FIELD GUIDE TO
VINEYARD
HERBICIDE
DRIFT
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Preface

This guide generally addresses those who apply herbicides and grape and wine producers with an interest in learning more about herbicide drift, the potential options for limiting it, the damage that it causes in vineyards, and ways to respond to the damage. However, many of the principles in this guide can be applied to other production systems that are impacted by herbicide drift, though the specifics and concerns will require more context (e.g., sensitivity, growth stage, and perennial vs. annual crops) than this guide provides.

Introduction

In agriculture, “spray drift” (or simply “drift”) refers to the movement of pesticides away from the targeted area of management and onto an unintended area or plant. Herbicide drift concerns the movement of herbicides away from the targeted plants (often weeds) that are being managed; in general, it is associated with damage to off-target plants. Herbicide drift can involve particle drift and/or vapor drift. Particle drift (also called droplet or physical drift) occurs when very small droplets of the herbicide spray solution move away from the intended target during herbicide application (hence “particle” drift). Vapor drift (or “volatility drift”) occurs when herbicides volatilize or vaporize (hence “vapor” drift) during and/or after application. High-speed winds may not be involved since strong air currents are not necessary to move the herbicide vapor away from the intended target. Often, herbicide vapors occur under warm conditions, moving away from the application area through volatilization. They can be drifted by small changes in air currents, and changes in land topography can “guide” vapors to an unintended target.

Many types of herbicides (and pesticides in general) may drift when applied in a manner other than that specified by the product guidelines on the label. For example, though glyphosate (i.e., Roundup) does not readily volatilize, drift and damage to off-target plants may occur when it is applied during windy conditions. Herbicides based on plant growth regulators (PGRs), or “auxin” herbicides, such as those characterized by phenoxy and benzoic acids and pyridine, more readily drift. Auxins are plant hormones that regulate growth
and development in the plant and are in the highest concentrations in the growing tips. PGR herbicides mimic the action of these plant growth hormones. The herbicide molecules bind to auxin receptors, which results in abnormal plant growth due to disruption in the hormonal balance of the plant. These herbicides are systemic and translocate from absorption sites (i.e., leaves or roots) to areas of rapid growth. The most common auxin/PGR herbicides used and that have been documented to cause off-target herbicide damage are 2,4-D and dicamba. However, other auxin/PGR herbicides that have been documented to drift and cause injury are picloram (e.g., Tordon), triclopyr (e.g., Garlon), and clopyralid (e.g., Stinger). All PGR herbicides should be considered to have the potential to cause injury to non-target sensitive plants because of spray drift. PGR herbicides are commonly applied to lawns, turf, pasture, agronomic crops (e.g., corn, small grains, sorghum), and non-cropland (e.g., roadsides, rights-of-way). There is a wide variety of PGR herbicides, and many are included in prepackaged mixes.

Herbicide drift damage is often caused by 2,4-D, dicamba, and/or other volatile herbicides. The auxin herbicides just discussed are used to manage weeds in agronomic crops, turfgrass, ornamental landscapes, roadsides and rights-of-way, and pastureland. Many broadleaf plants (e.g., grapes and other fruit crops, vegetables, ornamentals, certain trees, non-tolerant soybeans, and tobacco) are extremely sensitive to PGR herbicides (Figure 1; Culpepper et al. 2018); thus herbicide drift damage is often observed by those who manage herbicide-sensitive plants. Damage occurs when off-target, herbicide-sensitive plants are subject to herbicide drift. The magnitude of the damage depends on such factors as the type, amount, and concentration of the herbicide, whether the drift occurs via particles or vapor, the species and growth stage of off-target plants, and the weather conditions.
Herbicide Drift Fundamentals

Herbicide drift is caused by several complex and interacting factors. In general, product chemistry, application practices, and weather conditions during and after application combine to determine the relative risk of off-target herbicide movement. Product chemistry impacts drift primarily by way of relative volatility. So, all conditions and application practices being equal, a more volatile herbicide (i.e., one with a relatively high vapor pressure) has a greater chance of moving off-target than a less volatile herbicide (with a relatively low vapor pressure). However, windy conditions at the time of application are likely to result in particle drift regardless of herbicide chemistry. A weather condition affecting herbicide drift is called a “temperature inversion,” which is a situation in which a layer of air near the earth’s surface is cooler and denser than the air above it; such a “temperature profile” is the inverse of the typical situation during the daytime, with the air nearer the earth’s surface being warmer and less dense than the air above it (Nowatzki 2018). Volatile herbicides applied before or during an inversion have the potential to move laterally off-target (Nowatzki 2018) and injure sensitive plants.

