Symptoms of Herbicide Injury

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Plants show many responses to environmental conditions. Naturally occurring substances either in excess or deficient in quantities, causes symptoms in plants. These symptoms can indicate a need to make changes in the plants environment. Foreign substances, i.e., pesticides, in the plants environment can also cause symptoms. When this occurs there is concern. When injury occurs to desirable plants there is usually an economic loss. Symptoms alone always suggest a problem, but may not indicate an economic loss. There has long been a need for educational materials to separate biotic stress from symptoms of herbicides. Herbicide symptoms frequently must be distinguished from plant diseases, nutrient deficiencies or excesses, water stress, salts, cold or other pesticides. Sometimes the symptoms observed may be from more than one source (mixture of pesticide, deficiency, fertilizer, etc). All too often when field symptoms are observed, the first question is "What herbicide was used?" A herbicide may have been used, but it may not have been the cause. Sometimes the herbicide may also be a contributor to the symptoms. The purpose for this work is to describe some of the symptoms of selected herbicides, primarily using horticultural crops. The examples will not cover all herbicides, all crops or all conditions.

Causes of Symptoms

Plants, like animals frequently show symptoms. Whether natural or induced, symptoms are consequences of physiological change. Symptoms caused by natural phenomena include small, light green or shiny leaves typical of new growth; yellowing, reddening or off color of senescing leaves in the fall, are also common. Needle or leaf drop is likewise a natural physiological occurrence. Physiologically induced symptoms may occur from lack of or excess of water, nutrients from fertilizer or soil itself. Other soil conditions, and pesticides can also cause physiological changes. Symptoms or "other than normal appearance" (as decided by an observer) often become "injury" and frequently these symptoms are diagnosed as the result of a "pollutant." One should know the morphological characteristics of the crop plant in question before symptoms can be evaluated.

Symptoms should be differentiated from injury. Whether a herbicide symptom occurs on the leaves, stems or roots, these are merely signs of a problem, i.e., the sniffle and watery eyes of a common cold in humans. Plant injury, on the other hand, occurs when the problem is severe enough to cause yield or quality loss.

Other injury losses could include reduced early growth leading to later harvest (missing peak market) not achieving trunk size, i.e. caliper large enough to bud, or spotted outer leaves, thus, rendering a product unmarketable. All negative reaction to a pesticide must be considered when assessing injury.

There are data showing that many plants can compensate from leaf loss (reduced photosynthetic area) or early stunting. Photosynthetic capacity of plants far surpasses needs for optimum yield.

Why do symptoms occur?

Plant symptoms from herbicides may be the result, from many causes. In most instances symptoms or injury results from a human deviation from label directions. When a herbicide is applied according to label directions, the result is generally without injury symptoms to desirable plants. This is not to say, however, that selective herbicides do not affect crop plants. Selectivity is a matter of degree. Also, the competitive effect of the weed and its mechanical removal is often greater than the effects of the herbicide on the crop. Also, situations occur where all of the environmental conditions, management and cultural conditions required on the label for safe usage are not met, thus symptoms can develop.

Some of the errors of misapplication include:

Rate of application: If one or two lb/A is recommended and a doubling or quadrupling of the rate is applied, symptoms can occur. When a compound is registered and recommended it usually has a four times (4X) the label rate as a safety factor. However, in certain soils, or under certain climatic or irrigation conditions, this margin of safety is reduced. An application where there is an overlap of material from the sprayer or granular applicator can double rates causing symptoms in certain crop species.

Application timing: The herbicide applied at the wrong time, can also result in symptoms. Timing can relate to the period between application and planting, stage of plant growth, time of application in relation to time of irrigation or rainfall or even the time of day the herbicide is applied. Translocated herbicides such as glyphosate or 2,4-D can give different symptoms when applied at different stages of growth. If the herbicide contacts a susceptible plant when new leaf growth is present, the symptoms are different than when applied to mature foliage. Sometimes leaves of some species will not show symptoms, but symptoms may occur in the shoot of deciduous species the following spring. Herbicide uptake may be greater in new foliage, but some herbicides will not translocate into other parts of the plant well except when applied to mature foliage.

Pesticide incompatibility: Certain pesticides combinations (herbicide plus herbicide, herbicide plus insecticide, herbicide plus fertilizer, or solvent systems of the pesticides) can have detrimental effects on plants. Propanil applied in combination with or within 14 days of a carbamate insecticide (carbaryl) can injure rice. Kelthane, an acaricide, when combined with 2,4-D increases herbicide activity on broadleaf weeds in corn. Combining some pesticides (maximum label rate of napropamide with low rates of glyphosate, or adding sethoxydim to 2,4-D) can decrease activity of one or both materials.

