triclopyr (Garlon, Pathfinder)]:

_ They affect plant growth similarly and appear to act at the same site as the natural plant auxin IAA (indole acetic acid); however, they are much more active than IAA and are applied at much higher rates than the natural occurring plant hormone.

_ The plant dies, in part, because the distorted growth prevents food from reaching the roots.

_ The herbicides translocate (move up and down) in the plant so they can be taken up by roots and leaves.

_ Because they translocate through the plant, they are effective when only part of the plant is treated.

_ Low pressure, low volume sprays, and wiping applications are possible because they translocate.

_ Distorted plant growth is visible at doses far below the lethal amount so drift to susceptible crops (grapes, tomatoes, cotton, soybeans, tobacco) is a concern.

_ They can leach in the soil.

_ Only picloram has useful residual soil activity.

_ These herbicides are available in liquid forms as water soluble salts (amine and mineral salts) and emulsifiable concentrates (EC) or esters. The formulation influences rate, method, and timing of application. The water-soluble formulations are applied to plant foliage or can be injected into woody stems. They are also considerably safer to fish than the EC or ester formulations. The EC formulations are best used to control woody plants and can be applied to the bark or leaves of trees.

_ Grasses are usually resistant to these herbicides at labeled rates.

_ They have low mammalian toxicity.

_ Some products containing picloram are classified as *Restricted Use Pesticides*.

Characteristics of the herbicides that prevents the plant from making certain amino acids but **has no** residual soil activity [glyphosate (Accord, Rodeo, Roundup Pro), sulfosate (Touchdown)] are that:

_ They inhibit synthesis of the amino acids phenylalanine, tyrosine, and tryptophane in plants.

_ They are generally broad-spectrum herbicides which must be absorbed by the leaves. However, they can be used selectively in some situations when applied at low rates, with directed methods, and when desired plant species are not actively growing.

_ They are readily translocated in the plant.

_ They require a week or more to control annual plants and longer for perennial weeds.

_ They do not cause rapid foliage discoloration, even from very concentrated sprays.

_ They control perennial weeds better when applied after the flowering stage; late summer to early fall application is best for woody plant control.

_ They are effective in wiping applications.

_ They have essentially no soil activity at normal use rates because it becomes bound to soil particles.

_ They have very low toxicity to mammals.

Common characteristics of herbicides that prevent the plants from making certain amino acids but **do have** soil activity [chlorsulfuron (Telar), imazapyr (Arsenal, Chopper), metsulfuron methyl (Escort), sulfometuron methyl (Oust)] are that:

_ They inhibit synthesis of the amino acids leucine, isoleucine and valine in plants.

_ They are taken up by the leaves and roots; however, foliage application is more effective.

_ They translocate in the plant.

_ Arsenal and Oust give broad-spectrum control of many grasses and herbaceous weeds; many grasses are resistant to Telar.

_ Although it may take several weeks for the plants to appear dead, they do stop growing soon after application.

_ All of these herbicides have useful residual soil activity.

_ All have low use rates (ounces or less per acre).

_ The activity of the sulfonylurea herbicides (Escort, Oust and Telar) is enhanced in high pH (alkaline) soils and by adding a nonionic surfactant.

_ They have low mammalian toxicity.

Common characteristics of herbicides that are light activated by carotenoids (oxadiazon (Ronstar), oxyfluorfen (Goal)) are that:

_ They damage cell membranes which kills tissue. The leaf tissue appears water-soaked, however, damage is not as rapid as with diquat.

_ They enter the roots, stems, or leaves of young plants.

_ They move very little in the plant.

_ They are strongly adsorbed by soil organic matter and are highly resistant to leaching.

_ Mammalian toxicity is low.

The following are some common characteristics of photosynthesis inhibiting herbicides [atrazine, bromacil (Hyvar), diuron, hexazinone (Velpar), prometon (Pramitol), simazine, tebuthiuron (Spike)]:

_ These herbicides stop photosynthesis in susceptible plants. After a few days, cell membranes are damaged which leads to tissue death.

_ They have no direct effect on root growth.

_ Weeds are controlled by root uptake because these herbicides move primarily in the xylem. Atrazine has some foliage activity; surfactants or oils can be added to increase this activity. Hexazinone is taken up by both roots and leaves.