Considerations for Managing Herbicide Drift

In some situations, reducing spray drift may be difficult. The main considerations for optimizing herbicide spray schedules and limiting the potential for off-target movement are the product chemistry, the application conditions, and the application practices (Figure 2). A fact sheet describing these considerations for managing dicamba volatility and drift can be found at https://richland.extension.wisc.edu/files/2021/12/Understanding-Dicamba-Volatility.pdf (Grint and Werle 2021). Below are more considerations and context concerning the general factors that impact herbicide drift. No matter the circumstance, the label is the law: all of the guidelines and recommendations on the product label should be followed.
**Figure 2.** A generalization of factors that increase auxin herbicide drift potential.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Increases drift potential if:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>High (&gt;85 degrees F)</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>Low (&lt;50%)</td>
</tr>
<tr>
<td>Wind speed</td>
<td>High (&gt;10 mph)</td>
</tr>
<tr>
<td>Temp. inversion</td>
<td>Yes</td>
</tr>
<tr>
<td>Spray droplet size</td>
<td>Fine (&lt;150 microns)</td>
</tr>
<tr>
<td>Boom height</td>
<td>High (&gt; 2-3 ft above crop canopy or target)</td>
</tr>
<tr>
<td>Drift control agent</td>
<td>None included in spray mixture</td>
</tr>
<tr>
<td>Tank mix with other chemicals</td>
<td>Yes (ammonium sulfate, glyphosate, and others increase volatility potential of dicamba)</td>
</tr>
<tr>
<td>Spray solution pH</td>
<td>Acidic (≤5 pH for dicamba)</td>
</tr>
</tbody>
</table>
MANAGING HERBICIDE DRIFT

Product chemistry
The chemistry of the active ingredient can influence an herbicide’s vapor pressure, which correlates positively with its “volatility potential.” Thus, as the volatility potential increases, so does the chance that the herbicide will drift off-target. For example, Figure 3 shows the vapor pressure and volatility potential of the active ingredients in several herbicides. However, the volatility of the trade products that contain one or more of these active ingredients may vary depending on the chemical composition. Both 2,4-D and dicamba, for instance, are packaged in various formulations, some of which are more volatile and apt to vaporize than others. Specifically, 2,4-D ester has been shown to be more volatile and, therefore, potentially more injurious to off-target plants than 2,4-D choline and 2,4-D amine (Sysnoskie et al. 2015). The discussion below touches on several other factors that can affect the volatility potential of herbicides and, thus, impact their ability to move off-target.

Application conditions
Wind, temperature, humidity, and temperature inversions are among the meteorological conditions that can influence herbicide drift potential.

WIND
It is best to spray when the windspeed is low (3 to 10 mph). In general, winds are calmer early in the morning and late in the evening. Again, it is important to read the label carefully. For example, the labels of some dicamba products (e.g., Engenia and Xtendimax) specify that application must occur between one hour after sunrise and two hours before sunset to help reduce drift issues. Notably, though it seems counterintuitive, the application of volatile herbicides is not recommended under completely calm conditions because of the greater chance of a temperature inversion (as discussed further below). Spraying when the wind blows away from sensitive crops and other areas (public spaces, residences, etc.) is likewise recommended.
### Figure 3

Vapor pressure and “volatility potential” of several commonly used herbicides. Yellow to red correlates with lesser to greater volatility, respectively. Figure adapted from Grint and Werle (2021); [https://richland.extension.wisc.edu/files/2021/12/Understanding-Dicamba-Volatility.pdf](https://richland.extension.wisc.edu/files/2021/12/Understanding-Dicamba-Volatility.pdf).

<table>
<thead>
<tr>
<th>Active ingredient</th>
<th>Trade name (example)</th>
<th>Vapor pressure (mm Hg at 25°C)</th>
<th>Relative volatility potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glufosinate</td>
<td>Liberty</td>
<td>0.000000000009</td>
<td>Low</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>Roundup</td>
<td>0.00000098</td>
<td>Low-medium</td>
</tr>
<tr>
<td>2,4-D</td>
<td>2,4-D Ester</td>
<td>0.0000706</td>
<td>Medium</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>Treflan</td>
<td>0.0000458</td>
<td>Medium-High</td>
</tr>
<tr>
<td>Dicamba</td>
<td>XtendiMax</td>
<td>0.000125</td>
<td>High</td>
</tr>
<tr>
<td>Clomazone</td>
<td>Command</td>
<td>0.00014</td>
<td>Extremely high</td>
</tr>
</tbody>
</table>
TEMPERATURE AND HUMIDITY
Herbicides that are prone to volatilization (e.g., auxin products) should not be applied during periods of high temperatures and low relative humidity. The volatility of these herbicides increases as temperatures rise above 60°F and is greatest at temperatures above 90°F. So, generally, herbicides should not be applied when the temperature exceeds 85°F. However, an herbicide such as glufosinate (e.g., Liberty) provides much better weed control under hot, humid, and sunny conditions, and this kind of herbicide is not prone to volatility issues like others.

