STUDY GUIDE

for

Agricultural Pest Control Advisers

on

WEED CONTROL

Cooperative Extension **University of California**
Division of Agriculture and Natural Resources

PUBLICATION 4050

INTRODUCTION

Green plants are the basic form of life and are indispensable in the environment because they utilize energy from light to combine minerals and carbon dioxide into usable food sources for bacteria, fungi, wildlife, livestock, and humans. Plants reduce soil erosion, add organic matter to the soil, provide both food and cover for wildlife, and beautify the landscape. Plants not only provide humans a source of food, livestock feed, and aesthetic value, but also serve as reservoirs of genetic characteristics useful in plant breeding.

Plants are considered to be weeds when they interfere with land or water resource utilization, or adversely affect human welfare. Weeds, then, are unwanted plants, plants out of place. A plant is a weed only in terms of human attitude; thus, a plant that is a weed to one person may be a wildflower to another. All plants may be weeds in given circumstances but no plant is always a weed.

Undesirable vegetation occurs on cropland, industrial sites, along rights-of-way, air fields, in landscape plantings, and in many other situations. Weeds reduce crop yields by competing with the crop plants for soil moisture, nutrients, and sunlight. Studies have shown that; in annual crops, the influence on final yield begins during the first few weeks of the life of the crop. Some plants may be considered weeds because they are poisonous to livestock or affect the quality of animal products, such as off-flavors in milk or milk products. Others, like nettle and poison oak, are directly noxious to humans. Weeds can harbor insect pests, harmful rodents, and plant diseases. Some plants, such as mistletoe, dodder, and broomrape, are parasitic on other plants and may be considered weeds. Aquatic weeds clog irrigation and drainage canals, ponds, and lakes, and often interfere with recreation. They can reduce productivity of fish and other wildlife, and can enhance mosquito production.

Mankind's ability to manage vegetation to meet needs for food, livestock feed, and fiber is paramount to survival. To produce crops efficiently, it is necessary at least to minimize, and ideally to eliminate, the complex yield-reducing forces of weeds. This must be accomplished selectively. That is, the employment

Trade names (registered trade marks) have been utilized in the text for all herbicides, except where two or more trade names exist (differing formulations, or more than one manufacturer) in which case the accepted common name has been used. Tables include both the common chemical and trade names. Herbicide names in this manual have only been used as examples; no endorsement of products, or recommendations should be construed from these uses.

of a weed control method, or combination of methods, must in itself offer a minimum in yield-reducing effect on the crop—and subsequent crops.

Methods that can be used for weed control include:

1. Preventive control
2. Crop competition and rotation
3. Physical control methods
4. Biological control
5. Chemical control

While chemicals are playing an increasing role in weed control, they do not provide a panacea for all problem situations. Alternative control methods must always be weighed, and causes of weed problems should be identified and cor- rected. While any vegetation control practice purposely alters the environment, non-chemical methods offer the advantage of avoiding environmental hazards that might arise from the use of herbicides. Weed control methods rarely are satisfactory substitutes for good land-use practices. Once well established on the land, a weed can be eradicated only by heroic effort. A control program, by con- trast, is nearly always the only practical measure.

Successful weed control depends on knowledge of plant identification and life history in addition to proper selection of a control method.

Weeds are more than just "nuisance" plants that annoy people; the average cost of weed control and losses due to weeds to the people of California is over 374 million dollars a year.

PLANT CHARACTERISTICS

A weed, by simplest definition, is a plant out of place. Weeds can be native plants or introduced plants that have escaped and become a nuisance or hazard. It is important to know certain general facts about plant species and how they differ from one another to conduct an efficient and safe weed control operation. A weed control advisor, maintenance supervisor, or farmer, with certain basic information, can better decide which method(s) of weed control to utilize. If chemical control is suggested, differing plant characteristics often indicate how to select the appropriate herbicide for particular local conditions.

What is a plant?

It is a complex life form, in both its structure and its living chemistry (bio- chemistry), that requires mineral nutrients, water, oxygen, carbon dioxide, and light to live. There are two basic parts of a plant, the underground part or *root* and the above-ground or aerial part, the *shoot*. The stems, branches, leaves, flowers, and seed collectively constitute the shoot. Some herbicides are used pri- marily because they are taken into the plant by the roots (soil-applied herbi- cides); other herbicides perform best if applied to the shoot (foliage-applied herbicides).

Plants are classified according to life cycles as being annuals, biennials, or perennials.

Annuals live 1 year or less; they start from seed, develop foliage, flower, set seed, and die. Seed of *winter annuals*, such as chickweed, mustard, yellow star-

thistle, annual bluegrass, and wild oat, germinate in the fall or early winter and over-winter in a vegetative form (without flowering). In the spring they flower, mature a crop of seed, and then die. *Summer annuals* germinate in the spring and complete their life cycle during the summer. Examp ; are barn- yardgrass (watergrass), puncturevine, Russian thistle, and pigweed.

Biennial plants have a similar life cycle to annuals since they die after flowering and setting seed, but they require 2 years to complete the sequence. Growth during the first year is usually vegetative (no flowering activity) and low growing, frequently as a rosette form; flowering and seed production occur in the second year. Typical biennials are common mullein, great burdock, purple starthistle, bull thistle, and bristly oxtongue.

Perennial plants live 3 or more years; they flower and set seed without dying. Perennials are either herbaceous (top growth usually winter kills) or woody (brush or trees). Bermudagrass, johnsongrass, dallisgrass, field bindweed, hoary cress, bracken fern, bulrush, and cattail are common herbaceous perennial weeds. Chamise, chokecherry, manzanita, gorse, live oak, white thorn, willow, and poi- son oak are woody perennial weeds.

Some perennials have underground structures, in addition to true roots. Such structures are: *rhizomes*, a modified underground stem (johnsongrass, bermuda- grass, and bracken fern); *bulbs* (wild onion); *tubers* (nutsedge); *creeping roots* (field bindweed); and *tap roots* (dock and dandelion). These underground struc- tures serve as food storage organs and produce new shoots from buds. Perennial plants are the most difficult to control because of this ability.

Annuals and biennials do not have such underground buds (growing points) and consequently are much easier to kill. Thorough cultivation or adequate spray coverage with contact herbicides kills annuals and biennials since there are no protected shoot buds underground.

Structure

Roots anchor the plant and supply water and dissolved minerals to the shoot tissue. The aerial shoot, with energy derived from light, converts water and carbon dioxide into sugars, upon which the plant cells of both the shoot and root live. Water moves upward; sugars move downward to the root or up to points of active growth on the shoot. This movement (translocation) takes place in conducting vessels that are interconnected throughout the plant. The water- conducting vessels are the *xylem* elements, and the vessels that carry sugars are the *phloem*. Herbicides, such as Karmex® and Princep®, translocate in the xylem along with the upward-moving water. The herbicides classified as soil-applied (soil-active) enter plants through the roots. Other herbicides, such as 2,4-D and dalapon, translocate chiefly downward in the phloem from the leaves and thus are placed in the foliage-applied herbicide classification.

Another characteristic of plants, which is important in selecting foliage- applied herbicides, is the waxy layer on the surfaces of leaves and stems. This wax, plus the underlying cuticle or outer "skin" of plants, can be a formidable barrier to the herbicide's entry into the shoot of the plant. Herbicides are of little value unless they can cross through the cuticle and enter the plant's living cells.

There is a far greater resistance to penetration of water-soluble, foliage- applied herbicides than to herbicides that are emulsifiable. Consequently, a

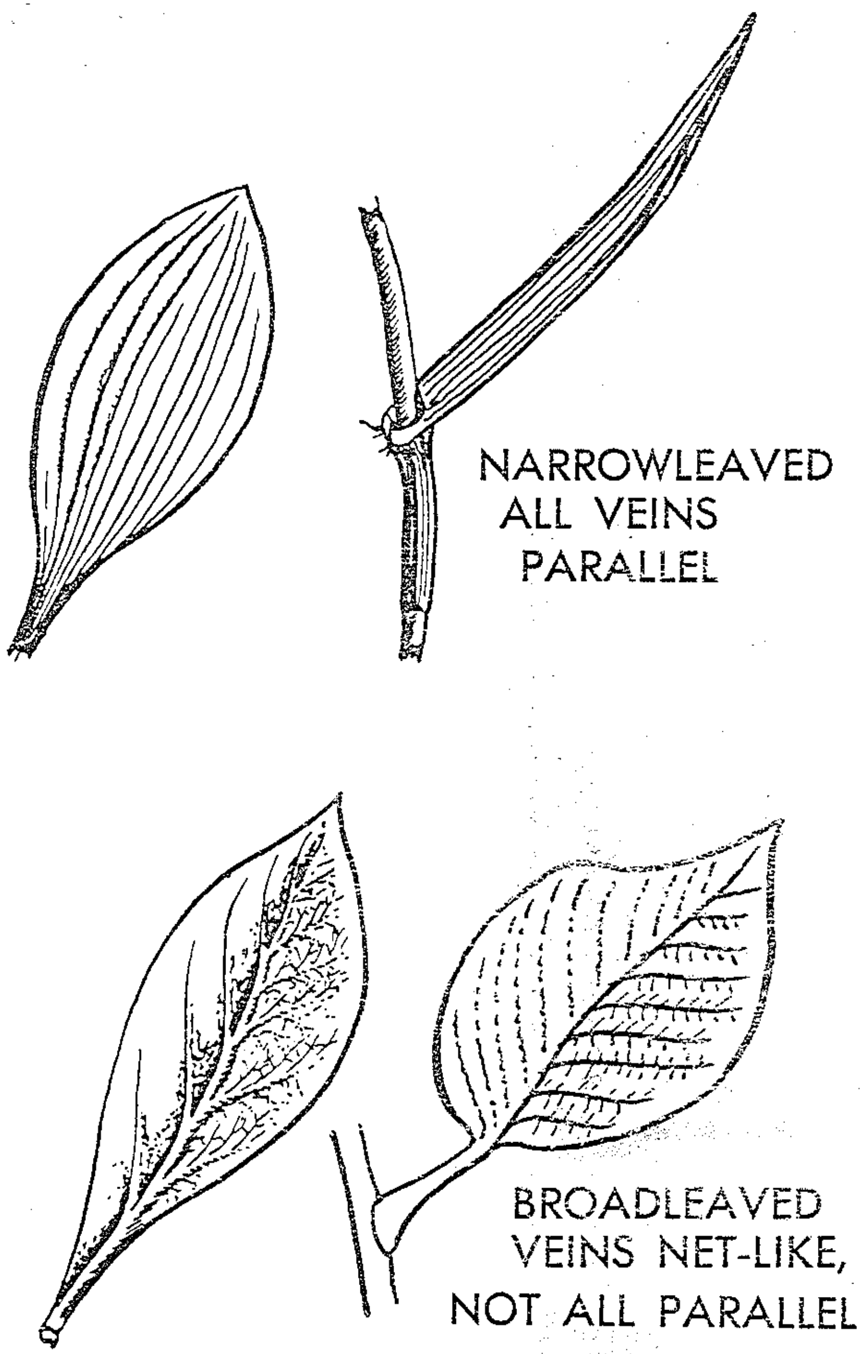

Fig. I.

surfactant (wetting agent) should usually be added to the spray tank when applying water-soluble compounds. Activity of emulsifiable herbicides, particularly the phenoxy or 2,4-D group, is usually not appreciably improved by adding a surfactant when applying them to herbaceous plants. Penetration into woody perennials is often improved by adding an oil, such as diesel oil, to the spray mixture (emulsion).