Addition of adjuvants: The addition of adjuvants (oil or surfactants) to some herbicides will increase activity on both weeds and crops. Adjuvants are commonly used with postemergence herbicides. Some preemergence herbicides show increased postemergence activity when adjuvants are added. Adjuvants can also affect the movement of herbicides in soils. This may increase the chance of injury to plants. The differential selectivity between crop and weed is often lost by adding surfactants and/or non-phytotoxic oils to the herbicide. The addition of adjuvants and subsequent symptoms would be more likely to appear on young foliage rather than injuring the older leaves which have thicker cuticle and waxy surfaces. Examples would be of old leaves with some of the perennial species that show greater tolerance to some herbicide applications. Glyphosate or triclopyr on Hedera sp. (English or Algerian ivy), or the salt, ammonium sulfate, applied to large-leaf iceplant (Carpobrotus edule).

Sprayer Contamination:

Incorrect Pesticide. Many herbicides have been developed for selective use in crops (control of a specific weed or all weeds in a specific crop) or for non-selective use (control of all vegetation). Even when herbicides are used for non-selective applications often some plant species tolerate the chemical. Symptoms or injury often occur when either there is a contamination of an improper herbicide which remains in the sprayer, or the wrong herbicide is inadvertently placed in the sprayer and applied on a crop. Sometimes a herbicide is substituted in error for a growth regulator because the name sounds similar (atrazine - atrinol), two herbicides that sound similar (Turflon and Treflan), or a container color is the same. Periodically an incorrect herbicide is used when the applicator or advisor does not know the tolerance of plants to the herbicide applied. Sometimes a herbicide is used in the wrong area "just to use up the last in the tank".

Residual or carryover in soils. It is often considered desirable to have an herbicide or weed control practice that will control all weeds for a crop cycle. Frequently this goal is attained by a relatively high rate, combination of herbicides or sequential applications. Control of weeds for slightly less than a crop cycle is more desirable so that herbicides do not remain in the soil to affect subsequent crops. Chemical residues in or on the crop may result from excessive rates even if symptoms are not evident. Frequently in many annual and most perennial crops a single herbicide application will not last long enough nor have a broad enough spectrum, with safety to the crop, to satisfy the growers.

Some examples of residual herbicides that have injured subsequent plants include: atrazine applied on corn or sorghum followed by various vegetables (tomatoes, beans, and lettuce), linuron or prometryn applied to carrots followed by beans or lettuce, simazine, or diuron applied in citrus, deciduous orchards or vineyards followed by most annual crops, napropamide applied to tomatoes followed by fall lettuce or barley, hexazinone (Velpar) in alfalfa followed by annual crops, alachlor applied in beans followed by lettuce, oryzalin applied in orchards followed after the trees are pulled to corn or cereal grains.

Another situation when injury has been observed is when a crop stand is lost (not due to the herbicide) after a herbicide was applied preplant or preemergence. Because of economics or horticultural reasons another crop must be planted in place of the original crop. Depending on the residual characteristics of the herbicide, symptoms or injury can result in this second crop. A similar situation can occur when there is positional selectivity in certain woody shrub or tree crops. When the mature plant dies and must be replaced, the new, normally tolerant plant may be transplanted into treated soil, i.e., treated soil is placed around the roots of the new plant, thus resulting in injury.

Soil Type and Soil Constituents

It is generally considered that organic matter and to a lesser extent, clay are the main constituents in soil moderating herbicide activity. B. Day found that an organic matter content of 1% or greater overshadowed all other soil constituents for adsorption of simazine and diuron. Organic matter also is the major soil regulating constituent (adsorption/desorption) for linuron, atrazine, and metribuzin.

The clay colloids play a major deactivating role with paraquat and diquat.
Metribuzin and simazine as well as other triazines are more active in higher pH soils. The sulfonyl ureas (chlorsulfuron, metsulfuron) persist longer in soils with a high pH. The Ca++ content of some soils appear to make simazine more available to plants than in a Mg+++ soil. Clay type (montmorillinite) binds more herbicide in the soil than kaolinite or illite clay soils. It is for these

reasons that rate ranges given on herbicide labels are tied to soil type and organic matter of the soil. The warnings "Do not use on soils containing less than 1% organic matter" are important considerations when using certain specific herbicides. The precaution statements relative to high organic matter soils (>58) relate to "lack of control" with an herbicide.

Irrigation

Irrigation is necessary in many of the arid areas of the world. The effect of irrigation must take into account not only the amount of water but the method of application of water, the timing that water is applied after application, and in some cases the quality of the water. If a herbicide is applied through the irrigation system it is important to know into what portion of the irrigation cycle it should be applied.

