BASIC GUIDE TO WEEDS AND HERBICIDES

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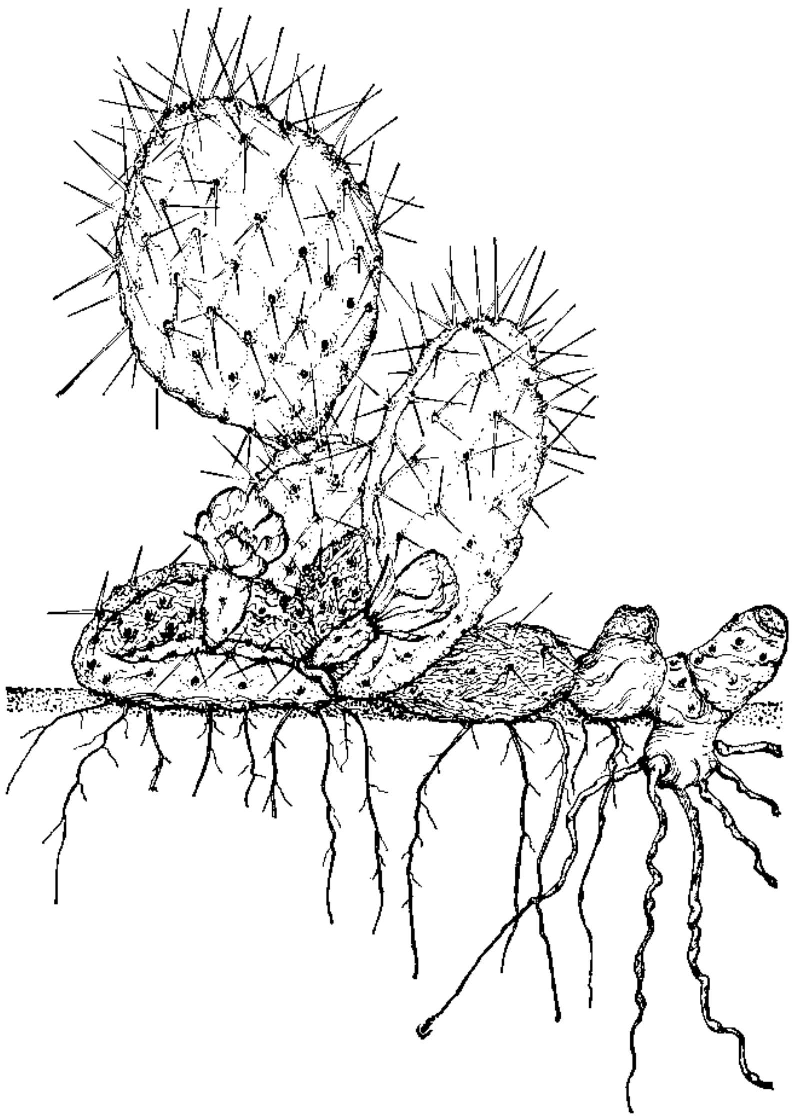

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Basic Guide to Weeds and Herbicides

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SECTION I - PRINCIPLES AND METHODS OF WEED CONTROL

INTRODUCTION

Recognition that a weed is a plant species growing where it is not desired, a plant out of place, or a plant that is more detrimental than beneficial, is a basic principle of weed control. Effective control of an individual species is dictated by the growth habits and methods of reproduction.

The growth habits in relation to climate, are extremely important in determining the period of greatest susceptibility of a plant species to a control practice within a particular crop. Weeds which have growth characteristics similar to the associated crop are often more difficult to selectively control.

Stage of growth, soil type, climatic conditions, crop, and species of weeds are important factors which influence control practices. Consideration of the location of the weed infestation such as crop land, rangeland, orchards, wasteland, or industrial site further confounds the selection of proper control measures. Thus, it is important to recognize that weed control is complex, and that basic principles should be utilized for maximum effectiveness in combating weeds.

WEED NAMES

Weeds and all plants for that matter have a scientific name and a common name. The first word of the scientific name is the genus, it is always capitalized. The second word is the species name. The genus and species are written in italics or underlined. The name or initial following the scientific name is called the authority. It represents the person or persons that described this particular genus and species. An example would be a weed with the common name leafy spurge and the scientific name *Euphorbia esula* L. L. stands for Carolus Linneaeus (1707-1778), founder of the modern plant classification system or the binomial system (genus and species).

Common names of weeds and other plants change from place to place. For example, *Agropyron repens* is called quackgrass by the Weed Science Society of America, wiregrass by Pennsylvanians, and couchgrass by Canadians and Britons. Scientific names may be awkward to use for the layman, however, they are preferred in scientific literature to avoid confusion. Efforts to standardize common names have only been partially successful.

LIFE CYCLES OF PLANTS AND CLASSIFICATION

In order to determine methods required to effectively control or eliminate an undesirable plant species, it is important to know the life cycle, i.e. length of time the plant lives, time of year it germinates and grows, and the type of reproductive capabilities the plant possesses. Plants are grouped according to three major types of life cycles:

1. Annuals are plants which complete their life cycle in less than one year. Annuals produce an abundance of seed since it is the sole source of survival. Most annual weed seeds will remain viable in the soil for one to seven years. Annual weeds are classified into two major categories:
   a. Summer annuals germinate in the spring, grow during the summer, produce seeds, and die in the fall. Seeds overwinter in the soil and germinate the next spring.
   b. Winter annuals germinate in the fall, grow and produce seed in the spring and early summer. The seed will lie in the soil during the summer months before germinating in fall.
2. Biennials are plants which live for more than one year but not more than two years. Biennials reproduce from seed only; however, they overwinter by means of a taproot system. Usually, seeds germinate one season and produce a rosette with a fleshy taproot. The plant elongates and produces flowers and seeds during the second growing season.
3. Perennials are plants which live for more than two years. Usually perennials do not produce seed the year of establishment. Most perennials reproduce by seed and many are able to spread by vegetative means. Perennials are classified according to their vegetative reproductive capabilities:
   a. Simple perennials are plants which reproduce almost solely by seed: however, they can produce new plants from cut pieces of vegetative parts. Simple perennials have no special means of reproduction (rhizomes or stolons). The taproots of these plants may become quite large and are usually fleshy.
   b. Bulbous perennials are plants which reproduce by bulbs, bulblets, and seed. Wild garlic produces aerial bulblets as the main means of reproduction, and also produces underground secondary bulbs. Death camas reproduces by seed, but established plants develop a deep bulb for nutrient storage and survival.
   c. Creeping perennials are plants which spread by means of specialized modified above-ground stems (stolons) or below-ground stems (rhizomes), as well as seed. Stolons and rhizomes produce vegetative buds which develop into independent plants. This group of plants is most difficult to control because of the diverse mechanisms for survival. In order to control creeping perennial weeds, seed production must be stopped and vegetative propagation must be curtailed by destroying both the above- and below-ground portions of the plant. Tillage implements drag rhizome and stolon sections throughout a field making containment more difficult.

WEED SEED GERMINATION

Germination includes several steps that result in the inactive embryo changing to a metabolically active embryo as it increases in size and emerges from the seed. It is associated with an uptake of water and oxygen, use of stored food and release of carbon dioxide. The seed must also have an environment favorable for this process. Specific requirements for seed germination differ for various species and although the requirements may be optimal a seed may not germinate because of some kind of dormancy.

WEED SEED DORMANCY

Dormancy is a type of resting stage for the seed and acts as a survival mechanism that prevents seeds from germinating when conditions for survival are poor. It may be innate, induced, or enforced.

INNATE DORMANCY

Innate dormancy inhibits germination at the time seeds are shed from the plant. After the seed shatters from the parent plant, time is required for immature embryos to develop, natural inhibitors to leach out, or extremes of temperature to crack hard seed coats and allow germination to occur.

INDUCED DORMANCY

Induced dormancy is a temporary dormancy that occurs when a seed is exposed to hot or cold temperatures or other environmental conditions. It continues after the environment changes and prevents germination during the wrong time of the year.

Often a period of after-ripening is required for the seed to germinate. The embryo may appear to be completely developed, but the seed will not germinate even though the seed coat has been removed to permit easy absorption of water and oxygen. Light and darkness have no effect. Occasionally cool temperatures for several months will end this type of dormancy.

Heat may induce dormancy in summer annuals like yellow foxtail and pigweed. This will prevent the seed from germinating in the fall. Cold temperatures during the fall and winter then break this dormancy allowing the seed to germinate in the spring when conditions are right. The process is reversed in winter annuals.

ENFORCED DORMANCY

Enforced dormancy is caused by unfavorable environmental conditions such as temperature, moisture, oxygen, light, and the presence of inhibitors. When these environmental limitations are removed, weed seeds will germinate freely.