Identification

Correct identification of weeds was not essential when weed control was principally a matter of utilizing cropping and physical methods of weed control. The successful use of herbicides, however, dictates the necessity of at least being able to identify major weed groups. Identification of individual species may even be essential in some cases to choose the correct herbicide. There are over 500 plant species in California that can create weed problems. Most of them are flowering plants (the higher forms of plant life that produce seed).

Over the years, it has been learned that some herbicides are effective on some groups of weeds while other herbicides are best utilized on weeds belonging to another plant group. Familiarity with two major plant groups is important in selecting the most effective herbicide. These two groups are called: a) narrowleaved weeds; and b) broadleaved weeds. Flowering plants belong to either group, but their classification does not entirely depend on the width of the leaf. The underlying botanical reasons for separation are much more technical, but knowledge of these more exact characteristics are not necessary to recognize the two groups.

Narrowleaved weeds include all the grasses, sedges, (bulrush, nutsedge), rushes, cattails, and many other plants that are less often weed problems, such as iris, and the lilies. A convenient characteristic to look for in the field is the *parallel veins* in the leaves. Dalapon, as an example, is much more effective on narrowleaved weeds—grasses in particular—than it is on the broadleaved group.

The **broadleaved weed** group is the larger of the two and includes willows, cottonwood, mustard, dock, smartweeds, pigweed, purslane, field bindweed, blackberries, and hundreds of others. In this group, the *leaf veins are net-like*, not all parallel. 2,4-D is, for example, used to control broadleaved weeds and has very little effect on grasses. A specific example is the control of mustard in cereal crops.

The decision to use a pre-plant or pre-emergence treatment has to be made before any weeds germinate. Records of weed species present in each field greatly aid in making the correct weed control decision.

Seedling identification is necessary to properly select post-emergence herbicides in many cases. Wrong identification can lead to inadequate weed control. Two examples would be: a) 2,4-D controls mustard but can give weak control of fiddleneck *(Amsinckia)*; or b) Betanal® is very weak in controlling pigweed, yet will control lambsquarters. If in doubt, check the identification with an authority.

Aquatic weeds are a somewhat special group and their identification is usually discussed as a separate topic. However, the previous plant groups, i.e., narrowleaved and broadleaved, annuals and perennials, still apply. Nearly all common aquatic weeds are perennials.

It is convenient to classify aquatic weeds into four groups based on growth habits: 1) emersed; 2) floating; 3) submersed; and 4) algae.

Emersed weeds are typical to natural marshlands but are usually a problem in shallow ponds, drain canals, and along the shoreline of either. Nearly all of the plants in this group stand erect and are rooted in moist or flooded soil.

Examples:

southern cattail	Baltic rush
hardstem bulrush	

Floating weeds, as the term implies, rest upon the water surface and rise or fall with water level fluctuations. The roots may hang freely in the water or be established in the bottom soil.

Examples:

azolla	water hyacinth
duckweed	water primrose

Submersed weeds grow completely under water, with floating leaves, or with stems a few inches above the surface. However, most of the stem and leaves are found below the water surface. Many canals, ponds and lakes become infested with plants in this group.

Examples:

American pondweed	American elodea
sago pondweed	horned pondweed
coontail	

Algae, in their weedy form, grow on the surface or completely in the water. Algal forms that grow suspended in the water as single cells or microscopic colonies are termed plankton algae (or phytoplankton). Plankton algae are important food for other aquatic organisms. These suspended forms can reproduce rapidly, causing the pond or lake to become pea-soup green, or occasionally brown. The sudden growth and attendant color change is called an algal "bloom."

The most troublesome algal group grows in long strands or filaments that can be seen with the unaided eye. These are the *filamentous algae* ("scum"). They accumulate on outlet trash racks in canals, and clog pumps and sprinkler heads.

Both types of algae impart offensive odors and tastes to drinking water. Some are toxic to livestock and people.

How To Get a Weed Identified

1. Sight identification by comparing with dried specimens or pictures, preferably colored. (Reference: *Grower's Weed Identification Handbook* or *Weeds of California*).
2. Use of the "keys" provided in a book such as *Weeds of California*.
3. Refer to an authority, such as farm advisor, county agricultural commissioner, state college or university, or University of California. If shipped by mail, the sample should be placed in a plastic bag, identified by location found, sender's name, and date collected. The sample should be protected from crushing. It is desirable to have the flower, fruit, seed, total vegetative parts, and roots.

METHODS OF WEED CONTROL

Preventive Weed Control

Prevention of a problem is normally better than the cure. Once weeds have become established, they are difficult and costly to control and may persist for years, if the seeds can lie dormant in the soil. A classic example would be allowing field bindweed to invade land and set seed. This exacts a terrible penalty, as the seeds can lie dormant but alive in the soil for 40 years or so.

Preventive control measures should be adopted wherever practical as a matter of principle. Such measures include:

a. Use clean seed.
b. Do not feed screenings, grain, or hay containing weed seeds without first destroying their viability by grinding, cooking, or ensiling.
c. Do not use manure unless the viability of weed seeds has been destroyed by thorough fermentation.
d. Do not permit livestock from infested areas to move directly to clean areas.
e. Clean harvesters, cleaners, hay balers, tractor wheels, and other implements before moving them from infested areas.
f. Avoid the use of gravel, sand, and soil from infested areas.
g. Inspect nursery stock for presence of weed seeds, and tubers and rhizomes of perennial weeds.
h. Keep the banks of irrigation ditches free from weeds.
i. Keep fence corners, fence lines, roadsides, railroad rights-of-way, and all other uncropped areas free from weeds.
j. Prevent the production of wind-borne weed seeds on any area.
k. Use weed seed screens for trashy irrigation water.

Crop Competition and Rotation

Crop yields depend on the extent of the weed competition from the day of crop emergence until harvest. Weed vigor and seed production are similarly influenced by crop competition. Cultural practices that shift the competition balance in favor of the crop favor productivity. Cultural practices that should be considered include:

Competition

a. Selection of crop varieties adapted to the region.
b. Optimum planting date; considering rapid crop establishment and anticipated weed species (e.g., winter versus summer weeds).
c. Maintenance of sufficient soil fertility to ensure good crop vigor.
d. Availability of adequate soil moisture for optimum crop growth. Poor irrigation practices create moisture stress in crops or, if applied in excessive amounts, (including poor drainage) reduce crop stand and promote water-tolerant weeds.
e. Use of highly competitive "smother crops," such as sudangrass.

Rotation

Many weeds are associated with particular crops, e.g., barnyardgrass (watergrass) in rice, mustard and wild oat in cereal crops, dodder in alfalfa. A crop rotation sequence that utilizes crops with differing cultural requirements will help control weeds with life cycles not adapted to the cultural practices of the crops. Crop rotation also permits the use of different herbicides to control weed increases due to resistance.

A rotation away from a solid-seeded crop, such as alfalfa or cereals, to an annual row crop, such as tomatoes or cotton, provides for a shift in weed control methods. A rotation from crop production to fallow permits the use of control methods not possible in the presence of crops. During the fallow period, cultivation or other control methods, such as use of herbicides or flooding, are necessary to achieve a significant reduction in weed population. Fallowing offers the only effective means for removal of established johnsongrass plants on heavily infested cropland.

Rarely will any of the competition or rotation methods provide satisfactory weed control by themselves. They are useful when integrated with other control methods.

Biological Control Methods

A plant's environment consists of many other organisms, including other plants, disease organisms, insects, and animals that feed upon plants. Biological weed control is the utilization of a disease organism, insect, or higher animal that brings sufficient pressure on the target weed to keep it at a low population level. Most advances in biological weed control have been made through carefully researched introductions of host-specific insects. The goal in biological weed control is to maintain a balanced population of both the control organism and the weed, with the density of the weed population reduced to an insignificant level.

To reduce the likelihood of an introduced biological agent from attacking non-target plants, considerable investment in time and money is required to locate and test them for host specificity. A single introduced biological control agent cannot be expected to control a complex of several weeds. However, there is always promise for biologically controlling single, aggressive weed species that are too widespread or inaccessible to be controlled by cultivation, herbicides, or other methods.

TABLE 1. Examples of Biological Weed Control in California

Control Organisms	Use
geese	weeds in cotton
Tilapia (fish)	aquatic weeds
stem and seed weevils	puncturevine
Chrysolina beetle	klamathweed
cinnabar moth	tansy ragwort
Cactoblastis moth	prickly pear cactus
sheep	weeds on rice levees

Physical Control Methods

Physical weed control methods include any technique that uproots, buries, cuts, smothers, or burns weedy growth.

Hand Methods. The use of the hand-wielded hoe is one of the oldest forms of weed control. It is still widely used in some crops. This method is declining because of increased labor costs and/or lack of available labor. Hoeing and hand-pulling may be more appropriate in high-income crops such as vegetables, ornamentals, or where selective herbicides have not been developed and registered. Hand hoeing or pulling should be utilized where a few weed escapees would otherwise set seed and increase the infestation.

Cultivation Methods. The desiccation of weeds following cultivation is more complete under hot, dry conditions since tilled weeds may root again in cool, moist surroundings. Pre-plant cultivations, with disk or harrow, after annual weeds are up reduces the population of weed seed. This is enhanced by pre-irrigation if soil moisture is below optimum for germination. The use of sweeps or subsurface knives to cut shoots of deep-rooted perennials before sowing a crop will allow the crop to germinate and get under way before the perennial reappears.