_ In general, they are not very leachable in the soil, but this varies with the compound, soil, and rainfall.

_ They all persist in the soil for residual weed control. The length of persistence depends on the herbicide, amount applied, climate, and soil.

_ An increase in the rate of breakdown in the soil has not happened after repeated application of these herbicides.

_ They have very low mammalian toxicity.

_ Atrazine is classified as a *Restricted Use Pesticide*.

Characteristics of the pigment inhibiting herbicide norflurazon (Predict):

_ The new foliage turns white because it inhibits the production of carotenoids, which leads to the destruction of the green chlorophyll in plants. Plants die because there is no production of plant food in the leaves.

_ Norflurazon is applied preemergent and has limited soil mobility.

_ It is considered a nonselective herbicide but does not leach deep enough in the soil to damage deeper-rooted established plants.

Characteristics of the herbicides that break up the lining of the cell walls [diquat (Diquat Herbicide-H/A, glufosinate (Finale)] are that:

_ They are very soluble in water.

_ They enter the leaves very rapidly; rain after 30 minutes does not affect results.

_ They kill plants quickly, usually within one or two days.

_ They result in damage to the lining of the cell walls which allows the cell contents to leak into the spaces between the cells. The leaves appear to be water soaked.

_ They are nonselective contact herbicides.

_ Their effect is more rapid on sunny days than on cloudy overcast ones.

_ Diquat is strongly adsorbed (tied up) by soil particles so it has no activity in the soil.

_ Diquat has moderated mammalian toxicity.

Common characteristics of the mitotic disrupter herbicides [DCPA (Dacthal), oryzalin (Surflan), pendimethalin (Pendulum), prodiamine (Endurance), pronamide (Kerb)] are that:

_ The growth of roots and shoots of germinating seeds or small seedlings is stopped by disrupting the mitotic sequence.

_ Established weeds are seldom controlled.

_ Translocation occurs primarily in the xylem, if at all.

_ They are often highly selective between species.

_ They are moderately to highly resistant to leaching in soil.

_ They are very low in mammalian toxicity.

_ Pronamide is classified as a *Restricted Use Pesticide*.

Characteristics of the herbicide that inhibits root growth of germinating seedlings [napropamide (Devrinol)] are that:

_ It enters the roots and stops root growth of susceptible species.

_ It effects only roots in direct contact with it.

_ It is most effective on annual grasses and does not control established weeds.

_ It does not leach in the soil.
_ It has low mammalian toxicity.

Characteristics of the herbicide that inhibits bud development [fosamine (Krenite)] are that:

_ It should be applied to woody plants late in the growing season before leaves start changing colors.

_ Except for pines, there is little or no visible effect until the next spring.

_ Susceptible woody plants do not start to grow the next year.

_ Since it moves only from the leaves to the buds, complete coverage of all the plant is necessary.

_ It has not soil activity.

_ It does not injure grasses at normal use rates.

_ It has very low mammalian toxicity.

Common characteristics of the grass specific herbicides [fluazifop-butyl (Fusilade), sethoxydim (Poast)] are that:

_ Their herbicide activity is limited almost entirely to annual and perennial grasses. Plants not in the grass family are usually tolerant.
_ They are absorbed by the leaves and have little soil activity.

_ They are applied at low rates.

_ Crop oil concentrates increase their effectiveness.

_ They have low mammalian toxicity.

Common characteristics of organic arsenicals (cacodylic acid, MSMA) are that:

_ Both are highly water soluble.

_ Cacodylic acid is a contact herbicide with movement only in the xylem while MSMA moves in the xylem and phloem.

_ They inhibit growth in general, inhibit the sprouting of rhizome and tuber buds, and cause aberrant cell division.

_ In contrast to the inorganic arsenicals, the organic arsenicals have low mammalian toxicity.

Characteristics of dichlobenil are that:

_ It inhibits growth of apical growing points and root tips.

_ It inhibits seed germination of grass and broadleaf plants.

_ It does not control emerged weeds.

_ It is volatile.

_ It is applied to the soil and should be incorporated by rain or mechanically.

PENETRATION AND TRANSLOCATION IN PLANTS

To be effective, a herbicide must enter the plant and arrive at the site of action in an active form, in sufficient quantity, and be present long enough to produce its effect.