A. Amount of water.

Lange has found that 1/4-1/2 in. of water will activate napropamide or pronamide whereas 2 inches of water in the first irrigation following herbicide application decreases weed control but may increase injury to crops. The amount of water is, of course, correlated with characteristics of a herbicide. A herbicide with a high solubility in water, bromacil (815 ppm) can be readily leached into the root zone of tree crops or asparagus. If water solubility is lower, but the material does not strongly adsorb to soil, symptoms can occur with heavy leaching [i.e., metolachlor (530 ppm) in sandy soils]. Conversely a material that is quite soluble in water, glyphosate (12,000 ppm), but adsorbs to organic matter or clay, usually will not cause symptoms from soil movement. Other herbicides that are commonly used selectively have a low water solubility and a high adsorption onto organic matter and/or clay (i.e., trifluralin, and related herbicides, dithiopyr and DCPA).

Materials that can cause problems from leaching.

Metolachlor (530 ppm) in sandy soil with a heavy irrigation has injured peach trees.
Terbacil, pyrazon, norflurazon, metolachor, bromacil, tebuthiuron, picloram, dicamba.
*EPTC can injure tomatoes if incorporated as a layby treatment and furrow irrigation water follows immediately.

Materials usually not causing problems from the amount of water available:

Trifluralin, DCPA, bensulide, oxyfluorfen, oxadiazon, pendimethalin, prodiamine, bensulide, oryzalin, benefin, dithiopyr, thiazopyr

B. Method of application of irrigation water

Various methods have been developed to apply irrigation water; some directly over the plant (sprinklers - center pivot, wheel lines, solid set, etc.) or along the sides of the seed line (furrows), flood - in check around the base of a plant such as trees or in border checks where water is excluded from the trees by berms; basins - sloping to the base of shrubs or trees or basins with a high area around the tree or shrub. There are also variations of any of the above.

Drip or trickle irrigation, microsprinkler and sub-irrigation, which is specialized and does not apply water to the top (foliage) of a plant and does not always apply water to the base of a shrub or tree. Because water is often being applied continually with drip or trickle irrigation, one would think that downward movement of the herbicide should be rapid. However, since the soil is moist during the warm, growing period, degradation of the herbicide is more rapid than under a regime of alternate wetting and drying. This breakdown appears to reduce the chance of injury to the roots of plants.

C. Timing of irrigation

With some water soluble herbicides (glyphosate) application of water shortly after the herbicide is applied may reduce the effectiveness. With other herbicides that are photo-degraded or are volatile, not irrigating for 7 days or more decreases the effectiveness (napropamide). With the more insoluble herbicides, the initial irrigation (0.5 to 1 inch of water) is of primary importance and the subsequent timing and amounts do not appear to be as important in the activation of the herbicides. With some preemergence herbicides that have postemergence activity (oxadiazon, oxyfluorfen) material left on foliage may cause symptoms: 1) If the foliage is wet at the time of application of a dry (granular) material; or 2) when granules collect in foliage and is wet from a subsequent dew or light rain without being washed off the foliage. Some materials normally not considered to have postemergence activity have shown symptoms on foliage (DCPA, melons); (trifluralin - cotton, cucurbits); (pendimethalin, Thyme).

D. Application through irrigation water.

Injury can result from herbicides applied in water in two ways. First, if excessive water is applied and a soluble herbicide is used, the product may be leached to roots of desirable plants. Secondly, volatile products can evaporate from the water and injure foliage of plants.

Most applications in water seem to safen the applications of herbicides, probably due to dilution of the compounds. This is especially true of products like oxyfluorfen or oxadiazon which cause severe leaf burn on some broadleaf plants but have been safened by sprinkler application.

Drift of Herbicides

Movement of herbicides in air to non-target plants constitutes drift. Drift may occur as vapor or as discreet small droplets usually 60 microns or less. Herbicides that have problems with vapor drift are those in the phenoxy acid group or triclopyr that are formulated as esters. The high volatile (HV) esters are short chain organic compounds, methyl ester or ethyl ester that have a high vapor pressure at normal air temperature. These are generally not used in present day agriculture. Formulating as a low volatile ester (LV) reduced vapor pressure. The volatility of these herbicides are further reduced by formulating them as soluble amines or salts. Since drift of chemicals can occur over long distances (miles) in some topographical areas or under certain climatological conditions, all weather conditions should be evaluated when gathering data for diagnosis of a symptom problem.