Repeated between-row cultivations, using sweeps, knives, or rolling cultivators, further reduce weed competition until the crop rows close over (lay-by). Throwing soil into the row at the base of the crop plants can be used by furrow cultivation to smother very young annual weeds. The deficiency of cultivation equipment in most crops is the inaccessibility of weeds growing close to and in the seeded crop row. In some crops (e.g., sugar beets, safflower, and grain sorghum [milo]), tine weeders, rolling cultivators, rod weeders, or rollers can be used to remove small, poorly rooted weeds from the crop row. The ability to control weeds in the crop row is the only advantage of hand hoeing as a cultivation measure.

Between-row cultivation is often combined with selective herbicides applied as a band in the seeded row. This method of integrating mechanical and chemical weed control reduces cultivation injury to the crop and simultaneously reduces the amount of herbicide required.

Widely spaced perennial crops, such as grapes, fruits, and nuts, permit selective cultivation to reduce weed competition. To avoid mechanical injury to the trunk with the cultivator, islands of weeds must be left around the individual vine or tree. Close cultivation can also injure the crop root system.

Where the crop is trained on a trellis, it is not practical to cultivate in the crop row. Weeds in grape rows can be removed by the French plow. The tillage blade moves away from the trunk when a forward trip mechanism contacts the trunk. After passing the trunk, the blade moves back into the vine row.

The seed of most plant species germinate within the top 1 inch of the soil. The seed supply can be exhausted from this germination zone most rapidly if no disturbance of the soil occurs. Control methods such as smothering, flaming, or post-emergence herbicides do not disturb the soil. Cultivation, on the other hand, has the unfortunate effect of bringing up additional seed to the zone where proper conditions exist for germination. Since viable seed may remain dormant in the soil for 3 to 40 or more years, every practical measure should be taken to prevent flowering and seed development, thus preventing the perpetuation of the seed supply in the soil.

Discing or harrowing is commonly practiced during fallow years on grain farms to reduce soil moisture depletion by annual weeds. Reduction of established stands of difficult-to-kill perennial weeds, such as field bindweed or johnsongrass, requires a very rigorous program of repeated cultivations with disc or sweep. The goal is to gradually deplete the carbohydrate reserves in the roots or rhizomes, causing plant starvation. For maximum carbohydrate depletion of field bindweed, the cultivation frequency should be practiced every 10 to 14 days following emergence of new growth throughout at least one and probably two growing seasons. Relatively shallow-rooted perennial grasses, such as bermudagrass and johnsongrass, are susceptible to desiccation and to carbohydrate depletion. Desiccation is aided by harrowing (drags rhizomes to the surface) and chiseling (provides deeper drying of the soil).

Mowing/Shredding Methods. Mowing or shredding controls weeds by: 1) preventing seed production if done before flowering; and 2) depleting stored food reserves of perennial weeds, when practiced on a frequent schedule. Unfortunately, mowing is a practice often performed when most convenient rather than when most effective.

Mowing/shredding offers an effective method of vegetation management in vineyards and tree fruits. When integrated with strips of chemical control in the vine or tree row, cultivation or between-row mowing improves winter access for other cultural practices (e.g., dormant spraying). In addition, the weed sod often maintains or improves soil structure.

Mowing is an important cultural practice for irrigated pastures. Weed seed production can be controlled and foliage access by livestock improved through properly timed mowing.

Weeds along fence rows, ditches, around buildings, and on non-crop slopes, can be controlled with flails or mowers. Specialized mowing equipment can be used to control excessive aquatic weed growth in canals and ponds.

Dredging and Chaining. Dredging is used chiefly for the removal of submersed and emersed aquatic weeds along canals.

Chaining encompasses the use of a heavy chain attached between two tractors. The chain is then dragged along a canal bottom, tearing loose aquatic weeds. It can also be used for brush control in range improvement.

Flooding and Mechanical Smothering. Flooding, as a weed control method, is used principally to rid land of established herbaceous perennial weeds. It has been used successfully to control johnsongrass, Russian knapweed, hoary cress, and silverleaf nightshade (white horsenettle). Complete submergence for 5 to 8 weeks during the summer has been effective. However, field bindweed control by flooding has not been adequate. In areas suitable for rice production, rotation to this crop permits production, and perennial weed control. Annual weeds, such as barnyardgrass (watergrass) and sprangletop, have been reduced in rice by maintaining water depth to a minimum of 6 to 8 inches.

Wood or bark chips, straw, compost, and, more recently, plastic sheeting can be used to smother annual weeds around the base of perennial crops. The method is more effective when applied before emergence of the weed. It has limited value in killing many established perennial weeds.

Flame. In selective weed control, heat is applied with a tractor-drawn flamer in a directed (row crop) or broadcast manner (alfalfa) to kill herbaceous weeds.

This technique is generally more effective for broadleaved weed control. Flaming, at least in alfalfa, offers the additional advantage of simultaneously providing weed control and partial insect control.

Controlled burning is a valuable tool in the conversion of brushlands to productive grazing land. It also reduces wildfire hazard. Successful conversion of brushland by burning often requires the use of herbicides to prevent rapid reestablishment by brush.

Burning of dried vegetation on roadsides, canalbanks, and levees is typically done after flowering and seed production. This procedure is more accurately a trash removal practice rather than a weed control method, as the plants have already completed their life cycle.

Chemical Weed Control

The use of herbicides is uniquely beneficial. It allows economical, selective weed control in range, and farm production, as well as in turf and ornamentals.

Herbicides used for selective weed control in crops grown as solid stands (e.g., alfalfa, cereals, rice, and safflower) must be applied over the entire field, because once the crop has emerged there is insufficient space between plants to operate cultivation equipment. This type of treatment is often referred to as solid, overall, or broadcast.

Weed control in row crops, because of the inter-row spacing can be conducted on an integrated basis, restricting the herbicide to a band along the seeded row and employing cultivators between the rows. A band treatment, therefore, means that bands of herbicides are separated by areas of non-treatment.

Herbicides can be applied at different times in relation to crop and/or weed stage of growth. Specific terms are frequently employed to describe these different times of application.

Pre-plant treatments are made to the soil before the crop is planted. This can be done before listing, pre-irrigating, or other cultural practices. Treflan® is frequently used this way in cotton and beans. Typically, pre-plant treatments are applied after seedbed preparation and directly before sowing the crop. This type of treatment can also be considered as pre-emergence with respect to weeds.

Pre-emergence treatments are made to the soil after the crop is sown but before emergence of the crop or the weeds.

Post-emergence treatments are applied to crop and weed plants after they have germinated and started to grow. Where crops are involved, the term post-emergence usually means early in the growth of the crop and weeds. Other post-emergence treatments can be subdivided as:

Lay-by—an herbicide treatment applied to row crops as the last equipment operation in the field.

Pre-harvest—herbicide treatments applied before crop harvest, usually to remove weed growth that could interfere with the harvesting operation.

Post-harvest—an herbicide applied to kill weeds present after the crop has been harvested, but which is not part of the weed control program for the next crop.

The diagram (figure 2) shows how the sequences of herbicide application fit in with cultivation practices and stage of crop or weed growth.

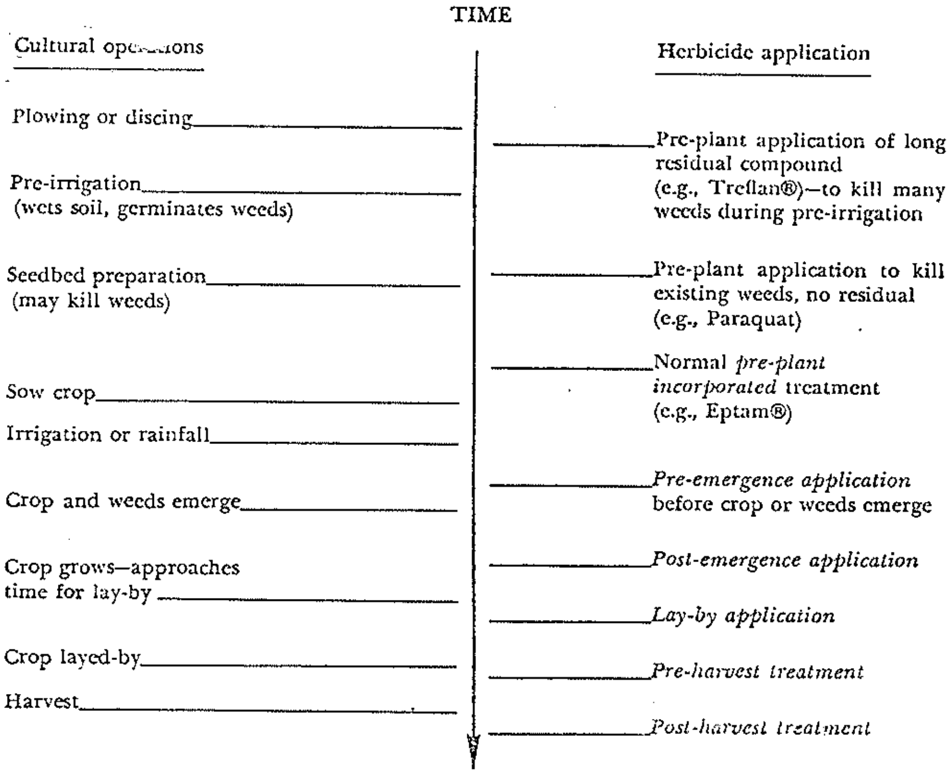

Fig. 2. Diagram showing sequences of herbicide application, cultivation practices, and stages of crop and weed growth.

Herbicides that are applied pre-plant, pre-emergence, and even several that are used post-emergence, must act through the soil. Therefore, the herbicide must be moved into the germination or root zone to be effective. In areas with adequate rainfall, this can be accomplished by leaching the applied herbicide into the soil. In irrigated regions, sprinkler or flooding followed by furrow irrigation can accomplish the needed activation. The direction of water movement from a furrow into the soil of the adjoining beds is in a lateral and upward direction; consequently, surface-applied herbicides cannot be effectively incorporated by leaching in furrow irrigation crops.

Physical mixing of the herbicide into the soil also provides the necessary placement in soil. The performance of soil-active herbicides with a high vapor pressure (high evaporation rate), susceptibility to breakdown by sunlight, low water solubility, or high adsorption to soil particles is improved by mechanically incorporating them into the soil, regardless of the irrigation method used.