Penetration

Herbicides usually enter the plant through the leaves, the roots, or the seedling shoot before emergence. The above-ground stem may also be an important site of entry in certain cases (i.e., basal bark treatment of trees with herbicide in oil or injection of water-soluble herbicides into the tree trunk).

Leaves

The leaf surface presents many barriers to the entry of herbicides.

Cuticle. Cuticle is more easily penetrated by various oils and organic solvents than by water sprays. Water-soluble sprays penetrate through aqueous routes thought to consist of pectin strands and hydrated cutin which are most available with adequate soil moisture and high humidity.

Wax. In addition to the wax in the cuticle, many plants have wax deposited on the leaf surfaces which makes them difficult to wet which in turn reduces penetration of water sprays. Spray additives and carriers greatly influence penetration through this barrier.

Stomata. Penetration through stomata is probably of minor significance. Stomata are usually on the under surfaces of the leaves, and the degree of opening varies greatly. Both factors reduce the importance of stomata as points of entry.

Roots

Entry of herbicides into roots is not as difficult as entry into foliage since no wax layer or well-developed cuticle is present in the area of absorption. The major problem with root uptake is getting the herbicide through the soil and into contact with the roots.

Seedling Shoots Before Emergence

The new shoot of the germinating plant (before it emerges from the soil) is an important site of entry for many volatile soil-applied herbicides that are active on germinating seeds or small seedlings. Before emergence, the shoot has a poorly developed cuticle and probably no wax layers, allowing the herbicide to penetrate the shoot more easily.

Stems

Young stem tissue of herbaceous plants may be penetrated by herbicide solutions in much the same way as are the leaves. However, stems are not as important as leaves because they have a much smaller surface area. Older stems and even the bark of trees can be penetrated by herbicides applied in oil carriers.

Translocation

Once a herbicide has penetrated the leaf cuticle or the root epidermis, there are still many barriers to its movement to the site of action. A number of herbicides are chemically bound, absorbed, or otherwise inactivated in the roots or leaves and do not move to other parts of the plant. Assuming the herbicide is not immobilized in the leaf or root, it moves in the plant primarily by one or both of two routes (Table 1).

Xylem

Herbicides that enter the roots or foliage may move upward in the xylem with the transpiration stream. The pattern of xylem movement of a herbicide applied to a leaf is toward the leaf tip only, if there is no phloem movement.

Phloem

Some herbicides move in the phloem. Herbicides applied to the leaves can be translocated to the roots of perennial plants. Phloem movement is associated with sugar transport and light conditions. Also, it is very important not to kill the leaf and the stem tissues rapidly since transport is via living tissue. Rapid foliage kill will result in poor transport and poor root kill. Sometimes repeated doses of a phloem transported herbicide will give better results than a single large dose that kills too rapidly.

FACTORS AFFECTING CHEMICAL WEED CONTROL

Plant Factors

Plant Types

Most plants are either grasses or broadleaves. Broadleaf plants include herbaceous forbs and many woody plants. The sedges, such as the nutsedges, are neither grasses nor broadleaves. However, they have similar characteristics to grasses.

Table 1. General herbicide translocation patterns (all can vary with species).

When Applied To Foliage	When Applied To Soil
1. Move in phloem and xylem	1. Move readily in xylem
chlorsulfuron	atrazine
2,4-D	bromacil
dicamba	chlorsulfuron
dichlorprop	dicamba
fluazifop-butyl	diuron
fosamine	hexazinone
glyphosate	picloram
MSMA	prometon
picloram	pronamide
sethoxydim	simazine
sulfometuron methyl	sulfometuron methyl
triclopyr	tebuthiuron
	triclopyr
2. Move only in xylem	2. Movement in xylem restricted
atrazine	2,4-D
bromacil	
diuron	
hexazinone	
simazine	
3. Little or no movement	3. Little or no movement
cacodylic acid	DCPA
diquat	oryzalin
oxadiazon	oxadiazon
oxyfluorfen	oxyfluorfen

Grasses. Grass seedlings have only one leaf as they emerge from the seed. Their leaves are generally narrow and upright with parallel veins. Most grasses have fibrous root systems. The growing point on seedling grasses is sheathed and located below the soil surface. The growing point gradually moves above the soil as the plant grows and matures. Examples: Bermudagrass, foxtail, Johnsongrass, and quackgrass.