Another drift concern is the occurrence of co-distillation of oxyfluorfen from moist soils that are warming in the spring. Symptoms can be observed on low-growing foliage. Most herbicides are only slightly volatile and vapor drift is not considered to be a major hazard. Uses of many common herbicides in closed greenhouses show injury to desirable plants. If a material is volatile, like some of the thiocarbamates (EPTC, pebulate) then they are either not absorbed by the plant in a vapor phase or no significant formative effects are present to be observed. Particulate drift has become more common with the increased aerial applications of herbicides. Particles may drift short distances, a matter of feet to 1/4 to 1/2 mile away from the target. Under unusual conditions: 1) large quantities of material applied in a short period of time in a concentrated area; 2) under air inversion conditions; or 3) stagnate air for a period of time followed by a wind, etc., particles may drift up to 20 or 30 miles away. Drift patterns may be quite easy to diagnose when the spray site and direct wind movement of particles away from a site is obvious by the symptoms present. Conversely they may be virtually impossible to diagnose if there are several application sites at different times and unusual environmental conditions have occurred. Symptoms of the herbicides, if they are distinct, can be helpful in piecing together the puzzle. Symptoms from drift usually fall into two categories: 1. Epinasty or other effects of auxin (hormone-type) herbicides. These include 2,4-D, MCPA, mecoprop, dichlorprop, dicamba, triclopyr, picloram or most likely, clopyralid. Symptoms from glyphosate will be placed in this category by some people; and 2. Various variations of chlorotic or necrotic spotting or in severe cases marginal leaf necrosis with yellowing of much of the leaf with no pattern involved on the leaves. If drift is extremely severe, total killing of plants, crop and/or weeds next to the application site may occur. A diminishing of the injury on plants should be evident with distance away from the site. These necrotic symptoms may sometimes be confused with other non-herbicide causes such as hail or sand blasting.

TYPE OF HERBICIDES

SUBSTITUTED DINITROANILINE

This group has a large range of chemistry. Some could be called benzetamines, but are listed here as substituted dinitroanilines.

The most common material, trifluralin, typifies the symptoms of the group. Other members of the group include pendimethalin, benefin, ethalflurafin, profluralin (NA), dinitramine (NA). oryzalin, prodiamine, isopropalin (NA), nitralin (NA), prosulfalin (NA), and butralin. NA = currently not used.

Two other products that give similar symptoms but are not in the family of chemistry are dithiopyr and thiazopyr.

All give somewhat similar symptoms. Two general symptoms are common. The most frequent is the suppression of roots with subsequent enlargement of root tips. Secondary and lateral roots are suppressed or delayed. With root suppression in annual plants such as tomato, broccoli, strawflower, etc. there is also a swelling of the hypocotyl region. This swelling appears at or just above the soil line and in some plants promotes breakage of the plants during cultivation. The one member of this group that appears to differ is butralin. It does not give the extensive swelling and suppression of the roots of the other members. At common use rates, pendimethalin seems to give less root enlargement than other materials.

In grasses, suppression and swelling of roots is common. Also an enlargement of the coleoptilar leaf is frequently observed in seedlings. If growth continues, plants are usually suppressed and slower growing than normal.

Injury degree is rate dependent and differs by rate somewhat between materials. In decreasing order of injury potential are oryzalin, prodiamine, dinitramine, nitralin, trifluralin, profluralin, pendimethalin, ethalfluralin, fluchloralin, isopropalin, prosulfalin, benefin and butralin. Foliar symptoms have been observed (though rare) in broadleaf plants as having smaller than normal leaves (roses) or shortened internodes (cotton).

Tolerant plant families: Asteraceae, Fabacieae, Brassicaceae require high rates to show symptoms.

DCPA

DCPA is a compound that does not fit neatly into any other chemical group. DCPA is applied preplant and incorporated or preemergence after planting.

Symptoms appear initially on annual plants as a stunting of total plant growth. Perennial plants normally show no effect of DCPA. In one instance it was observed that new foliage of hydrangea turned purplish instead of green. Annual plants may turn darker green color than normal. In tomato, cucumber, cantaloupe and potato there is swelling of the hypocotyl. It may become so severe that stem cracking and breakage occurs at the soil line.

Roots are inhibited. Lateral rooting and root hair formation both *are reduced* but not eliminated.

CARBAMATES

Carbamate herbicides here include a broad range of compounds frequently grouped under such names as carbamates and thiocarbamates.

Carbamates include the old herbicides propham, chlorpropham and barban, but also include the current phenmedipham, and desmedipham.

Thiocarbamates include: butylate, cycloate, diallate, EPTC, molinate, pebulate, thiobencarb, and metham (dithiocarbamate).

The carbamates produce severe distortion of roots. The roots are inhibited and thus the foliage of the plants are also reduced. Grass species are more sensitive than broadleaf. The symptoms of desmediapham are described under the Amide group.

The thiocarbamate herbicides are more generally used in row crops. Effects are primarily observed on new leaf development and the reduction of roots. Leaves may appear strap-shaped in broadleaves because of the inhibition of blade formation (the leaf looks like only the mid-rib). In grasses, the coleoptile leaf is entire and subsequent leaves are pushed out of the coleoptile leaf into a kinking pattern. Mature plants normally do not show symptoms. EPTC on onions and brassica crops (cabbage, broccoli) reduces waxes on the leaf surface giving a very glossy appearance to the leaf. Diethatyl (Antor) has also given this symptom on onions.

AMIDES

Only one material is in this chemical group, napropamide. Napropamide symptoms will be described for seedlings and established plants. Napropamide is applied as a preplant incorporated or as a postplant preemergence herbicide. Another new material, dimethenamid (Frontier), is a chloroacetamide and gives similar symptoms as carbamates and acetanalides (metolachlor).