Herbicide Selectivity in Crop Weed Control. Selectivity depends upon the degree of plant tolerance by either crop or weed species to a herbicide. An

TABLE 2. Herbicides That Must Be Incorporated Into the Soil Soon After Application to Prevent Appreciable Loss

butylate (Sutan®)	nitralin (Planavin®)
CDEC (Vegadex®)	pebulate (Tillam®)
cycloate (Ro–neet®)	triallate (Avadex®BW)
EPTC (Eptam®)	trifluralin (Treflan®)

herbicide's selectivity in a crop should not be taken to mean that no injury to the crop will occur; a low level of temporary toxicity may be tolerated in order to obtain the benefits derived from weed control. Likewise, weed control should not necessarily imply complete weed elimination, but may well offer yield-increasing benefits from weed reduction or stunting. An herbicide used selectively in a given crop will not necessarily control all the weeds that may be present. Like the crop, some weed species may be resistant to (tolerant of) the herbicide. Therefore, to gain maximum benefits of chemical weed control, the herbicide must have been established to be selective according to such factors as application rate, soil type, and irrigation practices for the particular crop. The herbicide is also expected to control at least some weeds common to the crop.

Conditions affecting herbicide performance often vary due to different weed species, stage of growth, weather, and soil type from farm to farm, or even between locations on a farm. Crop and weed selectivity therefore is relative, not absolute, and is influenced by complex interactions between plant, environment, herbicide, and application rate.

Where there is insufficient post-emergence selectivity in a crop, a directed spray may be used. The spray nozzles are directed under the crop foliage and onto the weeds (see diagram on next page). In some cases, leaf lifters may be utilized to further minimize the amount of herbicide contacting the crop. Another method of selective placement of the herbicide is the use of a shield over the crop row or the nozzle (hooded sprayer) to prevent spray contact with the crop. (See figure 3.) The crop shield or leaf lifter is mounted on the sprayer and moves with the sprayer through the field. These application techniques should be employed only when they are registered and included on the herbicide label. The use of ground sprayers in orchards and vineyards is another example of crop selectivity by directing the spray to the ground while avoiding the foliage.

Many herbicides used in crop production are soil applied; thus soil factors have a strong influence on the tolerance of both the crop and weeds. To avoid herbicide toxicity to the crop, recommended application rates are often lower for light (sandy) soils of low organic matter in which herbicides are more active.

There are weed species that are tolerant to every herbicide. The fact that a given herbicide is recommended for a given crop does not imply that all weeds encountered in the field will be controlled. Herbicide application rates in excess of the label recommendation to increase weed control should be avoided. A higher rate may significantly injure the crop, create an excessive herbicide residue in the harvested commodity (plant or animal), or adversely affect subsequent crops.

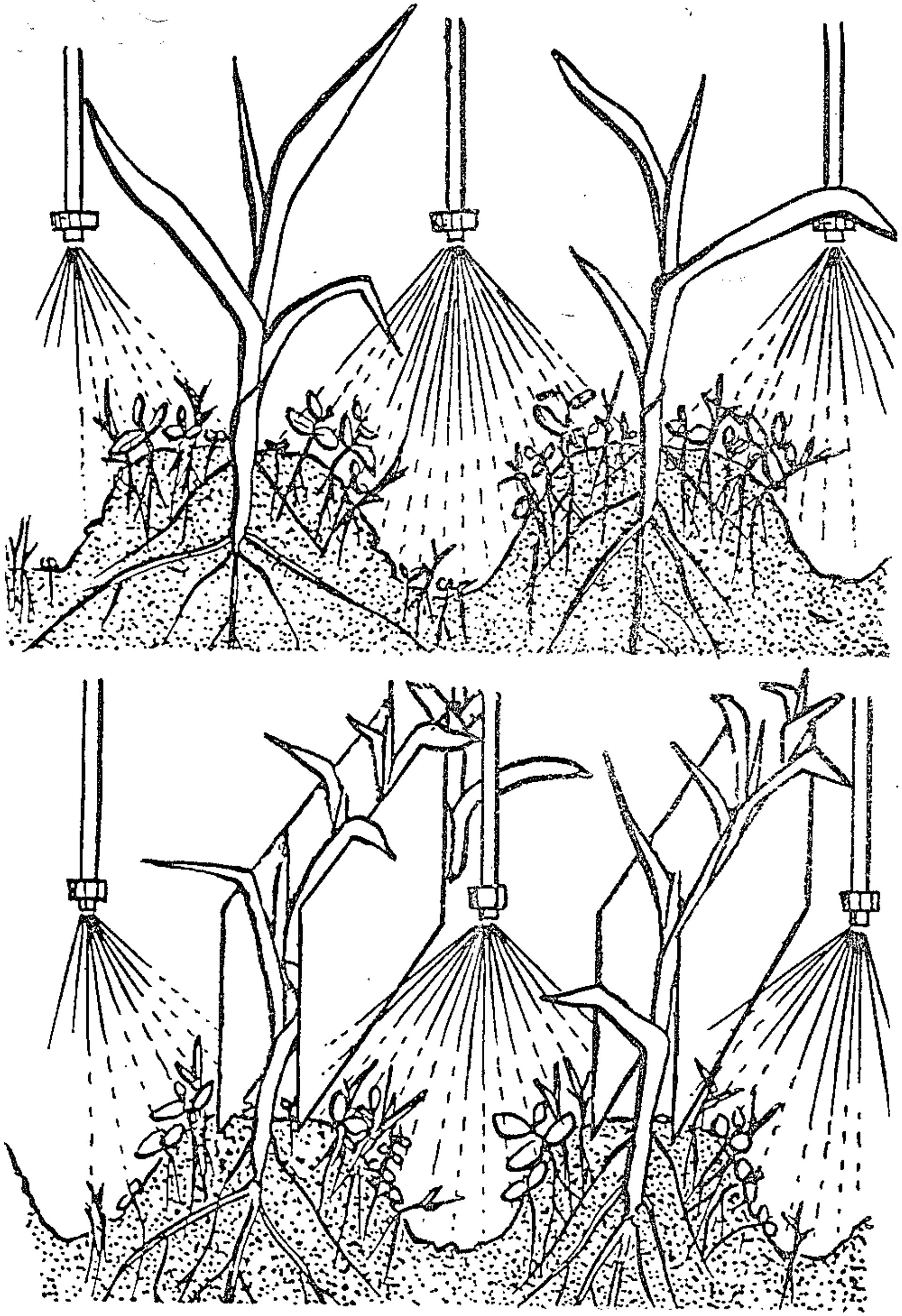

Fig. 3. Methods used to place herbicides selectively. Upper: drop nozzles direct herbicide onto weeds, keep it off crop. Lower: shielded spray hits most of weeds but is kept off crop plants.

TABLE 3. Examples of Annual Weeds Resistant to Specific Herbicides

Herbicides	Resistant Annual Weeds
alachlor (Lasso®)	Knotweed, wild oats, cocklebur, mustard, lambsquarters
atrazine (Aatrex®)	Cheeseweed, filaree, turkey mullein, puncturevine, Russian thistle, Hillman's panicum
bromacil (Hyvar®-X)	Monkey flower, common mullein, spikeweed, virgate tarweed
butylate (Sutan®)	Hairy nightshade
chloroxuron (Tenoran®)	Sowthistle
cycloate (Ro–Neet®)	Shepherdspurse, mustard, common groundsel, Russian thistle, purslane
diphenamid (Dymid®, Enide®)	Ground cherry, nightshade, sunflower, groundsel
diuron (Karmex®)	Turkey mullein, puncturevine, Russian thistle, wild oats, groundsel
EPTC (Eptam®)	Legumes, cheeseweed, common groundsel, mustard
monuron (Telvar®)	Turkey mullein, puncturevine
nitralin (Planavin®)	Sunflower, common groundsel, mustard, shepherdspurse, ground cherry, nightshade, burclover
norea (Herban®)	Grasses, pigweed, cheeseweed
paraquat (Ortho Paraquat)	Cheeseweed, filaree, knotweed
pebulate (Tillam®)	Mustard, London rocket, shepherdspurse, puncturevine, stinging nettle
phenmedipham (Betanal®)	Redroot pigweed, redmaids, barnyardgrass
prometryne (Caparol®)	Grasses
propham (Chem–Hoe®)	Composites, shepherdspurse, lambsquarters
simazine (Princep®)	Cheeseweed, filaree, Turkey mullein, puncturevine, Russian thistle, Hillman's panicum
terbacil (Sinbar®)	Mint, cats-ear, false salsify
triallate (Avadex® BW)	Most broadleaved species
trifluralin (Treflan®)	Sunflower, common groundsel, mustard, shepherdspurse, ground cherry, nightshade burclover
2,4-D	Most grasses

In some crops, an increase in resistant annual weeds can be corrected by substituting another, more effective herbicide registered for the crop or by adding a second herbicide. Herbicide mixtures are commonly used to broaden the spectrum of weeds controlled. The mixtures are either formulated together by the manufacturer (package mix) or they are added separately to the sprayer by the user (tank mixture). The use of tank mixes must be registered and recommended on a label. Unregistered herbicide mixtures or mixtures of herbicides

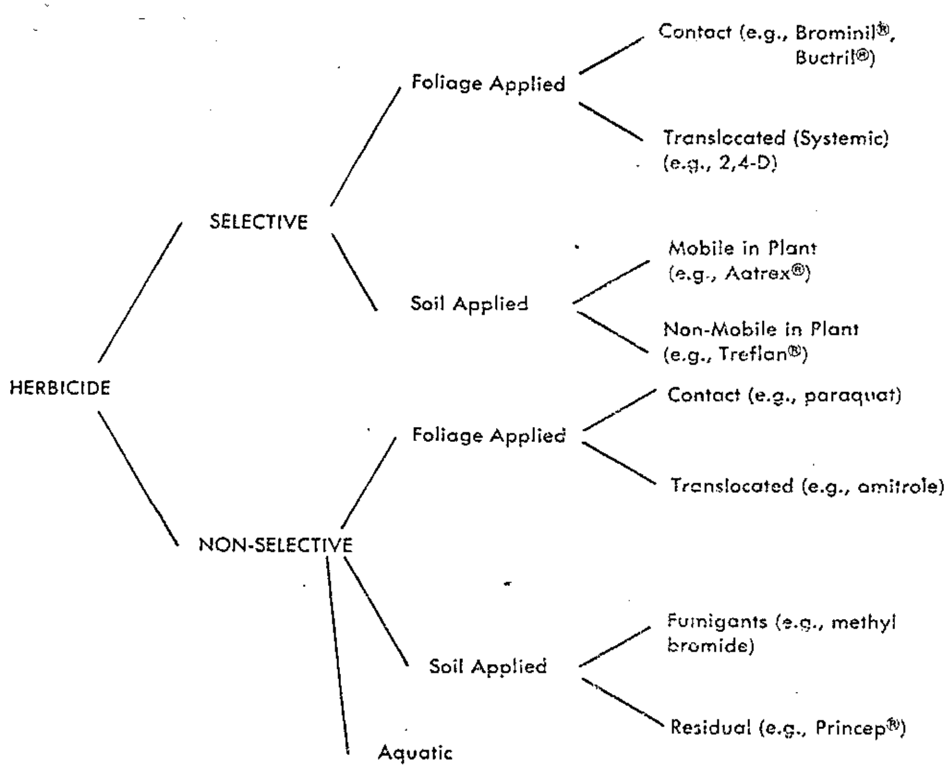

Fig. 4. Herbicide classification according to use categories.

with other chemicals may result in crop injury, illegal residues, or both. In addition, untried mixtures may not be compatible. If a tolerant weed population exists, rotation to another crop will often make it possible to introduce an herbicide that is effective in reducing the problem weed infestation.

