Herbicide Injury

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Herbicides are designed to kill undesirable plants. Unfortunately, desired plants can be injured or killed as well. In ornamentals, knowing how herbicide injury occurs and limiting its occurrence are imperative. Chemical damage to ornamental plants can be extremely expensive, and replacement costs are generally much higher than for other crops. A good understanding of how plants can be exposed to herbicides injury and the symptoms caused by a particular chemical, combined with a thorough investigation, will help pinpoint the sources of injury. Determining how plants were exposed to herbicides involves an examination of field patterns and/or symptoms on a group of plants, primarily. However, injury symptoms on individual plants are also useful in determining exposure and the kind of chemical that was applied.

"Is the old growth affected more than the new growth?"

This is one of the most commonly asked questions in plant diagnostics. This question actually has five parts. First, was the injury at a point in time (contact) with no subsequent symptoms expressed in time or position (space) on the plant? Second, if a chemical is suspected, is toxicity or deficiency assumed? Third, if toxicity is thought to be the problem, is it caused by a nutrient or some other type of chemical? Fourth, did the injury progress in time and/or space (systemic)? Fifth, if progressing, was it multidirectional (phloem) (symplastic movement) or only upward (xylem) (apoplastic movement)?

Exposure

There are four ways plants can be exposed to herbicide injury (Thompson and Ockley, **2006).**

1. Drift or volatilization.

Volatility is the ability to vaporize freely with the air. Some herbicides can evaporate and are lost in the form of gases or vapors. Some examples of volatile ornamental herbicides include Trifluralin, Dichlobenil, and Oxyfluorfen. Some herbicides such as 2, 4-D and atrazine, are not considered volatile compounds; however, they can evaporate over a period of time if hot and dry conditions prevail. Volatile herbicides are lost more readily from moist soils. When soils are moist, immediate incorporation of a volatile chemical is extremely important. This type of injury is most likely when temperatures are above 80˚F (Thompson and Ockley, **2006**, when using herbicides subject to volatilization, when herbicides are not activated within their label guidelines (Table 1) and/ or spraying around plants that are very sensitive to the herbicide being applied, ex. spruce to glyphosate (Fig. 1). Herbicide drift can be reduced by using low water volumes, spraying at low pressures, using large droplet size nozzles, activating herbicides within the timeframes indicated on their labels (Table 1), and/or taking note of potential injury problems to surrounding plants before spraying. Note: the more volatile the chemical the shorter the period to activate (Table 1).

Table 1. Preemergence herbicide time of activation (in days)

Chemical name	Trade name	Activation
Isoxaben + Trifluralin	Snapshot	3
Oryzalin + Oxyfluorfen	Rout	1
DCPA	Dacthal	4
Dichlobenil	Casoron	1
EPTC	Eptam	1
Isoxaben	Gallery	21
Metolachlor	Pennant	7
Napropamide	Devrinol	3
Oryzalin	Surflan	21
Oxadiazon	Ronstar	1
Oxyfluorfen	Goal	25
Pendimethalin	Pendulum, others	30
Prodiamine	Barricade	14
Simzaine	Princep	10
Trifluralin	Treflan	2

Source: M. Halcomb, Field Nursery Weed Control. Agriculture Extension Service the University of Tennessee. 2002. (Additions by: H. Mathers).

Figure 1. Hot spots in field resulting from herbicide leaching and buildup. (Photo by: H. Mathers)

2. Leaching or runoff.

Leaching in the context of herbicide injury refers to the downward movement of a substance in solution through the soil. The amount an herbicide will leach or run off depends on its solubility, the volume of water passing through the soil, the porosity of the soil or media, and the affinity of the media to adsorb the chemical. Groundwater contamination and herbicide runoff into recirculation ponds have increased nursery growers' and landscape managers' awareness of an herbicide's leaching potential. Herbicides are given relative leaching potential indexes (RLPIs) (Stamps 2001); these are based on the organic carbon absorption coefficients and half-lives of the herbicide. They range from values of 3 (high potential to leach) (Simazine) (Table 2) to greater than 2,000 (low potential to leach) (Isoxaben) (Table 2). We need some movement of soil-applied herbicides into the soil in order for them to be absorbed by the weed roots; however, we don't want the herbicide to go off-site or move too deeply where it is ineffective, causes rooting damage to the desired plant or moves to the root zone of another plant (Thompson and Ockley, **2006)**. Repeated herbicide leaching to a particular part of a field or landscape such as a low area can lead to what are known as "hot spots" (Fig. 2). Leaching or runoff injuries are most common when the wrong chemical is used for a particular site, too high a rate is applied and/or application is made at the wrong time.