CONTROL-PREVENTION-ERADICATION

CONTROL

Control is the process of containing and limiting weed infestations. There are six principle methods of control:

1. Mechanical control involves the use of tools to physically cut off, cover, or remove from the soil any plants that are undesired. Several methods are available:
   - a. Hand pulling is laborious and inefficient, although it can be effective on biennial and annual weeds. Most perennials are not effectively controlled by pulling because they are capable of producing new shoots from the root system.
   - b. Hoeing and spading are used to cut off small weeds.
   - c. Tillage (disturbing root systems) with mechanical implements can be utilized in two ways: 1) It is effective on small annual weeds as a means of severing or covering the plants. 2) Tillage can be used to disturb perennial root systems, however, multiple tillage operations are required for effective control.
   - d. Mowing will prevent seed production and reduce weed competition, but success depends upon proper timing. Mowing before flower buds form often prevents production of viable seed, but some plants, such as dandelion and perennial sowthistle, can still produce viable seed after the flower stalk has been cut off. However, it is ineffective on low-growing weeds. Multiple mowings of perennials may serve to deplete the root reserves, resulting in the death of the weed. Mowing can also result in stimulating dormant buds to produce new shoots which further reduces root reserves and sets the weed up for herbicide applications.
   - e. Flooding, where feasible, can be an effective method of weed control. It is a physical means of removing oxygen from the soil. Most annual and perennial weeds adapted to arid and semi-arid climates cannot tolerate prolonged flooding and will soon die.
   - f. Smothering is accomplished by placing a physical barrier, such as a black plastic sheet, at the soil surface which the weeds cannot penetrate. This prevents the weeds from emerging into the sunlight, which is needed for photosynthesis, and they will soon die. This method is often used in high value cash crops and in gardens around the home.
2. Crop competition is effective where the growth habits of the crop, in relation to the weed, favor the crop. The crop will compete more efficiently for sunlight, water, nutrients, and space than the weeds. This is probably the most economical and easiest method of weed control.
3. Biological control utilizes natural predators, with little or no harm to desired plants, to control weeds. Insects, diseases, parasitic plants, selective grazing, and competitive replacement plants are some examples of biological control agents. Often biological control is a cycle where the weed is removed and the predator agent population decreases as a result of the elimination of the food source. The weed

species may increase again until the predator population recovers sufficiently to control the weeds. This cycle continues until a balance occurs.

In Wyoming an introduced biological control agent, the musk thistle weevil, feeds on the seeds and will limit the spread of this weed. Also the larvae of the painted-lady butterfly has effectively defoliated Canada thistle in Wyoming.

4. Crop rotation can be a means of controlling weeds by providing a strong competitive crop on disturbed soil during all periods of a growing season. Weeds can flourish prior to crop establishment and after harvest. Early emerging crops can limit the growth of later germinating weeds. Farm managers should provide crop cover on cultivated areas during as much of the growing season as possible.

5. Fire is an effective tool for removal of unwanted vegetation. Intense heat can sear green vegetation which usually dries sufficiently in 10 to 14 days that complete burning can be accomplished. Burning can destroy weed seeds on the soil surface and emerging seedlings. Burning is more effective in controlling small annual weeds, but less effective on perennial species.

6. Chemicals are the most modern and efficient means for controlling unwanted plant species. Selective herbicides date back to the turn of the century, but the greatest advances have occurred in the last four decades. It is important to realize that herbicides are a product of modern technology and a tool for controlling weeds. However, chemicals are not a replacement for good management practices and conscientious farming.

PREVENTION

Prevention is forestalling the contamination of an area by a given plant species. This is the most practical method of controlling weeds. However, the task of implementing an effective prevention program requires extreme caution and alertness. Rules of an effective weed control program are:

1. Use clean seed.
2. Do not feed screenings, grain, or hay containing weed seeds without first destroying their viability by grinding, cooking or ensiling.
3. Do not use manure unless the viability of weed seeds have been destroyed by thorough fermentation, such as storing in a slurry tank for six months. About 90% of the weed seeds fed to a cow in hay or grain are destroyed by the animal's digestive system. A chicken destroys about 99% of any weed seed in the feed due to grinding in it's gizzard. As a result, chicken manure usually has fewer weed seeds than cattle manure.

4. Do not permit livestock from weed infested areas to move directly to clean areas. Barbed seeds, like those of burdock and cocklebur, become attached to animal hair, while others are eaten by domestic animals, pass through their digestive tracts and infest the field with weeds.
5. Clean harvesters, cleaners, hay balers, disks, plows, and other implements before moving them from weed infested areas.
6. Avoid use of sand, gravel, and soil from infested areas.
7. Inspect nursery stock for presence of weed seeds, and tubers and rhizomes of perennial weeds.
8. Keep banks of irrigation ditches and other waterways free from weeds. Most seeds can float for a short time, and some are small enough to be carried long distances by water.
9. Keep fence corners, fence lines, roadsides, and all other uncropped areas weed free.
10. Prevent the production of wind-borne weed seeds on any area. Seeds of some weeds such as dandelion and thistle are adapted for wind dispersal.

ERADICATION

Eradication is the complete elimination of all live plants, plant parts and seeds of the target species from an area. True eradication may be difficult since all living plants and seeds (sources for reinfestation) must be destroyed. Eradication is usually only economical under conditions where small areas are infested with perennial weeds.

HERBICIDE RESISTANCE IN WEEDS

Weed resistance to herbicides is a common occurrence in nature. It also occurs with other pesticides in insects and fungi. Resistant strains develop when a particular pesticide is used repeatedly on the same pest. Such use selects for naturally occurring resistant individuals, allowing them to multiply over several seasons until they become a major threat.

The Weed Science Society of America has a committee that documents and studies herbicide resistant weeds. This committee has found at least 46 species of weeds that are resistant to at least six different herbicide classes.

Also, weed biotypes that are resistant to a certain herbicide mode of action have a good chance of being resistant to other herbicides that have the same mode of action.

TYPES OF RESISTANCE

1. Genetic mutation. This is where the herbicide has actually caused a change in the genetic makeup of the weed enabling it to survive the attack of the herbicide. This form of resistance is rare.
2. Naturally occurring herbicide resistant biotypes (individuals of a given species which have a slightly different genetic makeup). This is where a small population of resistant biotypes or weeds of the same species already occurs within the total population. When a herbicide is

applied to this weed population the resistant individuals survive and reproduce, thus developing a large population of resistant weeds. The resistant biotypes may develop over a short period of time.

It is almost certain that all herbicide resistance known to date is with naturally occurring herbicide resistant biotypes.

FACTORS FAVORING DEVELOPMENT OF HERBICIDE RESISTANT WEEDS

There are several factors that favor the rapid development of a herbicide resistant weed population.

1) The presence of naturally occurring resistant biotypes within the native weed population. If there are a large number of resistant biotypes in the total population resistance will occur rapidly.

2) Monoculture cropping practices. Use of the same herbicide or herbicides on the same crop, on the same fields, and on the same weeds year after year sets up an ideal environment for resistant biotypes to rapidly spread.

3) The continual use of highly effective herbicides. Highly effective herbicides will control almost all of the susceptible biotypes in a given weed population. Therefore, the initial small number of resistant biotypes not controlled by the herbicide goes unnoticed because the overall level of control is so high. Controlling the susceptible biotypes reduces the amount of seed returned to the soil, giving the resistant biotypes a competitive advantage and enabling them to multiply until they dominate the population.

By using less effective herbicides more susceptible biotypes survive and set seed. This keeps the ratio of susceptible biotypes to resistant biotypes very high and will prevent the resistant biotypes from becoming dominant.

4) The continual and repeated use of long residual herbicides. When susceptible biotypes are controlled over a long period of time, the soil reservoir of susceptible seed becomes depleted and replaced by seed from resistant biotypes.

MANAGEMENT OF HERBICIDE RESISTANT WEEDS

The following guidelines will help to prevent or delay herbicide resistant weeds from becoming an economic problem.

1. Use crop rotation. Often crop rotation means that a wide variety of herbicides will be used in a weed control program, which will make it difficult for resistant biotypes to increase.
2. Use tankmixes or sequential treatments. Using tankmixes or sequential treatments involving herbicides with different modes of action on the same spectrum of weeds will limit resistant biotypes.
3. Use short residual herbicides rather than long residual herbicides or use long residual herbicides sparingly.
4. Use other weed control methods in conjunction with, or as a replacement for, herbicides whenever possible.

The following are some documented cases of certain weeds resistant to specific herbicides.

RESISTANT WEED	HERBICIDE	YEAR REPORTED	LOCATION
Dandelion	2,4-D	1950's	Belgium
Downy brome	atrazine	1977	Nebraska
Groundsel, common	atrazine	1968	Washington
Kochia	atrazine	1976	Idaho
Kochia	chlorsulfuron (Glean)	1988	ND, CO, KS
Lambsquarters	atrazine	1970	Canada
Lettuce, prickly	chlorsulfuron (Glean)	1987	Idaho
Pigweed	atrazine	1972	Maryland
Thistle, Russian	chlorsulfuron (Glean)	1988	ND, CO, KS

SECTION II - HERBICIDE CLASSIFICATION

HERBICIDES

Herbicides are pesticides used to kill plants or interrupt normal plant growth. During the last 40 years they have largely replaced mechanical methods of weed control. Herbicides provide a more effective means for weed control than cultivation, hoeing, and hand pulling. Herbicides along with other agriculture chemicals, such as fertilizers, and pesticides are one of the methods available to combat rising costs and the shortage of labor. Most heavy herbicide use is confined to North America, Western Europe, Japan, and Australia.

Herbicides may be selective or non-selective depending on how and when they are used. In addition to classification based on selectivity herbicides may also be classified based on time of application, area covered, mode of action, and chemical structure.

SELECTIVE HERBICIDES

Selective herbicides are chemicals which can remove certain plant species with little or no damage to other species. Selectivity is usually obtained as a result of the way the herbicide is used. The selectivity of a chemical is not absolute and may depend on the following: a) The amount of chemical applied. b) The way it is applied. c)

The degree of wetting the foliage. d) The precipitation following treatment. e) The inherent tolerance of a plant species to a specific herbicide. f) Differences in growth habits of crops and weeds.

Since selectivity of a herbicide can depend on all of the above factors, a chemical may be utilized as a selective or non-selective treatment depending on the intended use. For example 2,4-D can control grass seedlings although the primary use is the selective control of broadleaf weeds in grass crops. Atrazine at high rates is an effective soil sterilant even though its primary use is selective weed control in corn.