Broadleaves (Forbs). Herbaceous (plants that do not develop persistent woody tissue above ground) broadleaf seedlings have two leaves as they emerge from the seed. Their leaves are generally broad with net-like veins. Broadleaves usually have a taproot and a relatively coarse root system. All actively growing broadleaf plants have exposed growing points at the end of each stem and in each leaf axil. Examples: dandelion, mullein, pigweed, plantain, ragweed. *Woody Plants*. Woody plants are those that form wood. They include brush, shrubs, and trees. Brush and shrubs are woody plants that have several stems and are less than 10 feet tall. When trees are present, brush or shrubs may be called understory. Trees usually have a single stem (trunk) and are over 10 feet tall. Examples: hickories, oaks, pines.

Plant Life Cycles

A plant's life cycle is either annual, biennial, or perennial.

Annuals. Annuals complete all stages of development in less than 12 months. There are two distinct kinds of annuals: winter annuals and summer annuals.
Winter annuals germinate in the fall, overwinter, mature, set seed, and die in the spring. Examples: bedstraw, cheat, downy brome, henbit, little barley, pepperweed, wild mustard.

Summer annuals germinate in the spring, grow, set seed, and die in the fall. Examples: common ragweed, crabgrass, foxtail, giant ragweed, marijuana, partridge pea, pigweed.

Some weeds are specifically winter or summer annuals. Others can germinate and grow in either the fall or spring. Knowing the growth habits of annuals is important in planning how and when to control.

Biennials. Biennials complete their life cycle in two years. Biennial plants complete the seedling and vegetative (rosette) stages of growth the first year, then the seed production and maturity stages in the second. Some herbicide labels identify biennials as annuals. Examples: bull thistle, common evening primrose, common burdock, common mullein, teasel, wild carrot, wild parsnip.

Perennials. Perennials may complete all four stages in the first year and then repeat the vegetative, seed production, and maturity stages for several years following, or the seed production and maturity sages may be delayed for several years. Some perennial plants die back in the maturity stage each winter; others, such as trees, may lose their leaves but do not die back to the ground. They all reproduce by seed but many are able to spread and reproduce vegetatively. Perennials are difficult to control due to their persistent root system.

Perennials can be divided into three general groups, depending upon how they reproduce.

Simple perennials spread by seed, crown buds, and cut root segments. Most of the herbaceous plants have a large, fleshy taproot. Examples: chicory, curly dock, dandelion, goldenrod, buckhorn plantain, spiderwort, white heath aster, white oak, white pine.

Creeping perennials spread vegetatively with stolons (horizontal stems running on the soil surface usually rooting at the joints), by rhizomes (underground horizontal stems modified for food storage and asexual reproduction), or by seed. Examples: Bermudagrass, Canada thistle, common milkweed, hemp dogbane, horsenettle, horsetail, Japanese honeysuckle, Johnsongrass, poison ivy, quackgrass, Virginia creeper, yellow toadflax.

Bulbous perennials reproduce vegetatively from underground bulbs or tubers; they also produce seed. Examples: wild garlic, wild onion.

Developmental Stages

All plants have four stages of development: 1) seedling, 2) vegetative, 3) reproductive, and 4) maturity. Plants in the seedling stage are small and vulnerable. Seed leaves (cotyledons) may be present as well as first true leaves. In the vegetative stage rapid growth of stems, roots, and foliage occur. There is also rapid uptake of water and nutrients. Seed production or fruit set occur in the reproductive stage. Growth is limited and there is slow uptake of water and nutrients. Movement of water and nutrients is directed mainly to reproductive parts, flowers, fruits, and seeds. In the maturity stage there is little or no growth and slow movement of water and nutrients in plants.

All weeds are most easily controlled at the seedling stage regardless of life cycle. As plants mature, they tend to be more difficult to control. Foliage is more difficult to penetrate and root systems grow deeper and larger. The larger size of the plant usually means that more herbicide must reach the site of action. Biennials are best controlled at the seedling or rosette stage. Contact herbicides may not be effective at the rosette stage, but foliage-absorbed, translocated herbicides should be effective. Many biennials become less sensitive to herbicides after they produce a flowering stalk. Perennial plants are also best controlled while seedlings. If a plant has become established and is truly perennial in nature, contact herbicides provide only temporary suppression. Phloem transported herbicides are most effective if applied when carbohydrate flow has been diverted from vegetative growth to replenishing depleted root reserves.