Broadleaf plants germinate and if root systems get below the treated zone and the herbicide is at a significantly low rate the plants will survive. Frequently the total plant is suppressed when compared to an untreated plant.

The root system of annuals and perennials is suppressed but there is no swelling of the root tips, loss of root hairs, or absence of secondary rooting, thus differentiating symptoms from the substituted dinitroanilines. Perennial plants must be planted into napropamide for stunting symptoms to develop. Symptoms have not been observed on established plants at rates anywhere close to label recommendations.

ARYLOXYPHENOXY AND CYCLOHEXANEDIONE DERIVATIVES

These different but similar acting compound groups are often thought of as alike. Compounds in the aryloxyphenoxy group include fluazifop (Fusilade 2000), fenoxaprop (Whip, Acclaim), haloxyfop (Verdict), fenthiaprop, diclofop (Hoelon, Illoxan), and quizalofop (Assure). Some of the compounds have not made it to market as yet. Sethoxydim (Poast), and clethodim (Prism, Envoy) though chemically different, give similar symptoms as the aryloxyphenoxy compounds.

Primary symptoms are shown on grasses since most broadleaf plants are tolerant. Injury has been observed on flowers (reduced petal size and spotting of petals) of some broadleaf ornamentals. Leaf spotting has occurred on some azaleas and tip burn on Bar Harbor juniper. Symptoms are temporary and regrowth is normal.

In grasses, usually the first effect is a cessation of top growth, followed by yellowing (without pattern) in young leaves within 7-10 days. Later the older leaves become yellowish and may show some purple. Internodes just above the node (meristemmatic area) turn necrotic brown and appears to "rot". The young shoot can easily be separated from the remainder of the lower shoot.

SULFONYLUREA

The herbicides in this class are used at very low rates and are extremely active primarily on broadleaf plants. The principal herbicides in this group are chlorsulfuron (Glean, Telar), sulfometuron (Oust), chlorimuron (Classic), metsulfuron (Escort), halosulfuron (Manage), thiameturon (Harmony), rimsulfuron ( ), thifensulfuron (Pinnacle) and bensulfuron (Londax). Most of the materials are used for broadleaf control in grass crops (turf, cereals, rice), noncrop land or soybean. Foliage and root uptake can occur.

Symptoms are observed in new foliage primarily. In new growth, internode length is shortened and small chlorotic leaves appear in small, sometimes distorted whorls. Purplish pigmentation also sometimes is observed in mature foliage. In new growth, symptoms may appear somewhat similar to glyphosate.

On trees, from an application, drift or from dust setting on mature leaves, symptoms may appear on new growth in the spring as a shortening of internodes and reduced growth.

Soil residual varies considerably between materials. Thiameturon is short residual (2+ weeks) and chlorsulfuron may last a year or more.

IMIDAZOLINONE

This new family of herbicides currently has four major materials: Imazapyr (Arsenal), Imazaquin (Image, Scepter), imazamox, imazethapyr (Pursuit), and imazamethabenz (Assert). The imazapyr has use as a total vegetation control material and imazaquin is being used in turfgrass (Image) and soybeans (Scepter).

Symptoms of this group are very similar to the sulfonylurea compounds and I cannot tell them apart at this time.

Soil residual of these materials (particularly imazapyr) is long and may affect annuals a year or more after application.

AMITROLE and CLOMAZONE

Amitrole is a compound that is in a chemical class by itself. It also produces unique symptoms. Since it is both foliar and root active it may appear from both broadcast or drift contact and soil application followed by rainfall or irrigation to move the material into the root zone.

Symptoms appear in new growth. This may show as a white to yellow appearance in new buds or new leaves. One must be aware where new growth occurs to see symptoms. For example, shoot tip leaves or even flowers may show symptoms. In monocotyledon plants chlorosis may appear at the base of leaves and new leaves (onions or iris). In conifer plants (pines, firs) chlorosis is observed at the base of needles or in new needles. Old foliage (even sprayed leaves) normally do not show any effect.

If symptoms are not very severe some of the tissue will regreen over time. If rates are high, leaves may senesce or not regreen.

Symptoms most frequently will be observed as drift from non-cropped areas or applications where rainfall or irrigation water carries the herbicide into areas of desirable plants. Clomazone is unique because it causes similar symptoms as amitrol. Foliar bleaching occurs from post application or from vapor drift onto foliage. If soil is treated, the seedlings usually emerge, but are bleached white somewhat like Norflurazon, but then turn necrotic after several days.