Table 2. Herbicide leaching and runoff potentials.

Chemical Name	**Trade Name**	**Application Method**	**Leachate Potential**	**Runoff Potential**
Benefin	Balan	Soil	VL	H
Bensulide	Betasan	Soil	M	H
Bentazon	Basagran T/O	Foliage	M	L
DCPA	Dacthal	Soil	L	H
Dichlobenil	Casoron, other	Soil	M	M
EPTC	Eptam	Soil	L	L
Fenoxaprop	Acclaim	Foliage	VL	M
Fluazifop	Fusilade	Foliage	VL	M
Glyphosate	Roundup,	Foliage	VL	H
Isoxaben	Gallery	Soil	L	L
Metolachlor	Pennant	Soil	M	M
Napropamide	Devrinol	Soil	L	M
Oryzalin	Surflar	Soil	L	L
Oxadiazon	Ronstar	Soil	L	M
Oxyfluorfen	Goal	Soil	VL	M
Pendimethalin	Pendulum,	Soil	VL	H

	others			
Prodiamine	Factor	Soil	VL	H
Pronamide	Kerb	Soil	VL	M
Simazine	Princep	Soil	H	M
Trifluralin	Treflan	Soil	L	L

Source: Leaching potentials taken from the 1995 North Carolina Agricultural Chemicals Manual. Runoff potential is based on information available in the research literature. VL = very low, L = low, M = Moderate, H = high.

Figure 2. Slight glyphosate drift on spruce. (Photo by: H. Mathers)

3. Misapplication.

The third way plants can be exposed to herbicide injury is by misapplication. This occurs when the wrong chemical is used, rates applied are too high, improper timing is used for applications, the sprayer is contaminated even with a small amount of herbicide from a previous application (Thompson and Ockley, **2006),** and/or irrigation water is contaminated. Irrigation water can become contaminated in nursery ponds because pesticides applied to containers can be lost through misapplication or by leaching out of the bottom of the pot (Riley et al. 1994). Phytotoxicity occurs when herbicides leached into the ponds are applied in the irrigation to plants sensitive to these herbicides (Fig. 3). An example of using the wrong chemical for a particular application is the use of Paraquat for sucker removal. Paraquat is a contact herbicide and is also used as a post-harvest desiccant. Using Paraquat for sucker removal has resulted in severe constrictions in the bark as shown in Figure 4 A and B.

Figure 3. Vein clearing and interveinal chlorosis occurring from irrigation water contaminated with Princep. (Photo by: H. Mathers)

Figure 4 A and B. Parquat injury on trunks of Ash in field (A) resulting in severe constriction (B) similar to scion incompatibility type symptoms. The Paraquat was applied to remove suckers. (Photos by: J. **Lewilynn)**

4. Soil or soil amendment contamination.

Soil, composts, manures or fertilizers may be contaminated (Thompson and Ockley, **2006).** A few years ago, home gardeners started complaining that their compost materials were distorting the growth of plants in their vegetable gardens. The contaminating chemical turned out to be clopyralid, an herbicide commonly used in turf. Clopyralid had been applied to lawns, the grass was mowed, the clippings collected, sent to composting facilities, composted and applied onto the vegetable gardens as composts. The clopyralid had not broken down in the composting process and resulted in herbicide injury to crop plants.

Soil contaminated with herbicides can result from the continual use of one herbicide especially those with high adsorption and residuals. An herbicide residue can result from applications you have made or that the previous landowner or manager made. An example is planting nursery stock in a field that has received repeated applications of Plateau, an ALS inhibitor (Fig. 5). Soils can be chemically analyzed for herbicide residues, but this is expensive, complicated and can be done only in specialized laboratories. Moreover, the results of the analysis do not indicate the effects on the next crop.