NON-SELECTIVE HERBICIDES

Non-selective herbicides are chemicals which are toxic to all plants. They may be used to remove a wide range of vegetation from an area. When no selectivity is intended, these chemicals can be used for vegetation control along fence rows, around pipe lines, traffic signs, storage areas, parking lots, and other areas where total vegetation control is desired.

TIME OF APPLICATION

There are several methods of herbicide application based on when they are applied. These include preplant incorporated, preplant, preemergence, postemergence, and lay-by.

Preplant incorporated is when the herbicide is applied to the soil and incorporated before a crop is planted.

Preplant is an herbicide application prior to planting a crop.

Preemergence is an herbicide application after planting the crop but prior to crop or weed emergence.

Postemergence applications occur after crop or weed emergence.

Lay-by treatments are applications of herbicides after the last cultivation.

These terms normally refer to application in relation to crops; however, they may also allude to application in relation to weeds. Always be certain whether reference is being made to the crop or to the weed.

HERBICIDE APPLICATION METHOD

Herbicides may be applied: band, broadcast, spot treatments, and directed spraying. A band treats a narrow strip along or over the crop row. Broadcast applications cover the entire area. Spot treatments are confined to small areas of weeds. Directed sprays are applied between crop rows to selected weeds or to the soil to avoid contact with the crop.

MODE OF ACTION

The mode of action refers to the chemical interaction which interrupts a biological process necessary for plant growth. When related to herbicides it is the chain of events, from the first contact of the herbicide with the plant to its final effect, which often lead to the death of the plant.

TRANSLOCATED HERBICIDES

Translocated or systemic herbicides are absorbed by either roots or above ground plant parts and are then distributed throughout the plant system. For effective control uniform application is required, whereas complete coverage is not. Classification of translocated herbicides can be divided into five areas: Herbicides that 1) regulate growth, 2) inhibit enzyme activity, 3) inhibit meristematic activity, 4) inhibit photosynthesis, and 5) herbicides that inhibit cell division and growth.

HERBICIDES THAT REGULATE GROWTH

Phenoxys: 2,4-D; 2,4-DB; 2,4DP; MCPA; MCPB; MCPP
Benzoic acids: dicamba (Clarity, Banvel)
Picolinic acids: clopyralid (Stinger), picloram (Tordon), triclopyr (Garlon)

These herbicides upset normal plant growth by causing cells of leafy veins to rapidly divide and elongate, while cells between veins cease to divide resulting in long, narrow strap-like young leaves. Water content also increases making plants brittle. Cell division and respiration rates increase and photosynthesis increases. Roots lose their ability to take up soil nutrients and stem tissues no longer move food through the plant.

Injury symptoms. Broadleaves: leaves malformed; leaf veins appear parallel rather than netted; stems become crooked, brittle, with shortened internodes.

Grasses: new leaves do not unfurl, appear onion-like; stems brittle, curved, or crooked, with short internodes; fusion of brace roots.

HERBICIDES THAT INHIBIT ENZYME ACTIVITY

Non-classified organic herbicides: glyphosate (Roundup), dalapon (Dowpon M)
Imidazolinones: imazapyr (Arsenal), imazaquin (Scepter), imazethapyr (Pursuit), AC-222,293 (Assert)
Sulfonyl ureas: benzsulfuron (Londax), chlorimuron (Classic), chlorsulfuron (Glean, Telar), metsulfuron (Ally, Escort), sulfometuron (Oust), thiameturon (Harmony), DPX-L5300 (Express)

These herbicides work by inhibiting the action of one or more enzymes that catalyze chemical reactions in the plant. This leads to the shutdown of metabolic activity in the plant, causing the eventual death of the plant.

Injury symptoms. Sensitive plants stop growth almost immediately; become straw colored, turn brown and die; seedlings die in two to four days; established perennials in two to four weeks.

HERBICIDES THAT INHIBIT MERISTEMATIC ACTIVITY

Aryl-oxy-phenoxys: clethodim (Select), diclofop (Hoelon), fenoxaprop (Acclaim, Whip), fluazifop-P (Fusilade 2000), haloxyfop (Verdict), quizalofop (Assure)
Similar chemistry: sethoxydim (Poast), mefluidide (Vistar, Embark)

These herbicides are rapidly absorbed by grasses and are translocated to the growing points where they inhibit meristematic activity. This leads to an immediate stoppage of growth. They are most effective on warm-season grasses such as shattercane, corn, fall panicum, giant foxtail, crabgrass, and wild proso millet. Cool-season grasses like quackgrass, orchardgrass, timothy, and small grains are not as sensitive. These herbicides are not effective on broadleaf weeds.

Injury symptoms. Grasses: Growing points are killed first, resulting in the death of the inner whorl of the leaf; often turn a purplish color.

HERBICIDES THAT INHIBIT PHOTOSYNTHESIS

Triazines: atrazine (various), cyanazine (Bladex), simazine (Princep), propazine (Milogard), ametryn (Evik), metribuzin (Sencor, Lexone), prometon (Pramitol), hexazinone (Velpar)
Substituted ureas: linuron (Lorox), diuron (Karmex), chloroxuron (Tenoran), fluometuron (Cotoran), fenuron + TCA (Urab), monuron + TCA (Urox), tebuthiuron (Spike)
Uracils: terbacil (Sinbar), bromacil (Hyvar X)
Phenyl carbamates: desmedipham (Betanex), phenmedipham (Betanal)
Other chemistry: amitrole (Amitrol), bentazon (Basagran), clomazone (Command), propanil (Stam), pyrazon (Pyramin)

Photosynthesis is the process by which chlorophyll-containing cells in green plants use the energy of light to synthesize carbohydrates from carbon dioxide and water. This mechanism is the plant food processing system, when it breaks down the plant slowly starves to death. The above herbicides all inhibit photosynthesis. The triazines, substituted ureas, uracils, and phenyl carbamates block chlorophyll electron replacement. Amitrol and clomazone inhibit pigment formation. When used as preemergence herbicides they allow seeds to germinate normally but cause them to lose their green color, after which they soon die of starvation. These herbicides are more effective on seedlings than established plants.

Injury symptoms. Broadleaves: leaves become mottled, turn yellow to brown, (white to brown with amitrole and clomazone).
Grasses: leaves turn light green to white.
Herbaceous and woody perennials: due to large root reserves they are able to survive for long periods of time; plants may lose their leaves several times before death occurs.

HERBICIDES THAT INHIBIT CELL DIVISION AND GROWTH

Phenyl carbamates: chlorpropham (Furloe, CIPC), propham (Chem-hoe), asulam (Asulox)
Thiocarbamates: EPTC + safener + extender (Eradicane extra), EPTC (Eptam), butylate + safener (Sutan$^+$), vernolate (Vernam), pebulate (Tillam), cycloate (Ro-Neet), diallate (Avadex), triallate (Avadex BW, Far-go)
Substituted amides: alachlor (Lasso), metolachlor (Dual), acetochlor (Harness), propachlor (Ramrod), napropamide (Devrinol), CDAA (Randox), pronamide (Kerb), diphenamid (Enide)
Nitriles: dichlobenil (Casoron, Dyclomec, Norosac)
Dinitroanilines: trifluralin (Treflan), Benefin (Balan), fluchloralin (Basalin), isopropalin (Paarlan), oryzalin (Surflan), pendimethalin (Prowl, Stomp), dinitramine (Cobex)
Other chemistry: bensulide (Prefar, Betasan), siduron (Tupersan)

With the exception of the dinitroanilines and bensulide and siduron, these herbicides cause abnormal cell development or prevent cell division in germinating seedlings in the shoot and root tips. Plants slowly lose their vigor.

Injury symptoms: Broadleaves: leaves turn dark green, become wrinkled, fail to unfold from the bud; roots become shortened, thickened, brittle, clublike.
Grasses: germinating seedlings do not emerge, in those that do emerge leaves fail to unfold, resulting in leaf looping, onion-like appearance; tip of terminal leave becomes rigid instead of flag-like.

The dinitroanilines and bensulide and siduron prevent cell division in developing root tips and are effective only on germinating grasses and some broadleaves.

Injury symptoms. Broadleaves: seeds germinate but fail to emerge or emerge as stunted seedlings; seedlings that do emerge have thickened, shortened lower stems, small leaves, and short, club-shaped roots; seedlings of taprooted plants such as alfalfa are not affected, nor are established plants.
Grasses: seeds germinate but usually fail to emerge; injured seedlings have short club-shaped roots and thickened, brittle stem tissue.

CONTACT HERBICIDES

Contact herbicides are chemicals that do not translocate or move in the plant. They kill only the plants or portions of the plant actually contacted by the herbicide. They are generally more effective on annual weeds, rather than perennial weeds. Some are inactivated in the soil, and must be applied to the foliage. For effective control adequate coverage of the foliage is essential.

FOLIAR APPLIED CONTACT HERBICIDES

Bipyridyliums: paraquat (Gramoxone), diquat (Ortho Diquat)
Selective oils: Stodard's solvent
Nonselective oils: kerosene, fuel oil, diesel oil
Dephenyl ethers: acifluorfen (Blazer, Tackle)
Other chemistry: ametryn (Evik), bentazon (Basagran), bromoxynil (Buctril), difenzoquat methyl sulfate (Avenge), endothall (Endothal, Aquathol, Hydrothal), linuron (Lorox), pyridate (Tough, Lentagran)

FOLIAR OR SOIL APPLIED CONTACT HERBICIDES

Diphenyl ethers: oxyfluorfen (Goal)
Other chemistry: oxadiazon (Ronstar)
Inorganic herbicides: sodium chlorate (Sodium Chlorate), sodium borate (Polybor), mixtures of sodium chlorate and borate
Injury symptoms. Cause cellular breakdown by destroying cell membranes, allowing cell sap to leak out. Paraquat, diquat, linuron, ametryn, and pyridate can also have a secondary effect in which they inhibit photosynthesis by causing a buildup of toxic materials.