NITRILES

Though three herbicides are classed in this group two herbicides dichlobenil (preemergence) and bromoxynil (post emergence) are commonly used in the United States. An analog of dichlobenil, chlorthiamed used in Europe has given similar symptoms because of a similar breakdown product benzamid causing the symptom. On perennial plants such as grape or apple, symptoms can be first observed on old foliage as a tip chlorosis or marginal leaf chlorosis with a necrotic leaf tip. The necrotic leaf tip is distinctive. Chlorosis may progress into the interveins of the leaves with the leaf margins becoming progressively more necrotic. High rates may cause a plant to defoliate but regrowth (refoliation) normally occurs and the plant survives if there is no subsequent use of the material. Annual plants show leaf chlorosis with rapid progression to necrosis and killing of the plants. Roots of the plants are suppressed and enlarged, causing a reduction of total growth.

Bromoxynil and ioxynil are used as postemergence herbicides. Symptoms appear on foliage as necrotic spotting from contact injury. In young onions, the tips (top ½ to 2 inches) may curl, almost as if it were treated with a hormone herbicide. These two herbicides should not be available for root uptake and will not show patterns of injury.

TRIAZINES

This broad group of chemicals includes materials applied primarily preemergence, however, some materials (atrazine, terbutryn) have some postemergence activity when used with surfactants or oils. Additional preemergence activity is observed if the application is followed by rainfall or an irrigation.

Materials in this group include ametryn, atrazine, cyanazine, cyprazine, desmetryn, dipropetryn, hexazinone, metribuzin, procyazine, prometon, prometryn, propazine, secbumeton, simazine, simetryn, terbuthazine and terbutryn.

Symptoms appear to fall into two groups, differing by chemistry. All materials have not been tested to substantiate this theory but it does hold true for the principal s-triazines; simazine, atrazine and prometone compared to the methyl-thio triazines, ametryne, terbutryn and prometryn.

In perennial crops such as trees and vines, almonds, apples, walnuts, peaches, grapes, many woody ornamentals, etc., symptoms from low rates of the s-triazines start as a yellowing around the leaf margins on mature leaves. Young leaves do not show symptoms. As time progresses into the summer the interveinal areas of the leaves also yellow. Progressive injury includes marginal leaf necrosis with more interveinal yellowing. There is a more distinct yellow to green between intervein and veins than with iron chlorosis which might be confused. If high rates on annual plants or on trees are present, necrosis is initiated in young leaves before these chlorosis patterns can develop.

The second group, the methyl-thio triazines is the reverse of these symptoms. The veins become chlorotic with the intervein remaining green. The contrast is very striking and appears similar to a uracil or substituted urea chlorosis. Since terbutryn is the only one of the materials that is used to any extent in horticultural crops this alternative is not often a viable choice. Annual crops show a rapid necrosis of young leaves and normally the plants are killed.

In bioassays with seeds, generally 10-14 days is required for sensitive crops (radish, squash, beans, oats) to show chlorotic symptoms.

SUBSTITUTED UREAS

This group of herbicides are commonly applied preemergence to the soil, Linuron and in some cases diuron, are applied postemergence, usually with a surfactant. Materials in this group include chlorbromuron, chloroxuron, cycluron, diuron, fenuron (NA), fluometuron, linuron, monolinuron, monuron (NA), neburon (NA), norea (NA), siduron, tebuthiuron, tetrafluron and trimeturon.

In woody broadleaf plants, symptoms usually appear in early summer on mature foliage. They progress as transpiration increases during the summer. Symptoms are rate dependent with higher rates giving greater and more rapid symptoms. Using diuron, monuron and linuron as exemplifying the group symptoms, they usually first appear as veinal chlorosis (yellowing) on the outer south-southwest portions of trees or on a treated side. As symptoms progress there can be yellow blotchiness, veinal yellowing or even some interveinal yellowing in mature leaves. Leaves are usually retained until normal senescence. If high rates are involved, necrosis may appear without extensive chlorosis.

In annual plants the veinal chlorosis may not occur or be very slight with more overall yellowing and necrosis appearing on mature leaves.

In bioassays, seedlings germinate and appear to grow normally for a number of days (7-10) before the leaves turn chlorotic and necrotic and the seedlings collapse.

Symptoms - characterized by linuron and diuron

Soil applied - seedlings may germinate and appear to grow normally for a number of days (7-10) before the leaves turn chlorotic and necrotic and the seedlings collapse. In transplants root uptake occurs until mature leaves show veinal yellowing with some leaves showing a partial leaf chlorosis (blotchy appearance) along with the veinal symptom. Depending upon rate and susceptibility of the plant the crop may die or continue growing with chlorosis becoming no more severe.

In perennial plants, mature leaves show veinal or the blotchy chlorosis characteristic, immature leaves do not have symptoms. Perennial plants retain the leaves with symptoms until normal senescence. Excessive rates can be observed to reach new foliage before symptoms of chlorosis occurs in mature leaves. These symptoms appear as a rapid progression of massive chlorosis to necrotic tissue, similar to drought.