Figure 5. Buildup or residue injury from Plateau, an ALS Inhibitor herbicide, applied to soils high in pH, in cooler climates increases the potential for buildup. (Photo by: H. Mathers)

An inexpensive and fairly reliable way to determine herbicide carryover is to make a crop biological assay – a bioassay. Bioassays should also be done if you are renting a parcel of land where you do not know the cropping history, if you are managing an existing landscape site where you are not aware of the previous herbicides applied, if you receive in new topsoil from an field previously used for agricultural crops, or if you are concerned about contamination by any means (ex. soil or media pile exposed to chemical runoff). Soil sampling for a crop bioassay is similar to sampling for soil testing. Samples should be gathered from several areas of the field. Remember that the assay is only as reliable as the sample collected. If possible, a non-treated or check soil sample should be taken from an adjacent non-treated area for comparison.

If herbicide residues in the soil are suspected, certain plant species are better indicators of that herbicide than others. The plants in Table 3 are suggested bioassay species for the corresponding herbicides. About 10 seeds should be planted per container. Do not plant excess seeds. If too many plants are used, the amount of herbicide in the soil may be diluted. Injury symptoms on seedlings should become apparent anytime between emergence to 3 weeks, depending on the herbicide being tested. Water plants sparingly, but do not allow the soil to dry out.

Table 3. Bioassay species used for ten selected herbicides.

Herbicide	Trade Name	Bioassay species
Atrazine	Atrazine	Cucumber, oats, wheat, Japanese millet, tomato, pumpkin, pea
Dichlobenil	Casoron 4G	Carrot
Diuron	Diuron 4L, 80DF, 80 WDG	Cucumber, barley, oat, pumpkin, ryegrass
Metolachlor	Pennant Liquid	Japanese millet
Napropamide	Devrinol	Wheat
Oryzalin	Surflan	Oat, barley, wheat
Pronamide	Kerb	Wheat
Simazine	Princep Liquid	Oat, ryegrass, wheat, mustard, sugarbeet, tomato
Trifluralin	Treflan	Oat, barley, annual ryegrass, cucumber
2,4-D	Various	Cucumber, mustard, tomato

Source: Washington State University, Cooperative Extension, 1987.

Injury patterns on an individual plant

Contact

Just as herbicides are classified as contact or systemic chemicals, symptoms of their injuries can also be defined as being from direct contact or toxic translocation. The principles that apply to how effective contact and systemic herbicides are in controlling weeds also influence the damage they can cause to ornamental plants. Shoot-foliage applied contact chemicals generally weaken and disorganize the plant cell membranes, causing leakage and eventual localized death. Shoot-foliage contact herbicides are generally most effective against broadleaf annuals, and their damage is greatest to annuals (Peterson et al., 2001).

The growing points of grasses are located in the crown (below or at soil surface) and thus spray contact in this region is difficult. Complete coverage is essential in weed control with shoot-foliage contact herbicides and the more thorough the coverage, the more complete the damage. Examples of shoot-foliage contact chemicals are gramoxone (Parquat), diquat (Reward), pelargonic acid (Scythe), Bentazon (Basagran), foliar-applied fertilizer salts, air pollutants, and herbicidal oils (Peterson et al., 2001). The physical application of shoot-foliage contact herbicides may be detectable on the leaf surface, i.e. spray droplet size. If spray-applied, the pattern of droplets or area where spray accumulated along veins or to run-off along leaf edges will show the most severe injury (Fig. 6).

Figure 6. Typical damage caused by a shoot-foliage contact herbicide, paraquat on red maple. You can see where the herbicide accumulated along the veins and where the run-off at the margins occurred (Photo by: **Unknown).**

Volatile chemicals can cause shoot-foliage contact like damage; however, with volatility injuries, the area between the leaf veins and along the leaf margins where the concentration of water within the leaf is lower will be the first to show injury (Fig. 7).

Figure 7. Injury caused by Goal (Oxyfluorfen) volatilizing and injuring lower leaves of a Yellowwood. (Photo by: H. Mathers).