SOIL STERILANTS

Soil sterilants are chemicals that keep the soil free of vegetation for one or more years. The length of time soil remains sterile depends on the herbicide used, application rate, rainfall, and soil type and composition. Many herbicides can be used as soil sterilants if used at high enough rates.
Organic herbicides: prometon (Pramitol), monuron TCA (Urox), tebuthiuron (Spike), bromacil (Hyvar X)
Inorganic herbicides: sodium chlorate (Sodium Chlorate), sodium borate (Polybor), mixtures of sodium chlorate and borate.
Injury symptoms. The organics are photosynthetic inhibitors and produce symptoms as describe previously. The inorganics are contact herbicides and kill plant tissue in a few hours or days.

SOIL FUMIGANTS

Soil fumigants are highly toxic, volatile liquids or gases used to fumigate for soil pests. Most fumigants must be released under a gas tight cover to prevent vapor escape. After 24 to 48 hours the cover can be removed and the remaining gasses allowed to escape. After a time all vapors will dissipate leaving no active residue. The area will remain weed free until weed seed is reintroduced or deeply buried seed is brought to the surface.
Organic herbicides: chloropicrin (Picfume, Larvicide 100, Clor-O-Pic), chloropicrin + methyl bromide (Dowfume, Brom-O-Gas), metham (Vapam), methyl bromide (Meth-O-Gas)
Injury symptoms. vapors penetrate 4 to 6 inches killing weed seeds, weeds, nematodes, fungi, and insects; weeds turn brown and die.

CHEMICAL STRUCTURE

I. Aromatic carboxylic acids
    1. Phenoxy herbicides: 2,4-D (various); 2,4-DB (Butyrac 200, Butoxone); 2,4-DP, dichlorprop (various); MCPA (various); MCPB (Can-trol, This-trol); MCPP, mecoprop (various)
    2. Benzoic acids: chloramben (Amiben); dicamba (Banvel)
    3. Phthalic acids: DCPA (Dacthal); naptalam (Alanap)
    4. Picolinic acids: clopyralid (Lontrel); picloram (Tordon); triclopyr (Garlon)

II. Aryl-oxy-phenoxys: clethodim (Select); diclofop (Hoelon); fenoxaprop (Acclaim, Whip); fluazifop-P (Fusilade 2000); haloxyfop (Verdict); quizalofop (Assure)

III. Aliphatic acids: dalapon (Dowpon M); TCA (Sodium TCA)

IV. Organic arsenicals: AMA(Super-dal-e-rad); CMA; DSMA (Ansar, Weed-e-rad); MSMA (Ansar, Bueno, Daconate, Weed-hoe, Weed-e-rad); cacodylic acid (Phytar 560, Rad-E-Cate)

V. Heterocyclic nitrogen derivatives
    1. Triazines: ametryn (Evik); atrazine (various); cyanazine (Bladex); hexazinone (Velpar); metribuzin (Lexone, Sencor); prometon (Pramitol); prometryn (Caparol); propazine (Milogard); simazine (Princep)
    2. Sulfonyl ureas: benzsulfuron (Londax); chlorimuron (Classic); chlorsulfuron (Glean, Telar); metsulfuron (Ally, Escort); sulfometuron (Oust); thiameturon (Harmony); DPX-L5300 (Express)
    3. Imadazolinones: imazapyr (Arsenal); imazaquin (Scepter); imazethapyr (Pursuit), imazapic (Plateau), AC-222,293 (Assert)
    4. Uracils: bromacil (Hyvar X); terbacil (Sinbar)
    5. Diphenyl ethers: acifluorfen (Blazer); bifenox (Mowdown); oxyfluorfen (Goal)
    6. Bipyridyliums: diquat (Ortho Diquat); paraquat (Gramoxone)

7. Other heterocyclic nitrogen derivatives: amitrole (Amitrol); bentazon (Basagran); maleic hydrazide (MH-30)

VI. Aliphatic nitrogen derivatives

1. Ureas: chloroxuron (Tenoran); diuron (Karmex); fenuron; linuron (Lorox, Lenex); monuron; siduron (Tupersan); tebuthiuron (Spike)
2. Amides: acetochlor (Harness); alachlor (Lasso); CDAA (Randox); diphenamid (Enide); metolachlor (Dual); napropamide (Devrinol); pronamide (Kerb); propachlor (Ramrod); propanil (Stam)
3. Phenyl carbamates: asulam (Asulox); barban (Carbyne); chlorpropham (Chloro IPC, Furloe); desmedipham (Betanex); phenmedipham (Betanal); propham (IPC, Chem-Hoe)

VII. Thiocarbamates: butylate (Sutan); butylate + safener (Sutan$^+$); cycloate (Ro-Neet); diallate (Avadex); EPTC (Eptam); EPTC + safener (Eradicane); EPTC + safener + extender (Eradicane Extra); pebulate (Tillam); triallate (Avadex BW, Far-go); vernolate (Vernam)

VIII. Dinitroanilines: benefin (Balan); dinitramine (Cobex); fluchloralin (Basalin); isopropalin (Paarlan); oryzalin (Surflan); pendimethalin (Prowl, Stomp); trifluralin (Treflan)

IX. Substituted nitriles: bromoxynil (Buctril); dichlobenil (Casoron, Dyclomec, Norosac)

X. Nonclassified organics: bensulide (Betasan, Prefar); chloropicrin (Picfume, Larvicide 100, Clor-O-Pic); chloropicrin + methyl bromide (Brom-O-Gas, Dowfume); clomazone (Command); diesel oil; endothall (Endothall, Aquathal); fuel oil; glyphosate (Roundup, Ranger, Rodeo); kerosene; metham (Vapam); methyl bromide (Meth-O-Gas); oxadiazon (Ronstar); pyridate (Tough, Lentagran); Stoddard's solvent

XI. Nonclassified inorganics: sodium borate (Polybor); sodium chlorate (Sodium Chlorate)

TYPES OF HERBICIDE TREATMENTS

FOLIAGE TREATMENTS

Foliage treatments are herbicide applications to the leaves of growing plants usually as sprays, mists, or dusts. Types of foliage treatments include contact and translocated herbicides.

SOIL TREATMENTS

Soil treatments are herbicide applications to the soil. These may also be contact or translocated chemicals. To be effective, the chemical must be carried into the soil by irrigation or rainfall in order to be absorbed by the root system of the weed. Selectivity can be obtained by specific location of the herbicide in the soil, by crop tolerance, stage of growth, or timing.

HERBICIDE FORMULATIONS

Formulations may affect selectivity and activity of a herbicide. Application methods and equipment can vary greatly depending upon the type of herbicide formulation selected for a weed control practice. Herbicides are not sold as pure chemicals but as mixtures or formulations of one or more herbicides with various additives. The type of formulation determines toxicity to plants, uniformity of plant coverage, stability in storage, handling, effectiveness, and safety.

1. **Soluble salts** form true solutions. They are compounds which dissolve in water and require little or no agitation to stay in solution. These do not become milky when diluted with water. These may have several abbreviations: S = solution, SC = soluble concentrate, L = liquid, and WSC = water soluble concentrate. Dalapon and 2,4-D amine are examples of soluble herbicides.

2. **Emulsifiable concentrates** (EC) appear milky when mixed with water. The emulsifiable material breaks up into small droplets that are suspended in the water. These are called normal or oil-in-water emulsions. There are also a few rare formulations of invert emulsions, which are water-in-oil suspensions. These may resemble salad dressing or face cream. Ester formulations are soluble in oil carriers. Since the emulsifiable formulations are insoluble in water, some agitation may be necessary which can usually be accomplished with the by-pass flow from the pump. Without agitation the liquids may separate.

Emulsifiable concentrates, when properly formulated should remain in suspension, in water, for at least 24 hours without further agitation.

Each gallon of emulsifiable concentrate usually contains 4 to 7 pounds of a petroleum solvent such as xylene. Because of the solvents in emulsifiable concentrates they can cause foliage burning at high temperatures (> 90 F).

An example of an emulsifiable concentrate is 2,4-D ester dispersed in water.

3. **Wettable powders** (WP) are finely ground, insoluble materials that are suspended in water. They contain a wetting agent to aid in the mixing of the powder with water before spraying. Without the wetting agent the mixture would float, making it almost impossible to mix in water. Wettable powder formulations usually contain 50 to 75% clay or talc, therefore, they will sink rapidly to the bottom of the spray tank unless agitated constantly. In order to maintain a uniform application rate, mechanical, or jet agitation in the spray tank must be provided. Slurries of the wettable powders and water mixed together prior to adding

to the spray tank may eliminate the problem of getting the formulation into suspension. Wettable powders will not burn foliage, even at high concentration. An example is atrazine 80W.

4. **Dry flowables** (DF) or water dispersible granules are wettable powders formed into prills so they pour easily into the sprayer tank without clumping. Nearly insoluble, they require agitation to remain in suspension. Atrazine may also be formulated as a dry flowable.

5. **Flowables** (F) or water dispersible liquids are wettable powders already suspended in water so they can be poured. Flowables are nearly insoluble in water, so require agitation to remain in suspension. Atrazine is also formulated as a flowable.

6. **Water soluble powders** (SP) or dry soluble powders (DS) form true solutions in water and require no agitation. Chloramben (Amiben) is an example of a soluble powder.

7. **Ultra-Low-Volume Concentrates** (ULV) are usually the technical product in its original liquid form. They are usually applied without further dilution in special aerial or ground equipment at rates of one-half pint to one-half gallon per acre as an extremely fine spray. Small droplets from ULV spraying may cause drift problems.