Most perennial crops, tree and vine crops in particular, are prone to invasion by perennial weeds (e.g., field bindweed, bermudagrass, and johnsongrass). The control of annual weeds reduces competition and improves the vigor of both the perennial crops and perennial weeds.

Herbicide Selectivity in Non-Crop Weed Control. Vegetation management of some non-crop sites requires that plant cover—for example annual grasses—be maintained on slopes to prevent erosion. More objectionable broadleaf annuals, such as yellow starthistle, prickly lettuce, and Russian thistle, can be removed selectively, leaving wild oats and annual bromegrasses for soil conservation. On canal-banks and roadsides, complete elimination of vegetation may be required.

Soil-applied herbicides are often used for broad-spectrum control of mixed annual weed species. Again, selectivity is relative. There are specific annuals that are resistant to any of the soil-applied herbicides when used at lower rates. Most established perennial weeds, such as field bindweed, bermudagrass, dallisgrass, and johnsongrass, are not controlled by the normal rates used for general annual weeds. Most perennials, in fact, grow more vigorously when the competitive annuals are removed. This, of course, is an undesirable selectivity if a weed control program must be expanded to use other herbicides or control methods to contain resistant weeds. Some annual or biennial weeds are also resistant to the commonly used herbicides.

Use of herbicides for either selective or non-selective weed control on industrial sites can affect crops or ornamentals on adjacent property. The common cause of injury to desirable plants on adjoining property is *spray drift* from the target area. This must be avoided.

Banks or berms that slope toward adjoining property and desirable plants are another important cause of injury to crops or ornamentals. Herbicides placed on slopes do move down and away if a rainfall of sufficiently high intensity occurs. Sprayers should be adjusted and operated to prevent spraying directly into the water. These are examples of off-target herbicide movement. They must be recognized in order to be avoided.

Another type of selectivity problem occurs when crops, usually grapevines or trees, are injured or killed because they have roots in the herbicide-treated right-of-way. Roots of many woody plants extend well beyond the outer branches (dripline)—perhaps as much as 50 or more feet. When in doubt about the toxicity of herbicides to adjoining vineyards, orchards, or shade trees, use only the herbicides and application rates registered for use in the specific crop or ornamental. This will assure crop safety and avoid illegal residues.

ponds, and lakes. The following compounds can be used in aquatic weed control:

acrolein (Aqualin®)	endothall (various)
copper sulfate	fenac* (Fenac®)
dichlobenil* (Casoron®, Casoron® AQ)	2,4-D* (various)
diquat (Diquat Water Weed Killer)	grade b xylene (various)

Herbicide Formulations

Herbicides, as packaged and purchased, do not contain 100 per cent active herbicide. That portion of the content that is not active herbicide is composed of inert chemicals that cannot be removed economically at the factory and/or compounds that have been specifically added by the formulator. These are added to make the herbicide easier to handle, less likely to decompose or settle out during storage, to minimize effects of water quality (hard water), or to increase overall effectiveness.

1. *Dry formulations* are packaged as:

A. *Water-soluble powders.* (SP) These dissolve in water to form a true solution. They require little agitation once mixed.

B. *Wettable powders.* (WP) The active ingredient is not soluble in water, but can be suspended as fine particles. These herbicides require constant agitation or they will settle in the spray tank.

C. *Granules.* (G) The active chemical is mixed with, or coated onto, clay or some other inert ingredient to form small pellets (granules). These are not diluted but used directly from the bag. However, special application equipment is needed.

Note: Powders (dusts) of herbicides are *never* used because of the drift hazard associated with application.

2. *Liquid formulations* are packaged as:

A. *Water-soluble concentrate.* (WS) Like a water-soluble powder this forms a true solution in water, thus requiring little agitation. They are sold as a concentrated water solution for ease of handling, safety, and economics.

B. *Emulsifiable concentrate.* (EC) The active ingredient is not soluble in water but it is dissolved in a special solvent along with emulsifiers. This mixture forms a milky-looking emulsion in water. The emulsion may be colored if the herbicide is colored. This type of formulation usually requires light to moderate agitation.

C. *Liquid suspension.* (L) This is the equivalent of a concentrated suspension of a wettable powder. Fine particles are suspended in a liquid concentrate, which disperses readily in the spray tank, making mixing much easier than a wettable powder. Constant agitation of the spray mix is required.

* Not registered for use in irrigation water.

ADJUVANTS

An adjuvant is a material that assists, aids, or modifies the spray solution in some manner. There is a widely held idea that any substance that will increase wetting will serve as an adjuvant for any pesticide. Nothing could be farther from fact. Some of the confusion has arisen because of terminology used by growers and non-technical users when discussing adjuvants. Terms commonly used interchangeably are activator, additive, adjuvant, detergent, soap, spreader, surface-active agent, surfactant, and wetting agent.

The meanings of these terms are different, and are outlined below:

Additive—any material added to the spray solution; may or may not be a wetting agent or surfactant.

Detergent—cleaning agent or solvent that does not necessarily enhance activity or modify spray solution characteristics.

Surfactant—material that accentuates the emulsifying, spreading, or wetting properties of spray solution at a surface, i.e., surface-active agent.

Wetting agent—compound which causes the spray solution to contact surfaces more thoroughly.

Spreader—same as wetting agent.

Emulsifier—a material that aids in the suspending of fine droplets of one liquid in another, e.g., oil in water.

Sticker—a compound used to increase the amount of spray deposit remaining on a plant surface.

Thickeners—compounds used to reduce the number of fine droplets produced at the spray nozzle; used to reduce drift.

Oils—compounds, such as diesel oil or crop oils, used to increase penetration into woody vegetation.

It is easy to see why confusion arises when discussing these compounds, but remember, to wet a surface only means to cover or soak that surface with a liquid.

Surfactants come in a wide variety of types and each is designed for a particular use. At present, there are several thousand trade name surfactants available. They may be grouped into three categories according to electrical charge.

Type	Charge
Anionic	Negative
Cationic	Positive
Non-ionic	Neutral, no charge

The non-ionic surfactants are most common in agricultural sprays because they are relatively unaffected by water hardness and are compatible with all types of herbicides. Anionic surfactants are the next most used but are incompatible with hard water and certain herbicides. Many commercial surfactants are blends of the different surfactant types, plus other chemicals, to produce a high-performance product. Buffer compounds are often used to prevent interference of extremely hard water with a spray solution. Generally, these surfactants are formulated for use *only* when hard water conditions prevail.

The choice of surfactant is the prime consideration when increasing the phytotoxicity of an herbicide. Another concern is the concentration of the chosen surfactant. Wetting of the surfaces is important to obtain coverage of the plant, and, in situations when contact herbicides are used, this may be all that is desired. However, it has been found that wetting of plant surfaces does not correlate completely with the increase in phytotoxicity. Maximum wetting occurs in the range of 0.01 per cent to 0.1 per cent concentration of the surfactant, while maximum phytotoxicity usually occurs in the range of 0.2 to 1.0 per cent concentration, as shown in the graph (figure 5). In other words, an increase from 2 fluid ounces to 1 gallon of surfactant per 100 gallons of spray solution can substantially increase the degree of phytotoxicity.

The average amount of surfactant used in most herbicide solutions is approximately 0.1 to 0.5 per cent (i.e., 1 pint to 2 quarts per 100 gallons of spray mix). The maximum effect obtained from a given concentration will vary with surfactant and herbicide. Phenoxy-type herbicides (e.g., water-soluble amine of 2,4-D) generally show maximum increase around 0.2 to 0.5 per cent, while other types of foliar-applied herbicides (e.g., dalapon, amitrole, Paraquat®, etc.) often show maximum effects from 0.5 to 1.0 per cent.

Use should be made of this range of surfactant concentrations by taking into consideration the environmental factors preceding and at the time of spraying. In areas, or times, of high humidity and cool temperatures, the need to include high surfactant concentrations in an herbicide spray solution is less than in areas, or times, of low humidity and high temperatures. It must also be remembered that in extremely hot, dry weather, the benefits derived from the use of a surfactant will be lessened. Older plants are generally more difficult to control than are younger plants. Plants suffering from water stress or nutrient deficiency or covered with dust are more resistant to penetration and movement of herbicides.