Preemergents are also contact herbicides, generally root contact herbicides. Symptoms from root-contact chemicals are localized where the chemical contacts the root, but produces general symptoms in the shoot with the lower part of the plant showing symptoms first (Green et al. 1984). The shoots may show water and nutrient stress, reduced growth and wilting. If the injury is from direct contact with the chemical, the symptoms are similar to a drying injury.

Lower leaves generally show symptoms first, and the plant appears to be dying from the bottom up (Fig. 8). Root-contact injury should not be confused with volatile chemical injury, which will also cause symptoms first at the bottom of the plant. However, unlike volatility injury, the root-contact injury will not show symptoms of burn in the area between the leaf veins and along the leaf margins.

Figure 8. Flumioxazin (SureGuard) root damage on Golden vicary privet (*Ligustrum* ×*vicaryi*). (Photo by: H. Mathers).

Listed below are the symptoms caused by Surflan and Pendulum (dinitroaniline herbicides), as examples of injury caused by root-contact herbicides. Dinitroanilines may cause roots to become shortened, thick and swollen at the tip. The chemical inhibits the development of new roots. Root damage is usually limited to the top 5 cm of the soil since the chemical has limited water solubility. Other symptoms include stem swelling at the soil line and stunting (Fig. 9A - Surflan). A callous-like growth may develop at the soil line (Fig. 9B - Pendulum), become brittle and cause stem breakage (Fig. 9C – Pendulum), or cause the plant to fall over (a lodging type injury) (Fig.9A). Leaves may appear darker green. Shoots may look normal, but the plant wilts when conditions are dry. When roots are unearthed, they are stunted with few laterals. Over application to young nursery stock, especially tightly rooted liners, may cause injury.

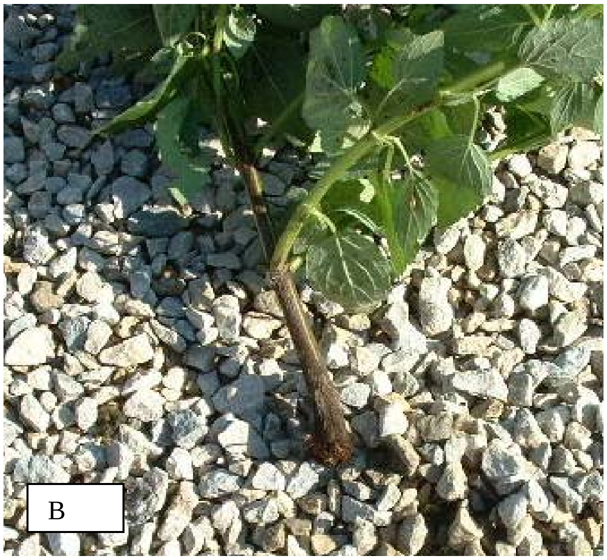

Figure 9 A, B and C. Symptoms of stem swelling at the soil line (A) (Surflan) and stunting. A callous-like growth may develop at soil line (B) (Pendulum), become brittle and causing stem breakage (C), or the plant to fall over (a lodging type injury) (A). (Photos by: H. Mathers A; Luke Case B and C).

Systemic

Systemic herbicides include phenoxy herbicides (2,4-D), dicamba (Banvel), plicoram (Tordon), and glyphosate (Roundup) (Peterson et al. 2001). Systemic herbicides are translocated throughout the plant to their sites of physiological action. Translocated herbicides are effective against all types of weeds; however, they have their greatest advantage when used to control established perennials. Systemic herbicides, therefore, also cause more damage to ornamentals which are also perennials. Complete coverage is not required with translocated materials; however, uniform applications are critical and as with contacts, the more thorough the coverage, the more complete the damage. Postemergents are generally best when applied to young plants and may take several days to work. Newer glyphosate formulations such as Roundup Ultra work very fast. Postemergent contact with active growth of the ornamental plant, including green bark, will result in injury. Contact with the ornamental plant or conditions that could promote contact, such as high winds, should be avoided. Poor results can occur with postemergent applications if the weed is under stress at the time of application, if rainfall occurs within six hours or heavy rainfall within two hours. Faster action is *not* always optimum. Some growers have switched back to slower-acting generic glyphosate or Roundup original formulations, and they are finding better control of some weeds such as perennial white clover. The faster the postemergent works, the less time you have to take corrective action(s) if a misapplication has been made to an ornamental plant. Corrective measures will be discussed in the third article in this series.