URACILS

There are two herbicides in this group used as preemergence soil applied materials (bromacil and terbacil). Since both of these herbicides are relatively soluble in water (815 to 710 ppm) there is a tendency for them to leach into the root zone of perennial plants. Annual horticultural plants do not tolerate either of the uracils.

Like the substituted ureas and triazines, symptoms appear in early summer or as temperatures and transpiration increases. The more tolerant plants (citrus, apples, peaches, almonds) show symptoms on mature leaves as a striking veinal yellowing.

Terbacil may give some blotchy chlorosis as well. Sensitive trees such as walnuts or figs develop necrotic leaves. This necrosis frequently appears rapidly with no veinal chlorosis. These leaves normally fall and new leaves are formed. Depending on rate of the material present in the soil these new leaves may be smaller and chlorotic at low rates or they may also drop and new leaves form. If trees are healthy, this may occur at least two times in a season, if the trees are not healthy, they may be killed.

PYRIDAZINES

Two herbicides of major importance, pyrazon and norflurazon, are members of this small group. Both materials are applied preemergence though because they are slightly soluble in water can give some postemergence activity from root uptake.

Symptoms on broadleaf plants with pyrazon appear as a mild interveinal chlorosis. It does not have the contrast from green to yellow of the triazines. These symptoms appear in the mature foliage with the young immature leaves appearing normal. Roots may appear stunted but only as an overall reduction in growth. No abnormal swelling of root tips occur.

Norflurazon in perennial plants, from a soil application appears as a veinal yellow to whitish chlorosis. Contrast between green and yellow-white is striking. Frequently the chlorotic areas may show some purplish color (an unmasking or accumulation of anthocyanin). Symptoms appear on mature foliage. As symptoms progress, more of the foliage becomes chlorotic than green and necrosis appears. Leaves may eventually drop, and new buds may push. Early symptoms in perennials could possibly be confused with the uracils (terbacil or bromacil) or methyl thio triazines (terbutryn, ametryn).

In annual plants, mature leaves become chlorotic to whitish purple. New foliage initially does not show symptoms. Frequently symptoms are found on annual broadleaf weeds or if there is an edge effect, grasses will readily show symptoms.

In soil bioassays, seedling plants often appear white in leaves or cotyledons. Symptoms appear very shortly after emergence.

BIPYRIDILLIUMS

This group is represented by two principal products, diquat and paraquat. One other product cyperquat is also a member of this group although it is not commonly used.

Diquat is principally applied to water for contact control of aquatic weeds but it is also used for postemergence contact control of terrestrial weeds and plant edging, whereas paraquat is applied as a postemergence contact herbicide to a broad spectrum of terrestrial weeds.

Symptoms usually occur from particulate drift of the compound. These symptoms may appear on leaves of crops or weeds and normally are observed in the field as a "normal" drift pattern. Depending upon concentration of the herbicide, chlorotic or necrotic spots may appear on young or mature foliage. These spots normally don't "fall out" of tree foliage thus it should not be confused with the "shot hole" disease. With large quantities of the herbicide on a leaf it usually becomes off color, then chlorotic and necrotic in a matter of a day or two. The length of time for this progression to appear decreases with bright, sunny days. If contact with foliage occurs under low light conditions such as late evening or cloudy weather, more chlorosis will occur with no specific pattern involved. Spots on the leaves will be larger or if large quantities of material is present and parts of a leaf may be completely chlorotic. If the leaf is wet at time of application or if rainfall or irrigation is applied very close to application, the chlorotic "spot" may appear to "run" on the leaf.

Though we normally do not think that paraquat translocates, it will move through some stems (iceplant) whereas diquat is used for edging.

DIPHENYLETHERS

This group of herbicides combine postemergence activity with residual activity on the soil surface. If the soil is cultivated after application the effect of the herbicide is nullified or greatly reduced. The activity of the group as preemergence herbicides centers around a girdling effect (contact) at the soil surface. Acifluorfen (Blazer, Tackle) and fluorodifen are somewhat weaker than oxyfluorfen (Goal) in activity. Lactofen (Cobra) has good postemergence activity.

Acifluorfen and oxyfluorfen symptoms will be described here with reference to bifenox as being representative of this group utilized in agriculture. Fluorodifen a material in this group not currently used and CNP* a material used in rice in Japan, have not been evaluated.

Symptoms most frequently appear on young leaves apparently due to low wax content. Appearance of necrotic brown to purplish spotting of leaves occur with acifluorfen when applied postemergence. Oxyfluorfen shows a similar symptom on woody plants like Ilex cornuta. Conifer species show the symptom of tip dieback on new growth, old growth does not appear affected except at excessive rates. On a sensitive plant like petunia silvery spotting and a glazing appearance occurs somewhat like smog damage.