Non-phytotoxic (phytobland) crop oils have been found to greatly increase the post-emergence activity of several herbicides. These oils are low in sulfon-

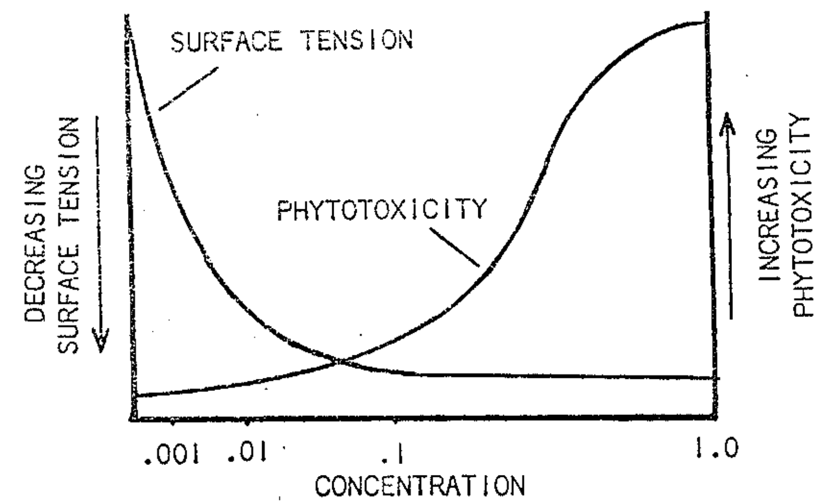

Fig. 5. Graph showing relationship between surfactant concentration, surface tension, and phytotoxicity.

ated resid[illegible] nd aromatics, and do not normally injure plants. The oil must form an emulsion in the spray mix; those formulated for adjuvant use contain the necessary emulsifiers. Quantities of 1.0 to 2.0 gallons/acre are employed for adjuvant purposes. Aatrex® plus oil for post-emergence weed control in corn is an example of this use.

The use of diesel oil or light mineral oil as a carrier can greatly increase the activity of phenoxy-type herbicides for brush control.

Proper selection of the adjuvant is of the utmost importance, and care should be used to correlate it with the use intended. In some herbicide products, the adjuvant(s) is formulated in the package sold to the consumer. In this case, the surfactant choice has been made, but the concentrations when mixed for use are often improper for maximum uptake. If this occurs, caution should be exercised in selecting and adding additional adjuvant. Remember, even though phytotoxicity of the herbicide is increased by adjuvants, it may not always be desirable, since crop selectivity may be reduced.

Adjuvants are not miracle chemicals, but when used properly they will enhance herbicidal efficiency. They will assist in lessening the possibility of damage to desirable plants by allowing the use of lower rates of the herbicide, and they decrease the cost of the herbicidal application.

CALIBRATION INFORMATION

1 foot per mile equals 0.1212 acres
5,280 feet equals 1 mile
43,560 square feet equals 1 acre
1 mile per hour equals 88 feet per minute
1 gallon equals 231 cubic inches
1 quart equals 32 fluid ounces

$$\text{gal./acre} = \frac{\text{gal./min. per nozzle} \times 495}{\text{nozzle spacing in feet} \times \text{mph}}$$

$$\text{Miles per hour (mph)} = \frac{120}{\text{seconds to travel 176 feet}}$$

$$\text{Miles per hour (mph)} = \frac{\text{distance traveled in miles} \times 60}{\text{time in minutes}}$$

Calibration Questions

Note: Calibration Charts A and B can be used, but use your arithmetic to check answers.

1. A spray rig sprayed a width of 20 feet for 5 miles. How many acres were sprayed? ________acres
2. If 800 gallons were applied over 16 acres, what was the rate of output in gal./acre? ________gal./acre
3. It took 1½ hours to apply 800 gallons. What was the rate of discharge from the boom in gal./min.? ________gal./min.

4 There were 12 nozzles on the boom in Question 3. What was the discharge rate per nozzle in gal./min.? ________gal./min.

5. A spray rig took 25 seconds to travel 176 feet. What was its speed in mph? ________mph

6. In a field check, a spray rig traveled 0.8 miles in 8 minutes. What is the speed in mph? ________mph

7. A 16-foot width was sprayed for a distance of 3 miles with about 330 gallons of solution. What was the rate of application in gal./acre? ________gal./acre

8. T F Increasing speed will increase gal./acre.

9. T F Doubling pressure will double nozzle discharge rate in gal./min.

10. T F Doubling nozzle discharge rate, without changing speed or pressure, will double the application rate in gal./acre.

Answers to Calibration Questions

1. 20 ft. × 0.1212 = 2.42 acres/mile × 5 miles = 12.1 acres
   Chart A = 12
2. 800 ÷ 16 = 50 gal./acre. Chart B = 50 gal./acre.
3. 1½ hours = 90 minutes
   800 ÷ 90 = 8.9 gal./min.
4. 8.9 ÷ 12 = 0.74 gal./min.
5. 120 ÷ 25 = 4.8 mph.
6. $\frac{0.8 \times 60}{8}$ = 6.0 mph.
7. 16 × 0.1212 × 3 = 5.8 acre. Chart A = 5.75 acre.
   330 ÷ 5.8 = 56.9 gal./acre. Chart B = 58 gal./acre.
8. False
9. False
10. True

WEED CONTROL AND THE ENVIRONMENT

There are two problems associated with weed control and the environment:

1. The influence of local environmental variations on the effectiveness of the weed control. This can be particularly significant in relation to herbicide activity.
2. The influence of the weed control practices on the environment. The use of herbicides is the prime concern within this area.

Influence of the Local Environment on Weed Control

There are a number of conditions, or factors, in weed control that greatly influence the choice of herbicides, application rate, application timing, type of equipment used to apply herbicides, and the final results obtained. Conditions may dictate that no herbicide be used, but that cultivation, mowing, draglining, or other mechanical method be used instead.

Local environmental factors that can modify weed control effectiveness are listed below. Two or more factors often work together as an interaction, and influence the weed control program planning and the final results.

- Weed species present
- Climatic conditions
  - Precipitation pattern and amount, or type of irrigation
  - Temperature before, at, and after application
  - Wind velocity and direction
- Soil type
- Land use on adjoining property

Weed Species Present. As indicated earlier, a weed control program must be related to the types of weeds to be controlled. Knowing whether the undesirable vegetation is annual or perennial, narrow leaved or broadleaved, and even which species are present, has a direct bearing on herbicide selection as well as application rate. An herbicide can give unsatisfactory weed control if a resistant weed species is present in large numbers.

Climatic Conditions. Rainfall distribution and amount, temperatures, and wind all play important roles in planning a weed control program. Soil-active herbicides require rainfall, overhead irrigation, or mechanical incorporation to leach, or physically move them, from the soil surface into the germination or the root zone of weeds. Excessive leaching of soil-applied herbicides on non-crop sites can be minimized in areas of approximately 15 or more inches of rainfall annually by using lower, economical rates applied midwinter (January) rather than in the fall. The rainfall frequency and quantity greatly affect activity and performance of soil-applied herbicides, especially if they are not physically incorporated.

Temperature affects the results with either foliage-applied or soil-applied herbicides. Plant response to foliage-applied herbicides is much slower during periods of cold weather. A treatment that shows pronounced effects with a few days in the summer may take several weeks to reach the same level of kill during cool weather. High temperatures can substantially increase activity of many herbicides; in several cases the selectivity can be reduced to the point where severe crop injury occurs. The use of MCPA in rice when temperatures are

around 100°F., or of Betanal® in sugar beets at over 85° to 90°F., are examples of this decreased crop tolerance at high temperatures. High summer temperatures can substantially increase loss of low volatile esters of 2,4-D and related hormone-type herbicides by converting them into vapor form, which can then affect adjacent crops or ornamentals.

Wind can be a major factor in determining where and when spraying can be done. Velocity and direction are important in terms of location of sensitive crops onto which drift could occur. Wind can also cause problems in band spraying by causing lateral misplacement of the band.

Soil Type. The soil affects weed kill in many ways. The types of soil (sandy, loam, clay, or muck) often determine the choice of herbicide and its activity, and will always affect the depth of leaching and the rate of chemical breakdown.

Adsorption of herbicides to the soil particles is the factor that is most important in determining how a herbicide will react in soil. Adsorption means that the herbicide molecules are "tied-up" to the soil particles, and are, thus, no longer free to be taken into plants (more adsorption means decreased activity), moved with water, and leached (more adsorption means less leaching). Different soils, as shown in Table 9, have different adsorption capacity. This means that herbicides applied to different soils have different activity and leaching characteristics. Within bounds of differences in adsorption, the greater the water solubility of an herbicide the more easily it will be leached.

Soils usually have an overall net negative electrical charge. An herbicide having a net positive charge will therefore react with the soil immediately and be chemically inactivated (paraquat is the only commonly used herbicide of this type). Herbicides having a net negative charge will be repelled by the soil particles; they are not held by the soil at all and consequently leach very easily (e.g., TCA).

TABLE 9. Soil Types in Relation to Herbicide Activity

Characteristic	Sand	Loam
Adsorption capacity	Very low	Low
Herbicide leachability	Rapid and deep	Moderate
Relative herbicide activity	High	Moderate
Characteristic	**Clay**	**Peat/Muck**
Adsorption capacity	Moderate	Very high
Herbicide leachability	Low	Almost none
Relative herbicide activity	Moderate to low	Very low

Since organic matter (peat or muck) has very high adsorption capacity, small changes in organic matter in other soil types can dramatically alter herbicide activity and leachability.

The foregoing discussions explain why the following type of statement often appears on herbicide labels: "Do not use in sandy soil; use 3 lb./A. on loam soils; use 4 lb./A. on clay soils; do not use in peat/muck soil." The activity would be *too high* in sandy soil, *too low* in peat/muck soil, and the higher rate in clay soil would compensate for the higher adsorption capacity.

Herbicid[illegible] ased on organic chemical molecules (most are) can be used as a source of food by soil micro-organisms (bacteria and fungi). The herbicide molecule is broken down as it is used for food, usually to carbon dioxide and water, or to a simple molecule that the micro-organism can further utilize in its own metabolism. The original herbicide thus disappears completely.

The rate of breakdown depends on two basic areas: the herbicide chemistry; and the presence and action of micro-organisms. The latter varies greatly with soil conditions, such as:

Organic matter—higher organic matter, more micro-organisms, faster breakdown.

Moisture—micro-organisms not active in dry soil, active in moist soil.

Temperature—micro-organisms very low activity in cool soil, active in warm soil.

Mineral nutrients—growth of micro-organisms slow if minerals lacking, fast if available.

Break-down therefore is fastest in a warm, moist, fertile soil with organic matter present. Conditions ideal for plant growth are usually also ideal for micro-organism activity.

Land Use on Adjoining Property. The farming area, types of crops grown on adjoining fields, and urbanization all play a role in the choice of weed control programs. Checks must be made for sensitive crops, gardens, and homes in the vicinity of the area to be sprayed; if drift could occur over such areas, spraying should not be conducted. The increasing pressure of population and concerns of environmental groups will limit the choice of material, time, and method of application in some situations.