Location of Growing Points

Seedling grass has its growing point below the soil surface. Control is difficult when the growing point is protected in this manner and the herbicide does not move in the phloem. If a herbicide does not reach the growing point, the plant may regenerate. Creeping perennial grasses have protected buds below the soil surface. Seedling broadleaf weeds have an exposed growing point at the top of the young plant. They also have growing points in the leaf axils. Perennial broadleaf plants are difficult to control because of the many protected buds on the creeping roots and stems.

Leaf Shape

The shape of the leaf can be important to the effectiveness of the herbicide. When applied to a plant having narrow vertical leaves, the spray solution tends to bounce or run off. On the other hand, a vertical leaf can direct the spray solution downward into the growing point. A broadleaf plant with flat, wide leaves tends to retain the spray solution. Retention of spray solution is important if the herbicide is to be absorbed through the foliage.

Leaf Surface (Wax and Cuticle) and Hairs

It is important for foliage-absorbed (postemergence) herbicides to penetrate the leaf surface. Thickness of wax and cuticle affect the entrance of a herbicide into the leaf. When applied to a leaf that has a thin cuticle, the spray solution makes good contact with the leaf surface. However, on a leaf with a thick, waxy surface, the spray solution tends to stand up in droplets, resulting in poor leaf contact. The wax and cuticle are less thick on young weeds. Best results are obtained by treating with herbicides at the early growth stage.

Some weeds are hairless; others have many and varied hairs. Generally, there are fewer and shorter hairs on seedlings compared to the older stages of growth, another reason for early control. When applied to a weed leaf that has hair on the surface, spray droplets tend to stand up on the hair and do not contact the leaf surface. Sparse hairs tend to hold the herbicide in contact with the leaf surface for longer periods of time.

Species

Species vary in growth habits and in susceptibility to herbicides. Generally, vegetation can be categorized as grasses, broadleaved weeds, and woody plants. Programming around such broad categories can be beneficial because the herbicides selected are those reasonably effective on the predominant species. Plants resistant to a herbicide treatment become more abundant with continued use of the same treatment while the susceptible species are eliminated.

Size

Seedling weeds are easier to control than established weeds. Smaller plants, regardless of their stage of growth, are usually easier to control than larger plants.

Climatic Factors

Relative Humidity

A herbicide applied to the foliage will enter a leaf more rapidly at high relative humidity rather than at low relative humidity. At high relative humidity, the weed leaf is more succulent, perhaps has less of a wax layer and a thinner cuticle, and the cuticular components are hydrated with molecules of water. Herbicides work best when plants are actively growing. High relative humidity and optimum temperature usually enhance active growth.

Light

Light is of obvious importance to the plant for photosynthesis. The speed of herbicide activity may be altered by presence or absence of light. However, operationally, light is an uncontrolled factor. Light may break down some herbicides if they remain on the soil or on the plant surface for a long time.

Precipitation

Soil moisture and rain affect the way herbicides work. They also affect how long herbicides stay on soil and plants. Herbicides work best with moderate soil moisture because soil moisture can prevent the herbicide from contacting and becoming bound to the soil particles. Some rain can be beneficial after root-absorbed herbicides have been applied because it carries them down into the soil. However, excessive rain can cause soluble herbicides to leach through the soil. Rain during or soon after foliar applications may wash the herbicide off the leaves and reduce effectiveness.

During drought periods plants usually undergo growth stress conditions which causes most translocated herbicides to perform poorly. Contact herbicides usually do not perform well under drought conditions because the plants produce heavy wax layers on the leaves to protect against excessive transpiration losses. During dry periods, herbicides remain on the soil surface until rain dissolves and carries them into the root zone. Herbicides with low water solubility are usually used in high rainfall areas and herbicides with high water solubility are used in arid or semi-arid regions.

Wind

Wind can move the spray solution off target at the time of application and can move soil particles, with attached herbicide, off-site after application. However, application during a light wind is preferred to application with no wind. Very fine droplets can remain suspended in air to be moved off-site in an unknown direction when the calm breaks. Applications made in a light wind permit the applicator to make adjustments and allowances for direction of movement. Hot, dry winds may make foliar herbicide penetration more difficult as well as slowing the plant's physiological processes which results in less control.