8. **Granules** are formulated by adhering the herbicide to a dry material such as clay, fertilizer, lime, vermiculite, or ground corn cobs. They range from 2% to 25% active ingredient. Granules are applied dry to the soil, they usually require more rainfall for activation than sprays. Advantages of granules are that no water is required for application, application equipment is inexpensive, they are not subject to the drift problems that sprays are, therefore, they may be applied anytime of the day. Some disadvantages are that they are bulky, heavy, expensive to ship, and application is not as uniform as sprays.

9. **Pellets** are like granular formulations, but are compressed into larger cylinders about 1/4 inch long. They are usually hand-applied to control clumps of brush.

10. **Dusts** are finely ground formulations of a herbicide that are blown onto the foliage of the plants. This method of application is nearly non-existent because of the extreme drift problem and the resulting hazard to adjacent crops.

11. **Fumigants** are used in horticultural nurseries, greenhouses, and on high-value cropland to control weed seeds and other soil pests. They come as liquids in pressurized containers and must be injected or released under a gas tight tarp to prevent loss to the air.

SURFACE ACTIVE AGENTS (SURFACTANTS)

Surfactants are chemicals that produce physical changes at the surface of liquids, because the changes they produce occur at surfaces they are also known as "surface active agents". They include wetting agents, emulsifiers, detergents, spreaders, sticking agents (stickers), dispersing agents, and other surface-modifying agents. They are commonly used in herbicide formulations to increase the effectiveness of the spray solution and herbicide formulation.

Surfactants may increase or decrease the phytotoxicity of an herbicide, therefore, an applicator should not add any surfactant to an herbicide formulation unless recommended by the manufacturer.

Water is not compatible with many of the chemicals used as herbicides. It will not mix with oil or oil-like substances. By adding a surfactant (emulsifying agent) to the oil, the herbicide can be mixed with water to form an oil-in-water emulsion and can then be easily sprayed.

Water is also repelled by the wax-like cuticle of plants. By adding a surfactant (wetting agent) to the herbicide the surface tension of the herbicide-water mixture is reduced allowing more surface area of the herbicide solution to come into contact with the plant surface, thus increasing its effectiveness.

When considering surfactants there are four surface relationships that must be taken into account.

1. Liquid to liquid. An example would be oil dispersed in water by agitation to form an emulsion or an ester formulation of 2,4-D suspended in water.
2. Solid to liquid. An example would be clay suspended in water, or a wettable powder herbicide suspended in water.
3. Solid to air. Carbon in the air to form smoke or a pesticide dust particle suspended in the air would be examples.
4. Liquid to air. An example would be fog, which is tiny water droplets suspended in air, or herbicide spray droplets in the air.

Water has a tendency to be repelled by other liquids in a suspension or emulsion, or by the solid forming the suspension. For the materials to stay in suspension a substance is needed that has an affinity for both the water and other material so that the two materials will be bound. A surfactant will modify the surface interfaces of the above relationships by orienting itself between the two surfaces so they are bonded in a more intimate contact, thus enabling the materials to remain in suspension.

A substance will generally have surfactant activity if it contains a strongly polar group that is attracted to water (hydrophilic) and a nonpolar group that is attracted to oils, fats, and waxes (lipophilic).

TYPES OF SURFACTANTS

Surfactants are classified into three categories, depending on their ionization or dissociation in water. This is the ability of the substance to become positively (cationic) or negatively (anionic) charged:

1. **Anionic surfactants**. In these surfactants the anion (-) part of the molecule exerts the predominant influence. They are often used in herbicide formulations alone or in

combination with nonionic surfactants. A disadvantage is that they may react with other charged particles (ions), including the herbicide itself, in the formulation or spray solution, thus reducing its effectiveness. Anionic surfactants make excellent wetting agents and are also good detergents.

2. **Cationic surfactants**. In these surfactants the cation (+) part of the molecule exerts the predominant influence. They are derived from ammonia and are not usually used in herbicide formulations. They are often phytotoxic and are very effective bactericides. A major disadvantage is that they precipitate readily in hard water and are poor detergents.

3. **Nonionic surfactants**. These surfactants do not ionize or become charged in water solutions. Therefore, they are unaffected by hard water, in other words, they do not form insoluble salts with calcium, magnesium, or iron ions that occur in hard water. They can also be used in acid solutions. These are a relatively new group of surfactants being developed mostly in the 1960's. They now make up a large portion of the surfactant market. An outstanding property of nonionic surfactants is that they make excellent emulsifiers, forming stable emulsions. As a result, these surfactants are often used as emulsifiers in emulsifiable concentrate herbicide formulations. They also make good dispersing agents, excellent detergents, and foam less than anionic surfactants. They are more soluble in cold water than hot water. They are usually blended with anionic surfactants to improve the wetting properties of EC type formulations.

SURFACTANT EFFECTS ON PLANTS

The usual action of a surfactant is to increase the activity of a foliar applied herbicide, however, in some cases the selectivity of the herbicide is lost.

They also favor uniform spreading of the spray solution, resulting in uniform wetting of the plant.

Surfactants let spray droplets stick to the plant, resulting in less bounce-off.

Droplets do not become suspended on hairs, scales or other projections on the leaf surface, thus allowing the herbicide solution to make intimate contact with the plant surface. As a result, substances such as the waxy cuticle or the fatty portion of the cell wall may be altered so the plant readily absorbs the herbicide

SECTION III - HERBICIDE SELECTIVITY

A selective herbicide is a chemical that is more toxic to one plant than to another. When such a herbicide is applied to a mixture of plants, some may be killed and others may be affected only slightly or not at all.

There are many factors which influence the selectivity and activity of herbicides. A knowledge of these factors is necessary to make proper herbicide selection and use. Selectivity is relative; it depends upon proper use of the specific herbicide.

The most important selectivity factors are: 1) morphological or structural differences; 2) absorption; 3) translocation; and 4) physiological differences.

MORPHOLOGICAL OR STRUCTURAL DIFFERENCES

Structural differences permit selective application of herbicides, protection of the plants growing region from herbicidal injury, and involvement of plant surface differences or orientation of plant parts which may affect spray retention and herbicide absorption.

Tall plants with chemically tolerant stems permit easy application of herbicides to weeds near the ground level. For instance herbicides are often applied to weeds and brush under tall trees without injury to them. Also drop nozzles are used to spray weeds in sensitive crops such as cotton, corn, and sorghum. The herbicide is sprayed close to the ground and only contacts the resistant stems of the crop plants.

The location of the plants' growing point can also be important. Broadleaf plants have exposed growing points at the tips of the shoots and in the axil of the leaves. In contrast, the growing points of grasses are located at the base of the plant and are protected by the surrounding leaves and in some cases may actually be below the soil surface.

Perennial plants are often dormant during the winter months. During this time winter annuals can be controlled before the perennial crop emerges. Also, deep-rooted plants are often tolerant to chemicals which remain primarily in the soil surface allowing shallow-rooted weeds to be killed. Annual weed control in dormant alfalfa is a good example.

The waxiness, hairiness, or pubescence of a plant may prevent spray droplets from adhering to the leaf. If the droplets adhere, they may dry on wax scales or on the hair without coming in contact with the leaf epidermis, thus preventing absorption. Hairiness may also increase herbicidal effectiveness. The hair may become saturated, increasing the quantity of the chemical spray held on the surface and reducing run-off.

ABSORPTION

Absorption is the movement of a material into the plant from an external source (usually the leaves and roots).

To be effective herbicides must enter the plant. Some plant surfaces absorb herbicides quickly, while other plant surfaces absorb slowly or not at all. The chemical nature of the herbicide is also involved. Therefore, differential absorption or selective absorption may account for differences in plant responses.

Initial leaf penetration of the herbicide may take place through the leaf surface or through the stomates. The volatile fumes of some herbicides and some solutions enter through the stomates; however, of far greater importance is the direct penetration of the leaf surface. To be effective the herbicide must penetrate the cuticle layer and cell walls.

The polarity of the leaf surface and herbicide used is important. The waxy cuticle and cellulose of the plant leaves and stems are nonpolar. Most organic substances are nonpolar. Included in the nonpolar group are oils, waxes, and 2,4-D ester, etc. Polar compounds include water, amino acids and salts of 2,4-D, etc. Nonpolar compounds tend to be absorbed into the leaves faster than the polar herbicides.

The addition of wetting agents may reduce the selectivity of the herbicide. A wetting agent tends to equalize foliar herbicide absorption in all types of plants. Wetting agents may also reduce the selectivity of the herbicide if the selectivity is dependent upon selective foliar absorption.

An increase in temperature is usually associated with more rapid absorption. Within limits, the rate of chemical processes tend to double with each 17 F increase.

Many herbicides are absorbed from the soil through the roots. In general, roots are best adapted to absorbing polar substances, and absorb nonpolar substances slowly or not at all. Upon contact with the soil, non-polar substances may be converted to a polar form. Picloram (Tordon) and dicamba (Banvel) are examples of root-absorbed herbicides.

Plant cells that are rapidly growing have a high rate of respiration. The factors that favor rapid growth also favor quick nutrient absorption, which also favors quick herbicide absorption.

TRANSLOCATION DIFFERENCES

Translocation of herbicides is a major problem in the control of deep-rooted perennial weeds. For effective weed control, herbicides must move through the phloem (food conducting tissue), through the xylem (water conducting tissue), and in the space between the cells (intercellular). Movement may take place from one of these systems to another system within the plant.