Vegetation control practices on canal banks, in addition, present a unique problem of avoiding water contamination. Nozzles should be adjusted and directed in a manner to avoid spraying into the water. As a general rule, when spraying on the inside of a canalbank, operate the sprayer in the opposite direction to that of the water flow, that is in an upstream direction. In doing so, this will avoid increasing the amount in the water if it should be reached. If the sprayer operates in the direction of water flow, the same parcel of water will tend to be next to the sprayer during the operation. The herbicide could accumulate if the spray inadvertently reached the water surface.

Effects of Weed Control on the Environment

The *only* reason for any weed control practice is to change the environment:

- to maintain the production of food and fiber sufficient to feed and clothe the growing world population.
- to enhance beauty and provide recreation, i.e., attractive lawns, gardens, landscapes, camping sites, fishing, swimming, and other outdoor sports.
- to ensure safety from fire, from effects of traffic obstructions, and from allergy sources—poison oak, ragweed, etc.

Manipulation of vegetation is essential to our health, well-being, and enjoyment of life. Vegetation control practices must necessarily change the botanical environment around us—the botanical composition of the flora, the ecology! This is true regardless of the methods used for weed control: hand pulling, hoeing, plowing, cultivating, burning, etc. It is even true for biological control

through the use of insects that selectively feed on plant specie[illegible] he weed control advisor, therefore, should be aware of the consequences of his actions.

Any successful weed control practice must affect the environment. It should be expected. The concern is with possible effects outside the target area or on non-target organisms. In weed control, the principal concern is with herbicides, although detrimental side effects (soil erosion, soil compaction, air contamination with dust or smoke, *etc.*) can occur with other control methods.

Certain chlorinated hydrocarbon insecticides have come under heavy criticism in recent years, because of:

Relatively long persistence in the environment
Biomagnification through certain organisms
Frequent detection in the food chain
Inherent toxicity to some wildlife species

No organic herbicide possesses the combination of all these characteristics. Most herbicides have received relatively little criticism because the majority are low in mammalian toxicity and have short persistence in the environment under most conditions.

What is known about environment contamination by herbicides can be reviewed under four headings:

Entry into the environment
Persistence in the environment
Residues in the environment
Effect on organisms in the environment

A number of pertinent references are included at the end of this study guide for further reading in this subject.

Entry Into the Environment. Herbicides, to be effective, *must* become an intimate part of the environment of the target plants. It is only when they move away from the target site or persist sufficiently to affect later plantings that they become a problem. Herbicides can move by drift of droplets during and soon after the time of application, by volatility from a treated area, by leaching, and by surface movement through wind or water erosion.

Spray drift. Small droplets produced as the spray solution leaves the nozzle may remain suspended in the air for varying periods of time, depending on droplet size. The distance these droplets will travel depends primarily on wind velocity. In any spray operation, a certain fraction of the liquid will be in small droplets and some drift, therefore, is inevitable. The effect of this drift depends on the herbicide involved and the proximity of sensitive plants. It should be noted that damage, if any, is usually confined to the agricultural community and, even then, to other plants, not animals.

The more spectacular effects of drift have come in the past from the phenoxy herbicides, particularly 2,4-D. This was due to the potency of these herbicides, the high degree of sensitivity of certain plants, and the striking symptoms developed by sensitive plants exposed to even minute amounts of phenoxy herbicides. Once this hazard was fully recognized it was possible to minimize drift through proper application techniques and regulations. In recent years, only occasional reports of damage from drift of phenoxy-type herbicides have been received and these are usually the result of error or accident.

A more recent example of unpredicted drift is that of propanil. This herbicide sprayed on rice for control of barnyardgrass can cause symptoms on prune trees some m away. It is an example of an unpredictable development and, while such developments have been rare, they do sometimes occur. As knowledge of air movement and droplet behavior improves, there should be fewer such occurrences.

These two examples again emphasize that problems developing from herbicide use are normally self-regulating, due to the undesired effects being readily visible on plants. Such problems can never go undetected for very long.

Vapor drift. Vapor drift results from movement of materials in a vapor phase from the treated area to other areas by wind or by air mass movement. Some forms of 2,4-D are highly volatile and can evaporate from treated fields or plants and contaminate an air mass. This problem has been greatly reduced through the use of low volatile forms of 2,4-D and other phenoxy herbicides in areas where susceptible crops or ornamentals are grown.

There has been some confusion between spray drift and vapor drift, but, in recent years, spray drift has been more common than volatility. It is rare in California today to find evidence of herbicide volatility as a cause of environmental contamination.

Leaching. Leaching is movement of a chemical down in the soil profile with water. Compounds that are highly water soluble (e.g., sodium TCA) leach readily with rainfall or irrigation, whereas compounds with low water solubility (e.g., Treflan®) leach to only a limited extent. The concern, in terms of environmental contamination, is not with the soil itself, but rather with vertical movement as a potential source for contamination of ground water supplies.

The amount of herbicide at different levels in the soil depends on several factors. The soil type (sand, silt, clay, muck, etc.) determines the depth of water movement in soil and consequently the depth to which any given herbicide will move. As discussed earlier, the soil type has an effect (through its properties for adsorption) of holding herbicide molecules against leaching forces. Certain clays, because of their structure, can tightly bind some herbicides. Organic matter and carbon particles also can retain herbicides against leaching forces.

The amount of water entering the soil, either by rainfall or irrigation, and the water solubility of the herbicide are also important factors. Even formulation of the herbicide may affect depth of movement; for example, the amine of 2,4-D moves more readily than ester formulations.

A final factor that affects leaching is the degradation of the herbicide by either chemical or biological agents. The more rapidly an herbicide is broken down, the less time there is for leaching.

Surface movement. Herbicides also might contaminate non-target portions of the environment by surface movement by wind or water, usually in association with soil particles. In field experience, water has been the major element in causing such surface movement. Factors affecting surface movement of herbicides with water include:

Slope or steepness of the area
Permeability of the soil
Amount and intensity of the precipitation
Formulation of the herbicide (principally solubility)
Rate of application
Vegetative cover

Persistence in the Environment. Herbicides, particularly soil-applied herbi-

cides, *must* persist in the environment for a long enough time t ovide some period of weed control. This creates something of a dilemma. Weed control during the growing period of the crop should ideally last until harvest. But, once the crop has been harvested, a different crop will probably be planted that could be susceptible to the herbicide used previously. Future crops cannot be jeopardized with herbicide residues, and yet weed control is desired throughout the growing period of any crop. Season-long control is normally a compromise effort consisting of a period of weed control during the germination and early crop growth, followed by dependence on crop competition, cultivation, or repeated short-residual herbicide treatments. Non-crop sites usually require at least one growing season of weed control per treatment with soil-active herbicides

Soil persistence. This is usually the major concern. It is difficult to set values on the length of time any herbicide will remain in the soil, because soil persistence depends on several factors. These include:

Rate and formulation of herbicide.
Soil type, as it affects microbial activity and herbicide availability.
Microbial populations; are the right species present?
Environmental factors that influence microbial activity.
(See Table 9, page 51.)

In general, herbicide breakdown is most rapid in warm, moist soils with good microbial growth. With some highly water soluble herbicides, leaching below the root zone may cause a rapid loss of immediate toxicity without actual breakdown. Cold, dry, and sterile soils usually inhibit break-down and prolong persistence.

Repeated applications of the same herbicide to the same piece of ground could lead to a build-up of chemical in the soil. Provided the break-down rate has been established, the maximum amount of build-up that could occur may be calculated using the following formula:

$$\text{Amount of chemical in soil (build-up)} = \frac{\text{rate of application}}{1 - \%\ \text{remaining (as decimal)}}$$

An example clearly shows how this formula can be used. Assume a 2 lb./A. rate of application and 50 per cent (0.5 as decimal) remaining at retreatment time. $\text{Maximum build-up} = \frac{2}{1-0.5} = \frac{2}{0.5} = 4$ lb./A. When the break-down rate exceeds 80 to 90 per cent at retreatment, there is little potential build-up problem; even at 50 per cent loss, the build-up would be only twofold. No large build-up of herbicides under current use patterns would seem possible.

There is another factor that makes soil build-up of herbicides unlikely. Some herbicides (2,4-D, for example) have been found to increase microbial populations. A second application, therefore, breaks down faster than the first application because the microbial population was enhanced.

Persistence in water. This is of concern for those herbicides used for aquatic weed control. This is true when herbicides are applied to the water itself, as for submerged aquatics, or when applied for emersed or ditchbank weeds where some portion of the treatment may get into canals, ditches or ponds.

Herbicide break-down in water is mostly microbial, with definite evidence of removal from water by precipitation and adsorption on particulate matter.

There is also evidence of persistence in bottom mud, where anaerobic conditions may reduce activity of the microbes responsible for decomposition.

Recent studies show only minute amounts of herbicides appearing in irrigation water from ditchbank spray operations. It would appear that careful ditchbank application of current herbicides present no appreciable hazard to downstream vegetation or to crops through irrigation. Treatments to the water itself have caused no reported crop loss when used as directed. However, most aquatic herbicides affect other aquatic organisms in addition to plants. For this reason, their use is usually confined to irrigation canals where game fish are not resident.

TABLE 10. Examples of the Relative Soil Persistence of Herbicides Measured as Duration of Weed Control

1 to 2 Months	2 to 6 Months	6 Months or More
alachlor (Lasso®)	chloramben (Amiben®)	atrazine (Aatrex®)
amitrole (various)	chloroxuron (Tenoran®)	benefin (Balan®)
bromoxynil (Buctril®, Brominil®)	chlorpropham (Chloro–IPC®)	bensulide (Prefar®)
butylate (Sutan®)	cyanazine (Bladex®)	bromacil (Hyvar®–X)
CDAA (Randox®)	dalapon (Dowpon®, Basfapon®)	chlorbromuron (Maloran®)
CDEC (Vegadex®)	diphenamid (Enide®, Dymid®)	cyprazine (Outfox®)
cycloate (Ro–Neet®)	DCPA (Dacthal®)	dicamba (Banvel®)
endothall (Endothal®)	linuron (Lorox®)	dichlobenil (Casoron®)
EPTC (Eptam®)	norea (Herban®)	diuron (Karmex®)
fluorodifen (Preforan®)	prometryne (Caparol®)	fluometuron (Cotoran®)
naptalam (Alanap®)	pyrazon (Pyramin®)	monuron (Telvar®)
nitrofen (Tok®–25)	terbutryn (Igran®)	nitralin (Planavin®)
paraquat (Ortho Paraquat)		picloram (Tordon®)
pebulate (Tillam®)		propazine (Milogard®)
phenmedipham (Betanal®)		simazine (Princep®)
propachlor (Ramrod®)		terbacil (Sinbar®)
propham (Chem–Hoe®)		trifluralin (Treflan®)
silvex (Kuron®)		2,3,6 TBA (Trysben®, Benzac®)
triallate (Avadex® BW)		
2,4-D (numerous)		

Reference: *Herbicide Handbook:* Weed Society of America
Weed Control as a Science: G. C. Klingman

GLOSSARY OF TERMS USED IN WEED CONTROL

Absorption—The process by which herbicides are taken into plants by roots or foliage (stomata, cuticle, etc.).