Xylem and Phloem Transport

Translocation of systemic herbicides can occur in the xylem, phloem or both (Peterson et al. 2000). The xylem is non-living tissue through which water and nutrients move in the xylem-transpiration stream from the roots to the leaves (Fig. 10). Phloem is living tissue transporting sugar, water and metabolites both upward and downward in the plant. If transported solely in the xylem system, the chemical will move upward in the plant only and symptoms occur primarily in the older foliage. If the chemical is translocated in the phloem, it may move multidirectional from the point of absorption, i.e. it may move from the shoot to the root or the reverse. Phloem transport is usually to “sinks” or areas requiring rapid growth. For this reason, phloem-translocated chemical symptoms occur primarily in new growth and meristematic regions of the plant. Phloem-translocated herbicides (Fig. 10), like Roundup, Finale and Vantage provide the best control of perennial weeds because they are suppressing root and shoot growth. Of the three, however, Finale has the poorest movement in the plant and is more like a contact herbicide.

Listed below are the symptoms caused by Roundup, as an example of injury caused by a phloem-transported herbicide. Roundup may cause tip chlorosis, tip dieback and abnormal leaf development. After absorption; the chemical is translocated to the growing points. New growth appears chlorotic, stunted, narrow or distorted and tightly spaced together, with a witches-broom appearance. There may be a purplish cast to foliage of broadleaf plants. Injury is usually the result of spray drift onto green foliage, green or thin bark. If overspray occurs in the fall, or if absorbed into the bark, damage may not appear until the new growth begins the following spring.

The herbicides that move in xylem and phloem (Fig. 10) like Tordon, 2,4-D, Banvel and ALS inhibitors (halosulfuron, imazaquin) also provide good long-term control of certain weeds. Listed below are the symptoms caused by 2,4-D, as an example of injury caused by a xylem- and phloem-transported herbicide. 2,4-D causes tip chlorosis, tip dieback, epinasty, twisting and abnormal foliage appearance. 2,4-D causes the largest percentage of herbicide injury to plants in the landscape. Injury may be the result of spray drift, volatilization or root uptake. Symptoms depend on the concentration to which the plants have been exposed. Low concentrations will cause shoot tips to twist and leaves to become cup-shaped with margins curling up or down. Leaf petioles may bend down, giving the plant a wilted look. Cracked calluses appear on longer stems (Fig. 11). At low concentrations, leaves which develop after contact may be long, strap-shaped, darker green in color with prominent veins. At higher concentrations, shoot tip and leaves turn chlorotic and die, eventually leading to the death of the entire plant. Check for similar symptoms in weeds adjacent to the damaged ornamentals.

Xylem-transported herbicides are most effective as soil-applied or early postemergence treatments because flow is only upward. The photosystem II inhibitors (triazines, diuron, bentazon), and pigment inhibitors (like norflurazon) are good examples of xylem-transported herbicides (Peterson et al. 2001). . Listed below are the symptoms caused by Princep, as an example of injury caused by a xylem-transported herbicide. Yellowing or leaf chlorosis, veinal, interveinal, marginal or overall chlorosis will occur with Princep injury. Plants may outgrow injury which is the result of low concentrations. New leaves will eventually become greener. The whole leaf may become chlorotic at high concentrations. Leaves may turn brown and die. Excessive root absorption of the chemical is the major cause of plant injury. Repeated applications over several years will cause soil buildup. Plants transplanted into areas of significant soil buildups may be damaged or killed by the carryover. Alachlor and metholachlor are xylem-transported herbicides; however, they are shoot-inhibiting versus photosynthetic inhibitors as discussed above. Toxic symptoms from xylem-translocated chemicals occur primarily in the older foliage (Green et al. 1984).