TRANSLOCATION THROUGH THE PHLOEM

Phloem tissues are composed of living cells. High rates of extremely toxic herbicides can kill the cells, stopping translocation. Movement in the phloem is generally from the leaves to the roots. Translocation is most rapid and most effective when large amounts of food reserves are being moved towards the roots. This usually occurs after full leaf development. It has been shown that 2,4-D can move from the leaves to the roots at rates up to 40 inches per hour. For effective weed control low rates, with repeated applications, usually give better results, because plant cells are killed slowly giving the herbicide time to be translocated throughout the plant. Uniform application is more important than the amount of carrier used.

TRANSLOCATION THROUGH THE XYLEM

In the xylem herbicides move from the soil through the roots and upward along with water and nutrients. An herbicide absorbed in a lateral leaf may be first translocated in the phloem to the xylem, then carried upward in the xylem. Conductive tissue of the xylem is non-living, therefore, high rates of toxic herbicides can be absorbed from the soil and translocated to all parts of the plant. Absorption and translocation may occur even though the roots have been killed.

Studies indicate that the following three conditions must exist for translocation downward through the xylem to be effective. a) There must be a water deficit within the plant; b) the herbicide must render the tissues permeable between points of application and the xylem; and c) the plant must be exposed long enough to permit the herbicide to penetrate.

INTERCELLULAR TRANSLOCATION

Non-polar substances may move through the plants' intercellular spaces. Oils may be absorbed by the plant through the cuticle, epidermis, bark, stomata and even injured roots. After they are absorbed the oils may move in any direction -- up, down, or radial. It is generally believed that oil generally moves through the intercellular spaces and that 2,4-D esters applied in oil will act similarly.

PHYSIOLOGICAL DIFFERENCES

Scientists only partially understand the physiological differences which account for selective herbicidal toxicity. Differences in enzyme systems, response to Ph changes, cell metabolism, cell permeability, variation in chemical constituents, and polarity may be involved. A change in one or more of these factors may either stimulate or block certain biochemical processes. For instance, an enzyme reaction may be blocked in one plant species but not in another. Activation of inactive 2,4-DB into active 2,4-D is one example. Small-seeded legumes have the ability to slowly metabolize 2,4-DB (Butoxone, Butyrac) into 2,4-D, while in most broadleaf weed this reaction takes place rapidly. Thus, most broadleaf weeds are controlled, whereas the small-seeded legumes are not injured. Corn has the ability to metabolize atrazine into a harmless chemical, whereas the target weeds do not.

The basic fundamentals of photosynthesis and respiration are important in understanding how herbicides affect plants. Entire textbooks are available on this subject and are too lengthy to include in this bulletin.

SECTION IV - FACTORS INFLUENCING EFFECTIVENESS OF FOLIAR-APPLIED HERBICIDES

The application of a herbicide to the leaves of weeds is a direct way of getting the chemical into the plant and eventually to the "site of action." It is common knowledge that populations of the same species of plants receiving the same herbicide, under similar conditions do not react similarly. If this is the case, there must be something influencing the uptake and movement of the herbicide reaction of the plant to the herbicide, or other factors of application which may influence the effectiveness.

For a foliage-applied herbicide to be effective it must successfully do the following: 1) reach the plant, 2) be retained on the leaf, 3) penetrate the leaf, 4) move to the site of action, and 5) remain toxic long enough to exert its action.

REACH THE PLANT

This factor is many times overlooked in practical field situations. There are at least three ways the proper amount of herbicide fails to reach the leaves:

1) **Spray drift**. This is the movement of the spray particles, including the carrier from the target area. Spray drift is more common with aerial application and where smaller droplets are produced. Large nozzles and lower pressures will reduce the potential of drift.

2) **Volatilization**. This is the change of a herbicide from the solid or liquid state into a gaseous form. Several herbicides are of such a volatile nature that significant losses of the herbicide can occur. It is important to recognize the difference between spray drift and volatility and select non-volatile herbicides where movement of the gaseous phase may cause crop damage.

3) **Canopy effect**. This is the shading of shorter plants by taller plants. Often an overlying canopy can intercept, not only contact herbicides but also translocated herbicides, and the herbicide fails to reach or contact shorter plants underneath the canopy resulting in poor control.

BE RETAINED ON THE LEAF

Once the herbicide comes in contact with the leaf, it must be retained on the surface long enough to be absorbed. Several factors can be involved in retention.

1) **Morphology of the plant**. Where the leaves are upright or horizontal, may determine whether the spray remains on the leaf or runs off.

2) **Waxiness**. Whether the leaf is waxy or non-waxy.

3) **Characteristics of the spray solution**. These can be altered by the addition of additives or "adjuvants". Wetting agents can often act as sticking agents when used in low volumes of water.

4) **Volatility**. Some herbicides may evaporate too rapidly for adequate retention time.

5) **Spray droplet size**. Sprays composed of small droplets and applied at high pressure and low volumes increase retention.

Herbicides may also be deposited on a leaf only to be removed by rainfall. Salts of various herbicides may be lost after the spray solution evaporates, leaving free crystals on the surface where they don't penetrate the plant. High temperatures can lead to loss of volatile herbicides and exposure to light may result in chemical breakdown before absorption can occur.

PENETRATE THE LEAF

The absorption or uptake of a herbicide is influenced by many factors. Herbicides can enter the leaves either through the lower or upper surfaces. Usually the lower surfaces are more permeable than the upper surface. The herbicide can penetrate the leaf through the stomates or directly through the cuticle. The relative importance of the two routes of penetration is open for debate and differences of opinion are common. The absorption depends upon species involved and the environmental conditions (light, humidity, whether the stomates are open or closed). The formulation of the herbicide is also important.

Four important things can happen after the herbicide is retained on the leaf.

1) It can remain on the surface as a crystal or a liquid. This happens to many salt formulations when the water carrier evaporates.

2) It can enter the cuticle and remain dissolved in the non-polar portion. This can happen with weed oils.

3) It can enter and move in the aqueous phase along cell walls to the vascular system. Amitrole and dalapon are examples.

4) It can enter and move directly into living cells and through them to the vascular system. 2,4-D is a good example.

The absorption of herbicides is a very important concept relating to the activity of foliar applied herbicides. The distances the herbicide must move in getting into the leaf are very small. However, the composition and character of the leaf surface may be a very significant barrier to the entry of herbicides. This one factor can contribute to failures when herbicide activity is dependent upon absorption and translocation.

Different tissues of the plant vary widely in their sensitivity to a herbicide. Newly developing cells are usually affected by low concentrations, whereas mature plants develop tolerances.

MOVE TO THE SITE OF ACTION (TRANSLOCATION)

Foliage applied herbicides can either be contact herbicides which kill only the tissues which they come into contact with or systemic herbicides which move from the point of application to other parts of the plant. The systemic herbicides include such compounds as 2,4-D, picloram (Tordon), and glyphosate (Roundup).

An important concept in relation to translocation deals with the symplast and apoplast portions of a plant.

The symplast (sym means together) comprises the sum total of living protoplasm of a plant. It is continuous throughout the plant. The phloem is a major component of the symplast. Phloem translocation is via the symplast.

The Apoplast (apo means separate or detached) is made up of the total non-living cell-wall continuum of the plant. The xylem is the major component of the apoplast. Xylem translocation is via the apoplast.

Herbicides can move short distances by simple diffusion, but for true systemic action they must move in the symplastic, apoplastic, or intercellular tissues of the plant. Some herbicides move in the symplast others in the apoplast and some in both.

Another important concept in the understanding of translocation is the "source to sink" concept. The sink refers to a site within the plant at which sugars are being used either to form storage materials or in active metabolism. Sugars tend to move from the areas of the leaf where they are manufactured (source) toward the sink, and in the process can carry herbicides, like 2,4-D, and other chemicals along. Since most translocation of herbicides from the leaves occurs in the phloem (living tissue) rapid burning of the leaves and stems can be detrimental to translocation. High rates of herbicides may kill the tops of weeds with little movement to the roots.

REMAIN TOXIC LONG ENOUGH TO EXERT ITS ACTION

An herbicide may be readily absorbed, however, as soon as it reaches the living protoplasm of a plant it may be subject to deactivation through plant metabolism. This process changes the chemical structure of the herbicide molecule within the plant. Most of these changes reduce the phytotoxicity of the herbicide, that is reduce the ability of the herbicide to damage the plant.

SECTION V - FACTORS INFLUENCING EFFECTIVENESS OF SOIL APPLIED HERBICIDES

An herbicide may be applied to the soil for the purpose of controlling weeds selectively in agriculture or nonselectively on industrial sites. Despite the variability in performance of soil applied herbicides they are used on a large scale. Therefore, it is very important that factors contributing to the performance of soil applied herbicides be fully understood.

There are many factors that influence the effectiveness of soil applied herbicides. Herbicides applied to the soil are directly affected by soil characteristics; whereas, those applied to the foliage are not directly affected by soil differences.

The number of soil factors, the many different kinds of herbicides, the large number of plant species, and climatic variations make the study of herbicides in the soil extremely complex and diverse.

Herbicides are applied directly to the soil as 1) preplant treatments, 2) preemergence treatments, 3) postemergence treatments, or as 4) soil sterilants. The time of application can refer to either the crop or the weed. Also, some herbicides are only applied to the soil surface and some are incorporated.

Since most annual weeds germinate in the upper 1/2 inch of the soil, the success of preemergence treatments depends upon the presence of high concentrations of herbicide in this zone. If germinating seeds in the soil surface are killed, the surface may remain weed-free for a period of time after the chemical has disappeared. Many weed seeds will not germinate if buried deeply in the soil.

For effective sterilization the herbicide must remain active in the rooting zone to kill both germinating seeds and deep-rooted plants.

PERSISTENCE IN THE SOIL

The length of time that a herbicide remains active or persists in the soil is extremely important as it relates to the length of time weed control may be expected. Residual toxicity is also of paramount importance as it relates to phytotoxic after-effects that may prove injurious to succeeding crops or plantings.