When applied preemergence to brassica crops such as broccoli the tips of the cotyledon leaves are frequently cupped, as if the leaves as they push through the treated soil, are burned leaving the cotyledons distorted. Girdling of the shoots of annual plants, principally broadleaves, is common and appears almost as if there is insect feeding at the soil surface. This symptom is observed on seedlings, after rainfall or irrigation causes the herbicide to contact stem tissue. This symptom can be observed in preplant applications to direct seeded crops.

* common name in Japan

GLYPHOSATE AND SULFOSATE

Symptoms of these two products are highly varied and depend on timing and method of exposure. I am not aware that they can be separated. Exposure must take place through leaves or young, thin or green bark. Soil exposure is minimal to nil if the soil has been tilled before planting or there is soil over roots.

In perennial crops: Symptoms (spring to summer: exposure new to maturing growth) have varied from chlorosis with no specific pattern in new growth when sprayed on older leaves to interveinal chlorosis, or a ring chlorotic spotting from drift. Necrotic vein endings are observed in old leaves from high rate applications. Overall leaf chlorosis can occur and the most common symptom of leaf distortion, puckering, and glossy small leaves of new growth following exposure to older foliage.

Exposure to mature foliage in the fall may not result in symptoms until the following spring when new growth initiates. Growth is delayed, with many small leaves, new bud breaks and shortened internodes. Depending upon exposure it may appear on one branch or cane or the total plant may show the effect. As growth occurs, depending upon date and amount of exposure, new growth may be normal and even mask the early symptoms. High rates of exposure, however, cause symptoms to persist during much of the season. These symptoms may appear in new foliage each spring for 2 to 3 years without additional exposure. Unless exposure is very high on mature foliage normally a tree or vine survives. This also depends upon the original health of the plant. In grapes it does not appear to reduce fruiting greatly even though foliage symptoms may be severe. In conifer plants like pines or furs the new candles or growth tips become necrotic and die forcing secondary whorls.

Annual plants: At high rates, symptoms frequently are limited to a short period of light green leaves and chlorosis in new growth [3-7 days (high rates) to 2 weeks (low rates) after application depending upon temperature and sunlight] before the total collapse of the plant. Low rates may show a chlorosis in new growth with a stunting of subsequent growth. Young tomato leaves can show interveinal chlorosis, whereas the mature leaves may not show symptoms. Some glyphosate symptoms (chlorosis of young growth and shortened internodes) could resemble the sulfonyl urea or imidazolinone groups.

PHENOXY—BENZOIC

Phenoxyacetic(2,4-D, MCPA) phenoxy propionics (2,4,5-TP, dichlorprop, mecoprop) phenoxy butyric (MCPB, 2,4-DB) benzoic (TBA) anisic (dicamba) or picolinic acid [picloram and clopyralid (Stinger, Transline] derivatives can be grouped together because of similar symptoms. Though each may have a characteristic symptom on an individual plant and have a greatly different rate response, symptoms generally cannot be differentiated unless directly compared.

Phenoxyacetic

Foliage application - low rates: In rapidly growing broadleaf plants (annual or perennial) symptoms appear in new growth. The time interval can be 3-10 days after application before symptoms appear. Interval is generally temperature dependent with increasing temperature decreasing time for observation. Leaves lose their planar angle, the petioles twist and there is general disorientation of growth in new foliage. Old leaves and stems in woody plants such as peaches, grapes, etc., do not appear affected.

Leaves of broadleaf plants take on various changes in development patterns. Changes in leaves occur in new growth, after exposure. Using grapes as an example, leaves become abbreviated at the tips where there are major veins. This may become so extreme as to cause "fan-shape" or "strap" leaves. Veins become very prominent with the reduction or absence of the intervein area. If no mature foliage is present for uptake slight hormone-like symptoms may appear on new growth with low rates. High rates kill the young tissue causing necrosis.

If rates are very low (as from a light drift situation) new growth on the same shoot may gradually appear with normal growth orientation and leaf shape. Absorption of the phenoxy acetic acids and related compounds can be observed from fresh cuts with similar symptoms appearing in regrowth foliage and stems. Immature stems of woody plants may develop split stems with meristemmatic "corky" zones. These appear as if they are forming aerial roots on plants such as grapes.

In grape, symptoms of 2,4-D have often been confused with fan-leaf virus. In diagnosis there should be a different field pattern from 2,4-D drift or accidental application as compared to the sporadic occurrence of the diseased plant.

Annual broadleaf plants exhibit similar leaf characteristics. Leaf petioles and stems twist severely. Symptoms can occur from root uptake after soil application, particularly in sandy soil, if rainfall or irrigation follow the treatment.

In carrots, root growth appears as irregular thickening giving a "warty" appearance or in some cases splitting occurs because of the irregular growth. Splitting alone is not a characteristic symptom because it can be caused by lack of proper water management. Leaf bases are enlarged with a reduction of length of new leaves and some twisting of the leaves can be observed.