Adsorption—Chemical and/or physical attraction of a substance to a surface. Can refer to gases, dissolved substances, or liquids on the surface of solids or liquids.

Acid Equivalent (a.e.)—The theoretical yield of parent acid from an active ingredient.

Active Ingredient (a.i.)—The chemicals in a product that are responsible for the herbicidal effects.

Acre—A unit of area (43,560 square feet).

Annual—A plant that completes its life cycle in one year, i.e., germinates from seed, produces seed, and dies in the same season.

Examples: (pigweed, ragweed, mustard, foxtail, crabgrass.) A winter annual is one that germinates in the fall, lives over winter, then flowers and seeds the following spring and summer, such as shepherds purse, hedge mustard, and peppergrass. Also see "Winter Annual."

Aquatic—A plant that grows in water. There are three kinds: *submersed*, which grows beneath the surface; *emersed*, which grows above the water, such as cattails and water lilies; *floating*, such as water hyacinth.

Aromatics—Compounds derived from the hydrocarbon benzene (C_6H_6).

Band Application—An application to a continuous restricted band such as in or along a crop row, rather than over the entire field area.

Basal Treatment—Herbicide treatment applied to the stems of woody plants at and just above the ground.

Bed—1) a narrow flat-topped ridge on which crops are grown with a furrow on each side for irrigation or drainage of excess water. 2) an area in which seedlings or sprouts are grown before transplanting.

Bed-up—To build up beds or ridges with a tillage implement.

Biennial—A plant that completes its growth in 2 years. The first year it produces leaves and stores food; the second year it produces fruits and seeds.

Broadcast (Blanket) Application—An application of spray over an entire area rather than only on rows, beds, or middles.

Blind Cultivation—Cultivating before seeded or planted crop emerges.

Brush Control—Control of woody plants.

Carrier—The liquid or solid material added to a chemical compound to facilitate its application.

Chlorosis—Loss of green color in foliage.

Compatible—Quality of two compounds that permits them to be mixed without effects on the properties of either.

Concentration—The amount of active material in a given volume of diluent. Recommendations and specifications for concentration of herbicides should be on the basis of *pounds per unit volume of diluent*.

Contact Herbicide—An herbicide that kills primarily by contact with plant tissue rather than as a result of systemic movement.

Cotyledon Leaves—The first leaf, or pair of leaves, of the embryo of seed plants.

Crook Stage—After the bean or onion seedling has broken through the soil and before the stem has become erect.

Crop—Any plant grown for the use or benefit of man, including turf or ornamentals, forest, fruit and nut trees, as well as range forages and crops.

Crown—The point where stem and root join in a seed plant; also refers to region of deciduous perennial plant (e.g., alfalfa) from which new growth occurs.

Deciduous—Indicates plants that lose their leaves during the winter.

Defoliator or Defoliant—A compound that causes the leaves, or foliage, to drop from the plant.

Desiccant—A compound that promotes dehydration of plant tissue.

Diluent—Any liquid or solid material serving to dilute an active ingredient in the preparation of a formulation.

Direct Spray—An application made to minimize the amount of herbicide contacting the crop foliage. This is usually accomplished by setting nozzles low with spray patterns intersecting at the base of the plants just above the soil line.

Dormant—State of inhibited growth of seeds or other living plant organs due to internal causes.

Dormant Spray—Chemical applied in winter or very early spring before treated plants have started active growth.

Emergence—Appearance of the first part of the crop plant or weed through the ground.

Emulsifying Agent—A material that facilitates the suspending of one liquid in another.

Emulsion—A mixture in which minute globules of one liquid are suspended in another liquid; for example, oil in water. Usually milky in appearance.

Epinasty—Increased growth on the upper surface of a plant organ or part (especially leaves) causing it to bend downward.

Flag Stage—The early post-emergence stage of onion seedlings between the "crook" stage and the emergence of the first true leaf. The bent tip of the seed leaf resembles a flag attached to a staff. Also referred to as the "knee" stage.

Formulation (of herbicides)—The way in which basic herbicidal chemicals are prepared for practical use. Includes preparation as wettable powders, granulars, emulsifiable concentrates, etc.

Fumigant—Chemical used in the form of a volatile liquid or a gas to kill insects, nematodes, fungi, bacteria, seeds, roots, rhizomes, or entire plants; usually applied in an enclosure of some kind or in the soil.

Growth Regulator—An organic substance effective in minute amounts for controlling or modifying plant processes.

Growth Stages of Cereal Grains—1) *Tillering stage,* when additional shoots are developing from the crown. 2) *Jointing stage,* when stem internodes begin elongating. 3) *Boot stage,* when leaf sheath swells due to the growth of developing spike or panicle. 4) *Heading stage,* when seed head is emerging from the sheath.

Hard Water—Water that contains certain minerals, usually calcium and magnesium sulfates, chlorides, or carbonates, in solution, to the extent of causing a curd, or precipitate, rather than a lather, when soap is added. Very hard water may cause objectionable precipitates to form in some herbicidal sprays.

Herbaceous Plant—A vascular plant that does not develop woody tissue.

Herbicide—A chemical used for killing or inhibiting the growth of plants.

Hormone—A growth-regulating substance occurring naturally in plants or animals. Also refers to certain man-made or synthetic chemicals with growth regulating activity. However, these are more correctly called synthetic regulators; they are not hormones.

Invert Emulsion—One in which the water is dispersed in oil rather than oil in water. Oil forms the continuous phase with the water dispersed therein. Usually a thick mayonnaise-like mixture results.

Lay-by—Refers to the stage of crop development (or the time) when the last regular cultivation is done.

Leach—Usually refers to movement of water through a soil, which may move soluble plant foods or other chemicals.

Miscible Liquids—Two or more liquids capable of being mixed, which will remain mixed under normal conditions.

Necrosis—The death of tissue (such as all or part of a plant).

Non-selective Herbicide—An herbicide that can be used to kill plants, generally without regard to species.

Noxious Weed—A plant arbitrarily defined by law as being especially undesirable, troublesome, and difficult to control. Definition of the term "noxious weed" will vary according to legal interpretations.

Perennial—A plant that continues to live from year to year. The plants are herbaceous or woody.

Pesticide—Any substance or mixture of substances intended for the control of insects, rodents, fungi, weeds, and other forms of plant or animal life that are considered to be pests.

Phytotoxic—Poisonous to plants.

Post-emergence—After emergence of specified weed or crop.

Pre-emergence Treatment—Treatment made after a crop is planted but before it or the weeds emerge.

Pre-planting Treatment—Treatment made before the crop is planted.

Rate and Dosage—These terms are synonymous. "Rate" is the preferred term. Usually refers to the amount of active ingredient material (such as 2,4-D acid equivalent) applied to a unit area (such as 1 acre) regardless of percentage of chemical in the carrier.

Residual—To have a continued killing effect over a period of time.

Resistant—Same meaning as tolerant. Resistance of weeds determines the rates of weed killing application required for control.

Rhizome—Underground stem capable of sending out roots and leafy shoots.

Scarificati—Process of scarring a seedcoat to make it more permeable to water.

Selective Herbicide—A compound that is more toxic to the weeds than to the crop. Helps control weeds without damaging the crop.

Soil Application—Application of chemical made primarily to the soil surface rather than to vegetation.

Soil Enrichment (microbiological)—A build-up of a particular group of microbes in the soil that are well adapted to breaking down a particular herbicide.

Soil Incorporation—Mechanical mixing of the herbicide with the soil.

Soil Injection—Mechanical placement of the herbicide in the soil.

Soil Persistence—Refers to the length of time that an herbicide application on or in soil remains effective.

Spike Stage—The very early emergence stage of corn in which the leaves are still tightly rolled to form a "spike." Usually before the corn is more than 2 inches tall.

Spot Treatment—Application of sprays to localized or restricted areas as differentiated from overall, broadcast, or complete coverage.

Spray Drift—The movement of airborne spray droplets from the spray nozzle beyond the intended contact area.

Stolon—Surface runners or horizontal, above-ground stems that develop roots and shoots at the tip or nodes, as in the strawberry plant.

Stool—To throw out shoots; to tiller.

Stunting—In relation to weeds or crop plants, usually refers to a retarding effect on growth and development. Stunting of weeds or grasses, even without kill, may often give effective commercial control.

Surfactant—A material that, in pesticide formulations, imparts emulsifiability, spreading, wetting, dispersibility or other surface-modifying properties.

Suspension—A liquid or gas in which very fine, solid particles are dispersed but not dissolved.

Synergism—Cooperative action of different chemicals such that the total effect is greater than the sum of the independent effects.

Systemic Herbicide—A compound that is translocated within the plant and has an effect throughout the entire plant system.

Tolerance (pesticide)—The amount of pesticide chemical allowed by law to be in or on the plant or animal product sold for human consumption.

Tolerant—Capable of withstanding effects. For example, grass is tolerant of 2,4-D to the extent that this herbicide can be used selectively to control broad-leaved weeds without killing the grass.

Translocation—Transfer of food or other materials such as herbicides from one plant part to another.

Vapor Drift—The movement of vapors from the area of application to other areas.

Volatile—A compound is volatile when it evaporates, or vaporizes (changes from a liquid to a gas), at ordinary temperatures on exposure to the air.

Wettable Powder—A powder that will readily form a suspension in water.

Wetting Agent—A compound that, when added to a spray tion, causes it to contact plant surfaces more thoroughly.

Weed—A plant growing where it is not desired.

Weed Eradication—The complete elimination of all live plants, plant parts, and seeds of a weed infestation from an area.

Weed Control—The process of limiting weed infestations so that crops can be grown profitably or other operations can be conducted efficiently.

Winter Annual—A plant that starts germination in the fall, lives over winter, and completes its growth, including seed production, the following season. (Examples: chickweed, downy brome.) Many plants commonly known as annuals can also be classified as winter annuals, depending on time of germination, etc. (Also see annual.)