Herbicides may disappear faster with large amounts of water that provide heavy leaching and with repeated cultivation or mixing of the soil. In some cases fertilizers can be added to the soil to reduce the injurious after-effects of certain herbicides.

The use of activated charcoal will also reduce the phytotoxicity of herbicides. Activated charcoal is generally only effective against organic herbicides, and not against inorganic herbicides. Activated charcoal is ordinary charcoal that has been finely ground to increase its absorptive surfaces, and has been electrically charged so it will attract herbicide molecules. The herbicide is still present in the soil but it is unavailable for plant uptake. Activated charcoal has no significant effect on the soil, plants, or fertilizers.

FACTORS AFFECTING PERSISTENCE

There are seven factors that affect the persistence of herbicides in the soil: 1) microorganism decomposition, 2) chemical decomposition, 3) adsorption on soil colloids, 4) leaching, 5) volatility, 6) photo-decomposition, and 7) removal by plants when harvested.

1. **Microorganism decomposition**. The principal microorganisms in the soil are algae, fungi, and bacteria. These organisms primarily use organic compounds, such as organic matter and other organics including organic herbicides, for food for energy and growth. Some organics are readily decomposed (utilized), whereas others resist decomposition.

Microorganisms immediately attack organic compounds, including organic herbicides, applied to the soil. Those microorganisms that can utilize the new food supply will flourish and increase in number. This action will increase the decomposition of the herbicide. It is possible that the increase in microorganism activity from an initial herbicide application will result in more rapid breakdown of subsequent applications and require higher rates of herbicide to obtain similar results. When decomposed, the microorganism population decreases in number because the food supply is depleted.

Other factors besides the food supply may quickly affect the growth and multiplication of microorganisms. These are temperature, water, oxygen, and nutrient supply. Most soil organisms are nearly dormant at 40 F , with 75 to 90 F being most favorable. Most organisms become dormant or die without water. They are also very sensitive to the oxygen supply in the soil. Deficiency of nutrients, such as nitrogen, phosphorous, or potassium can also reduce microorganism growth.

Soil pH also influences microorganisms. Fungi do best with soil pH level below 5.5 and bacteria do best at soil pH levels above 5.5.

Herbicides may remain toxic for extended periods of time if the soil is cold, dry, poorly aerated, or other conditions are unfavorable for microorganism growth.

A warm, moist, well-aerated, and fertile soil is most favorable to microorganisms. Under these ideal conditions microorganisms can most quickly decompose organic herbicides.

The usual rate of herbicide application does not affect the microorganism population to any great extent because the herbicide usually benefits one group of organisms and injures another. When the herbicide is decomposed, the microorganism population returns to previous levels. Herbicides vary in their persistence. Most chemicals used on cultivated crops will decompose in less than 12 months when applied at recommended rates.

2. **Chemical decomposition**. Chemical decomposition may destroy some herbicides and activate others. Chemical degradation reactions consist of hydrolysis, oxidation, isomerization, ionization and salt formation. Of these, hydrolysis and oxidation are the most important. Dalapon will slowly hydrolyze in the presence of water rendering it ineffective.

3. **Adsorption on soil colloids**. Soil colloids are microscopic organic and inorganic particles in the soil that have large adsorptive capacities. It has been calculated that one cubic inch of colloidal clay has 200 to 500 square feet of adsorptive surface area. Adsorption of herbicide on soil particles reduces the concentration of herbicide freely available in the soil water. This limits the amount of herbicide available for uptake by the plant. Because of the adsorptive capacity of soil colloids soils high in organic matter require larger amounts of preemergence and soil sterilant herbicides for weed control that do soils low in organic matter. Soils high in clay require more herbicide than sandy soils for preemergence or soil sterilant weed control because clay has more adsorptive surface area than does sand. Soils high in organic matter and clay content tend to hold the herbicide for a longer time than sandy soils, therefore, the adsorbed herbicide may be released so slowly that the chemical is not effective.

A certain amount of herbicide is required to saturate the adsorptive capacity of the soil. Above this "threshold level" heavier rates will greatly increase the amount of chemical in the soil solution, and thus increase herbicidal toxicity to plants.

4. **Leaching**. Leaching is the downward movement of a substance in solution through the soil. The movement of a herbicide by leaching may determine its effectiveness as a herbicide, may explain selectivity, or may account for its removal from the soil.

Most preemergence herbicides are applied to the soil surface and are dependent upon rainfall to leach them into the upper soil surface or germinating weed seed zone. Weed seeds germinating in the chemical impregnated zone are killed, whereas large seeded crops planted below the area of high herbicidal concentration escape injury.

Some herbicides can be removed from the soil by leaching. The extent to which a herbicide is leached is determined principally by:

1. Adsorptive relationships between the herbicide and the soil.
2. Solubility of the herbicide in water.
3. Amount of water passing downward through the soil.

In general herbicides which are completely water soluble are most easily leached. But some water soluble herbicides may react with various parts of the soil and form a molecule which is relatively stable. The strength of "adsorption bonds" may be more important than water solubility in determining the leaching potential of herbicides.

5. **Volatility**. Herbicidal loss from evaporation is probably more significant than is generally realized for many surface-applied herbicides. During a moderate summer, if the soil surface could remain moist, water would be lost at a rate of about 200 ton/acre/month from the soil only. Soil surface temperatures have been measured as high as 180 F.

All chemicals, both liquids and solids, have a vapor pressure. The evaporation of water is an example of a liquid, and the vaporization of naphthalene (moth balls) is an example of a solid that will vaporize. At a given pressure, vaporization of both liquids and solids increases as temperatures rise.

Herbicides may evaporate from the soil and be lost to the atmosphere as volatile gases. This loss is often underestimated and can result in poor weed control and/or damage to susceptible crops. An example would be 2,4-D ester.

Herbicides may move into a porous soil as a volatile gas. EPTC (Eptam) is thought to move as a volatile gas. EPTC and other volatile herbicides are often mechanically mixed into the soil soon after application to reduce vapor loss.

Rain or irrigation water applied to a dry or moderately dry soil will usually leach the herbicide into the soil, or aid in its adsorption by the soil. Once adsorbed by the soil, loss by volatilization is usually reduced. Where rainfall or immediate irrigation is not available, incorporation assists in reducing losses.

6. **Photodecomposition**. Photodecomposition, or degradation by light, has been reported for some herbicides. Chemicals applied to the surface are frequently lost, especially if they remain for an extended period without rainfall to leach them into the soil. This process begins when the herbicide molecule absorbs light energy, causing the molecule to breakdown and become deactivated.

7. **Removal by plants when harvested**. Plants may absorb herbicides from the soil in which they are growing. The absorbed herbicide may then be removed when the crop is harvested. Corn has been used to remove simazine and atrazine from soils where they have been applied as soil sterilants and the planting of ornamentals was desired.

HERBICIDE CONCENTRATION IN THE SOIL

A consideration when applying herbicides to the soil is herbicide concentration. Any herbicide applied to the soil for action is confronted by two important factors.

1. **Weight of the soil**. Soil weighs, on average 3.5 million lb/acre foot. Thus 3.5 lb of herbicide mixed into the top foot of soil is present at a concentration of 1 part per million (ppm).

2. **Water holding capacity of the soil**. The water holding capacity of soils varies and most herbicides act through the soil solution. Therefore, the concentration of herbicide in the soil solution will depend on the amount of water present in the soil at a given time.

Soil moisture per acre foot can vary from 300,000 to 1.5 million pounds. Thus, a water soluble herbicide would attain a concentration (in solution) five times as great in the first soil as in the second soil.

SECTION VI - HERBICIDE MIXTURES AND PROBLEMS IN MIXING HERBICIDES

The use of herbicide combinations is not new, but it has not received the attention and input that is necessary to fully understand and implement the practice.

Although the number of herbicides available is continually increasing, we have to realize that in most cases herbicides are quite specific in their activity toward either grass or broadleaf weeds and even other species within these broad categories. Excellent herbicides have limitations that might be alleviated with the proper addition of another herbicide.

There are several advantages that may be gained from the combination of herbicides over a single herbicide. Some of these are:

1. Control of a broader spectrum of weeds.
2. More consistent control over a wide range of climatic conditions.
3. Reduced potential of herbicide residue in crops and soils.
4. Lower rates of application resulting in decreased crop injury and lower costs.
5. Unexpected synergistic effects (increased herbicidal effectiveness beyond that expected).

There have been limitations and concern in the past concerning the legal use of herbicide combinations. At no time has the University of Wyoming recommended chemical mixtures unless the herbicides, herbicide-fertilizer mixtures, and other pesticides were registered by the Environmental Protection Agency (EPA) and the state of Wyoming.

EPA's policy on herbicides and herbicide-fertilizer mixtures is as follows:

1. An herbicide or mixture of herbicides may be mixed with other pesticides and/or with fertilizers if the mixture is not prohibited by the labeling.
2. Two or more herbicides and/or pesticides may be mixed if all the dosages are at or below the recommended label rate.

When making such mixtures it must kept in mind that these pesticide mixtures are applied at the applicator's own risk with respect to effects on crops, application equipment, applicator safety, environmental effects and residue tolerance.

MIXING HERBICIDES

Always be sure the sprayer has been properly calibrated. Calculate the amount herbicide to add to the sprayer tank based on the active material in each gallon of herbicide concentrate, or the percentage of active ingredient of dry herbicide formulation. Always read and follow the instructions on the manufacture's label pertaining to personal hazards in handling.