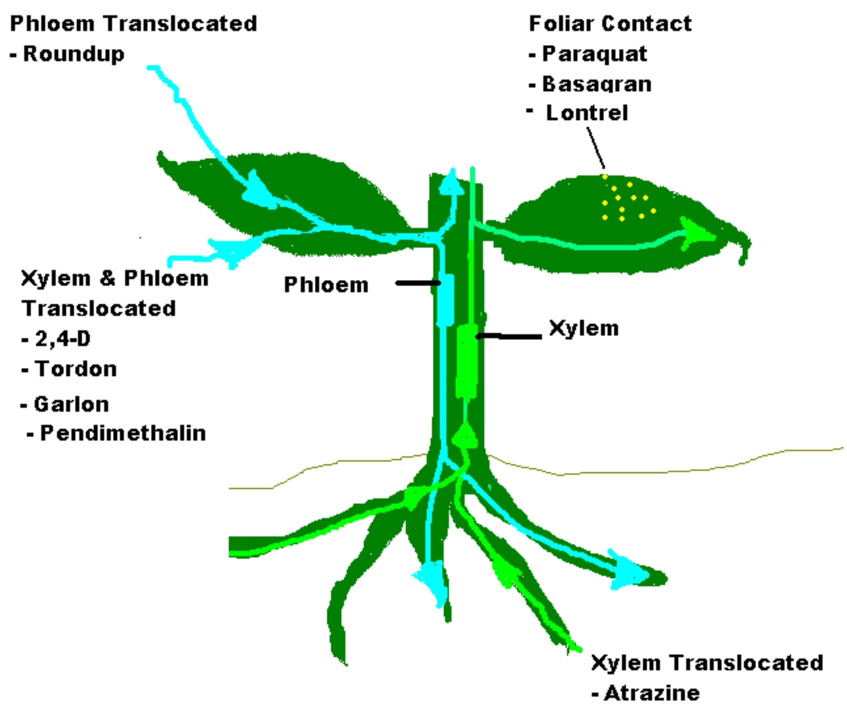

Figure 10. Herbicide translocation in plants. Source: Peterson et al. (2001). (Drawn and modified by: H.M. Mathers).

Figure 11. Callus proliferation on *Cedrus* caused by 2,4-D application. (Photo by: H. Mathers)

Summary

When examining a plant to determine contact vs. systemic herbicide injury or whether the chemical was phloem- or xylem-transported, there is one more important consideration to take into account. It is important to remember nutrients also move in the phloem or xylem and can also cause foliar contact injury by direct application. Nutrient problems can be toxicities (too much) or deficiencies (too little).

Toxic symptoms from *xylem-translocated* chemicals occur primarily in *older* foliage. *Deficiency* symptoms of *xylem-translocated* (phloem-immobile) nutrients occur first in *new* growth. Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B) and Calcium (Ca) are all phloem-immobile, and deficiencies of these nutrients will appear first or most severely on the youngest leaves. These nutrients are moved in the xylem in upward translocation and absorbed in the plant tissue. Once absorbed, they cannot be withdrawn when deficiencies develop in the root zone (Green et al. 1984). Because they are phloem-immobile, they cannot be withdrawn and phloem-translocated to young leaves and organs.

Conversely, *toxic* symptoms from *phloem-translocated* chemicals occur primarily in *new* foliage. *Deficiency* symptoms of *phloem-translocated* (phloem-mobile) nutrients occur first in *older* growth. Nitrogen (N), sulfur (S), Magnesium (Mg), Molybdenum (Mo), phosphorous (P), Potassium (K) and Chlorine (Cl) are all phloem-mobile nutrients, and deficiencies of these will appear first or most severely in the older leaves (Green et al. 1984). When phloem-mobile nutrients become deficient in the root zone, these ions may be withdrawn from the older plant tissue and re-translocated in the phloem to the new growth. Therefore, deficiency symptoms first appear in older growth.

In summary, when looking at suspected chemical injury occurring primarily in older foliage, it could be a phloem-immobile toxicity or a phloem-mobile nutrient deficiency. If it is occurring in new foliage, it could be a phloem-immobile nutrient deficiency or a phloem-mobile toxicity.

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