Temperature

Temperature generally does not affect weed control results. It may, however, affect the amount of time required for the herbicide to do its job. As temperature increases, the herbicide may work more quickly. In very cold weather, action of the herbicide may be slowed. High temperatures enhance herbicide volatility. Warm temperatures create warmer soils with increased microbial activity, which reduces the effectiveness of residual, soil-active herbicides.

Length of Growing Season

Along with soil type and rainfall, the length of growing season is an important factor in selecting residual soil-active herbicides. Normally, the longer the growing season the more resistant the vegetation. This necessitates higher rates of herbicide application to realize a given degree of control. Also, the combination of long growing season and high rainfall results in the leaching of residual herbicides below the root zone. Multiple applications may be required to obtain desired residual control.

Soil Factors

Soil Type

Two factors are important to herbicide movement in the soil: 1) texture of the soil (sand, silt, clay), and 2) soil organic matter. Herbicides are more likely to be adsorbed or tied up in soils high in clay soils or organic matter than in sandy or silty soils. Sand has very little ability to hold water or herbicides, so herbicides tend to leach readily in soils that are high in sand. Silt is comparable to sand in its adsorptive properties.

Clay soils are generally more impenetrable to water and herbicides. Also, because of the small size and high number of particles, they can tie up a sizable percentage of herbicide by adsorption. Usually, the rate of application of soil-active herbicides increases with higher clay content. Clays vary in their adsorption characteristics. Expanding lattice clays are more adsorptive than nonexpanding clays.

Organic matter content is probably the most important adsorptive characteristic of soil. It is more active than clay in its ability to tie up herbicides. It is also a medium for microbial activity. If a herbicide is subject to microbial breakdown, its life in high organic soils is usually shortened. Soils with high organic matter content often need higher rates of soil-active herbicides for good weed control.

Leaching

Leaching is the movement of a herbicide downward through the soil as the result of water movement. The amount of leaching that occurs depends on herbicide and soil characteristics. In soils, herbicides vary from not leachable to highly leachable. Water soluble herbicides tend to leach more readily.

Insoluble herbicides tend to remain at or near the soil surface (Table 2). Herbicides can remain concentrated at the soil surface, be partially leached (a diluting effect), or they can move through the soil in a concentrated front.

When the herbicide moves through as a concentrated front, new weeds may become established in the soil above the herbicide band.

Persistence

Soil persistence is the ability of a herbicide to remain active in the soil for an extended period of time. It can be an important attribute when residual weed control is desired as in forest seedling establishment or for total vegetation control at an industrial site. Persistence is undesirable when it hinders or delays desirable plant growth. Herbicides vary greatly in their resistance to breakdown and leaching in the soil. Because of the many factors involved, it is not possible to predict the exact time required for a given amount of herbicide degradation to occur. The following table suggests their relative persistence under similar conditions (Table 3).

Important environmental factors include soil moisture, rainfall, soil temperature, and soil pH. Soil moisture and temperature are important for microbial degradation. Optimum conditions for microbial activity reduce herbicide persistence. Large and frequent rainfalls tend to reduce soil persistence. Cold, dry conditions increase soil persistence.

Table 2. Relative movement of herbicides in soil.

High movement
- dicamba

Moderate to high movement
- bromacil
- 2,4-D
- picloram

Moderate movement
- atrazine
- DCPA
- hexazinone
- prometon
- simazine
- tebuthiuron

Low to moderate movement
- dichlobenil
- diuron
- napropamide
- oxadiazon
- oxyfluorfen

Little or no movement
- diquat
- glyphosate
- MSMA
- oryzalin

Table 3. Relative persistence of herbicides in warm, moist soil at crop use rates.

Little or no soil activity
- diquat
- glyphosate
- MSMA

Less than one month
- 2,4-D
- fluazifop-butyl
- sethoxydim

One to three months
- DCPA
- dicamba
- diuron
- oxadiazon
- oxyfluorfen
- pronamide

Three to six months
- atrazine
- dichlobenil
- oryzalin
- simazine
- oxadiazon
- oxyfluorfen
- pronamide

More than six months
- bromacil
- hexazinone
- napropamide
- picloram
- prometon
- tebuthiuron