The following steps should be taken when mixing herbicides:

1. Fill the sprayer tank with at least half the volume of water or fertilizer solution you will ultimately need.
2. Start continuous moderate agitation.
3. Add compatibility agents if needed. For maximum benefit, they must be in solution before herbicides are added.
4. Add, mix, and disperse dry herbicides (wettable powders, dry flowables, or water dispersible granules). These formulations contain wetting and dispersing agents that aid in mixing.
5. Add liquid flowables and allow thorough mixing. These also contain wetting and dispersing agents.
6. Add emulsifiable concentrates (EC's) and allow thorough mixing.
7. Finish by adding water soluble formulations (2,4-D amine, etc.).
8. Add any surfactants, crop oil concentrates, etc. last. Crop oils, especially, do not mix and disperse well if added first.
9. Add remainder of water or liquid fertilizer and maintain agitation while spraying until tank is empty.

Never pour concentrated herbicides into an empty tank. Never allow a sprayer containing mixed chemicals to stand without agitation, as heavy wettable powders may clog nozzles or settle into corners of the spray tank.

Wettable powder herbicides should be pre-slurried before addition to a spray tank. Adding the wettable powder directly to the spray tank can result in globs or unwetted material in the tank where it can clog spray equipment. This is particularly a problem with the more finely ground wettable powders.

Tank mixtures of a wettable powder and an emulsifiable concentrate can cause problems if not properly mixed. The proper procedure is to first pre-slurry the wettable powder and add it to the tank 3/4 full of water. The emulsifiable concentrate should then be added followed by the necessary water to fill the tank. If the sequence is reversed with the wettable powder added last, problems can arise.

FERTILIZER AND HERBICIDE MIXTURES

The mixing of liquid fertilizers and pesticides and applying at the same time has several advantages. The mixture can save time, labor, fuel, and may help reduce soil compaction.

There could be mixtures of a herbicide + fertilizer = "weed + feed"; fertilizer + insecticide = "feed and worm"; herbicide + insecticide = "weed + worm". The following material will only be concerned with the "weed + feed" concept of mixing herbicides with liquid fertilizers.

Even before checking the compatibility of herbicide + fertilizer mixtures, other factors of importance must be taken into consideration.

1. Do you have the right equipment for application? Fertilizer application is not as exacting as for applying herbicides. Uniform application covering every square inch is essential for the effectiveness of herbicides. The equipment ordinarily used for applying fertilizers does not give the uniform distribution pattern that equipment used for herbicide application provides.

Some fertilizer application equipment does not have the agitation necessary to keep herbicides uniformly dispersed.

Herbicide application equipment may not be able to withstand the weight and corrosiveness of liquid fertilizers nor apply the necessary volume of liquid fertilizer.

2. Are mixtures of herbicides and fertilizer practical? The applicator must determine if the timing of application, placement and distribution of each component in the mixture are similar enough to be applied as a mixture.

Several herbicides and fertilizers can be applied at the same time. For example, AAtrex (atrazine) can be tank mixed with liquid fertilizer and applied to corn either preplant incorporated or broadcast on the soil surface after the corn is planted but before the crop emerges. Placement of the mixture may raise a question of practicality. Suppose a farm operator sprays the herbicide and fertilizer mix over the corn row, in a band, at planting time. By using a nitrogen solution as a carrier for the herbicide the nitrate form of nitrogen will be incorporated by rainfall. If the ammonium (NH_4) form of nitrogen is used as a carrier and soil surface applied, it will react with the soil particles and be held in the top 1/4 inch of soil. This nitrogen will move downward only after being converted to the nitrate form. If the fertilizer carrier for the herbicide is a solution containing nitrogen and phosphorus it will have to be positioned in the soil near the roots for plants to adequately utilize it as phosphorus does not move readily in most soils. If the nitrogen and phosphorus fertilizer solution is banded over the corn at planting time, the corn will not benefit from the phosphorus as a starter in early plant growth. Thus, this combination would not be practical from a placement standpoint.

3. Distribution of the mixture. Liquid fertilizers are usually broadcast over the entire field. Applying the herbicide in

with the fertilizer means broadcasting of the herbicide also. Many herbicides can be band applied, a practice which reduces the total cost of the herbicide per acre in proportion to the row-spacing and width of the band treated. Therefore, the total benefits and economics of mixing should be taken into consideration.

4. Is the fertilizer-herbicide mixture compatible? Herbicides may not always mix evenly throughout the liquid fertilizer or the components may separate making their use impractical. A simple test should be used before mixing large quantities.

COMPATIBILITY

Even though guidelines have been presented with respect to tank mixes there still remains the question of compatibility when mixing two or more chemicals, especially, when directions for mixing and application are not included on the label.

Both chemical and physical incompatibility are possible. With chemical incompatibility the chemical may be completely deactivated, resulting in no weed control, or the chemical might be made highly phytotoxic resulting in damage to the crop. It is also possible to change the mammalian toxicity making a normally safe chemical highly toxic.

Physical incompatibility is most commonly evidenced by precipitation in the spray solution which takes the form of crystalline solids, formation of a gelatinous mass, or separation of components which takes the form of layering. Lack of compatibility may only result in the formation of a substance that plugs up screens and nozzles, however, extreme incompatibility may produce a settling out of material that can harden like concrete in the bottom of a tank and in hoses, pumps, and other internal parts of the sprayer. The result may be total loss of the pesticide and use of the sprayer.

Chemical compatibility of a mixture is impossible to determine without extensive research being conducted, whereas physical compatibility can easily be checked.

You should use only labeled tank mixtures or mixtures recommended by experienced scientists whose recommendations are backed by research. For all unlabeled tank mixtures, a jar test is strongly recommended to test for the compatibility of herbicide-herbicide mixtures, herbicide-insecticide mixtures, herbicide-fertilizer mixtures, or any combinations involving pesticides and/or fertilizers. In some cases, adding a compatibility agent (Compex, Unite, or comparable surfactants) may aid in maintaining component dispersion.

JAR TEST FOR COMPATIBILITY

The following jar test may be used to test the compatibility of herbicides with each other or herbicides and other pesticides with liquid fertilizers.

1. Add 1 pint of carrier (water, liquid fertilizer) each to two quart jars. Mark the jars with an identifiable letter, number or other means. Usually "with" and "without" is the most practical (representing with and without compatibility agent).

2. Add 1/4 teaspoon or 1.2 ml of compatibility agent to one jar (equivalent to 2 pints per 100 gallons of spray solution).

Table 1. Compatibility agent rate/100 gallons of carrier for use in 1 pint of solution.

Compatibility agent rate/100 gal (pints)	ml of agent per pint of carrier	Teaspoons[1]
1	0.6	1/8
2	1.2	1/4
3	1.8	3/8
4	2.4	1/2

[1]One teaspoon = 4.93 ml

3. To each jar add the required amount of pesticide in the order suggested in the section on mixing herbicides (Tables 2 & 3). Shake well after each pesticide addition to simulate continuous agitation.

Table 2. Dry pesticide rates for compatibility test.

Gallons of carrier to be applied/ Acre	Teaspoons[1] of wettable powder pesticide to be added per pint of liquid carrier for:		
	(1 lb/a)	(2 lb/a)	(4 lb/a)
10	3.5	7.1	14.2
20	1.8	3.5	7.1
40	0.9	1.8	3.5
60	0.6	1.2	2.4

[1]One teaspoon = 1.6 gram based on an 80 percent wettable formulation

Table 3. Liquid pesticide rates for compatibility test.			
Gallons of carrier to be applied/ Acre	Teaspoons[1] of liquid pesticide to be added per pint of liquid carrier for:		
	(1 qt/a)	(2 qt/a)	(4 qt/a)
10	2.4	4.8	9.6
20	1.2	2.4	4.8
40	0.6	1.2	2.4
60	0.4	0.8	1.6
[1]One teaspoon = 4.93 ml			

4. When all ingredients are added, shake both jars for 15 seconds and let stand for 30 minutes or longer. Then inspect the mixture for flakes, sludge, gels, or nondispersible oils, all of which may indicate incompatibility.

If, after standing 30 minutes, the components in the jar with no compatibility agent are dispersed, the herbicides are compatible and no compatibility agent is needed.

If the components are dispersed only in the jar containing the compatibility agent, the herbicide is compatible only if a compatibility agent is added.

If the components are not dispersed in either jar, the herbicide-carrier mixture is not compatible and should not be used.

SECTION VII - EVALUATING HERBICIDE INJURY

Often herbicide injury symptoms are due to other causes, such as insects, diseases, severe weather (hail, drought, flooding), fertilizer burn, and nutrient deficiencies. When crop injury is suspected consideration of the following can help to diagnose the problem.

1. The pattern in the field of plant injury or uncontrolled weeds.

a) A pattern of injury occurring in irregular patches that follow air drainage could indicate herbicide volatilization and movement of vapors.

b) Strips of injured areas or surviving weeds at predictable intervals indicate possible skipping or overlapping application.

c) Poor control at the edges of a field can result from only half coverage by the last nozzle on the boom and/or more sunlight availability along the edge.

d) Injury limited to the end rows or ends of the field is usually due to overlapping applications or high herbicide rates where turns at the end are made.

e) A definite break between the normal or uninjured part of the field and the rest of the field usually indicates some major difference in soil type or pH between the two sides.

f) A pattern of obvious over application as indicated by bare ground (both crop and weeds killed), followed by improved crop survival and appearance with good weed control, followed by lack of crop injury or weed control indicates inadequate or poor agitation in the sprayer tank. The evidence is even stronger if this pattern repeats itself at intervals that correspond to each new load.

2. What is the history of the problem area? For example what was the fertility program, cropping sequence, land preparation, soil pH, soil texture and organic matter, and seed source?

3. What were the weather conditions (temperature, moisture, rainfall, prevailing wind) at the time of herbicide application?

SECTION VIII - REFERENCE MATERIAL

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