TEMPERATURE INVERSIONS
Again, herbicides should not be sprayed during temperature inversions (Figure 4) because small spray droplets may become trapped in the layer of cool air near the earth’s surface and, being unable to move upward, instead move laterally. Inversions usually start to form around dusk and continue through the night into early morning. Common indicators of temperature inversions include nights that are clear and calm (winds < 3 mph) with little cloud cover and minimal wind, the presence of dew, fog, or frost, horizontal smoke patterns, and ground fog in low-lying areas; in addition, distant sounds may be easy to hear and odors may be especially distinct.

Application practices
The following considerations can help reduce the chance of herbicide drift associated with application practices.

SPRAYING PRESSURE
Low spraying pressures create large droplets, which are less likely to drift or volatilize. The droplets that nozzles produce may vary depending on the pressure, for instance, medium droplets being produced at low pressure and fine droplets at high pressure. However, some drift-reducing nozzles, though designed for high pressures to increase the spray coverage, produce droplets that are less prone to drift relative to other nozzle types. In most cases, contact herbicides such as Gramoxone, Liberty, Reflex, and Cadet should be applied using nozzles that produce medium to coarse droplets. Thus, some of the newer drift-reducing nozzles may not provide the best spray coverage for weed control, but increasing the spray volume can improve the coverage.
Figure 4. Typical air temperature stratification where the air near the earth’s surface is warmer than the above air (left); a “temperature inversion” where air is cooler near the earth’s surface and warmer above. Figure adapted from Doohan et al. (2023); https://ohioline.osu.edu/factsheet/anr-0137. Graphic by Gretchen Wieshuber.
CARRIER VOLUME/APPLICATION RATE
If possible, it is better to use 20 gallons or more per acre than 10 gallons or less per acre. Larger and heavier droplets fall more quickly to the target and are less affected by air movement during spraying. Thus, it can be wise to use a higher spray volume to reduce drift. When increasing the spray volume, it is usually necessary to use a nozzle with a larger orifice to produce spray droplets at lower pressure while maintaining a similar tractor speed.

USE OF PROPER NOZZLES FOR COARSE SPRAY DROPLETS
Several companies manufacture nozzles that are designed to reduce drift, including TeeJet’s AI, AIXR, and TTI and Greenleaf Technologies’ TurboDrop XL and Hypro Ultra Low Drift (as noted in Peters et al. 2017). Of course, after the proper nozzle has been selected, the proper speed, pressure, and output must be determined and achieved as demonstrated in the video “Boom Sprayer Calibration,” https://extension.psu.edu/calibration-how-tos-easy-way-to-sprayer-calibration. The standard nozzle droplet size ranges from extremely fine (< 60 microns) to ultra-coarse (> 655 microns). The use of coarse nozzle sizes increases the droplet size and reduces the chances for herbicides to become suspended and move in the air.

SPRAY BOOM HEIGHT
The boom height correlates with the chance that an herbicide will move laterally in the air because of the increased distance from the targeted weed. It is also important to use nozzles with a spray angle of at least 110 degrees to allow the boom to be lowered more than the nozzles with lesser angles while maintaining the proper spray pattern and overlap. In general, for a boom with 20-inch nozzle spacings, a boom height of approximately 24 inches should be maintained above the crop canopy or target weeds when spraying in a burndown or fallow setting.

SPRAYER GROUND SPEED
At tractor speeds greater than 10 mph, the boom bounces and spray vortexes occur, sending spray droplets high into the air.
USE OF “HIGH-TECH” SPRAYERS
Some of the new sprayers use a pulsing system with modulation to optimize application and reduce drift. Notably, though, some of these new sprayers increase the pressure to maintain output when the ground speed increases, thus producing additional fine droplets.

USE OF DRIFT RETARDANTS AND OPTIMAL TANK MIX CHEMISTRY
There are many good products on the market for this purpose. However, some are not compatible with certain drift-reducing nozzle types. Certain spray adjuvants can improve the deposition of herbicides on their intended targets. “Drift reducing” or “drift control” agents are tank mixed with herbicide solutions to reduce the number of fine particles and/or increase the average particle size to “coarse” (i.e., 250-500 microns).

BUFFER ZONES FOR SENSITIVE CROPS IN ADJACENT FIELDS
A buffer of at least 250 to 300 feet between sprayed areas and sensitive areas can reduce the risk of herbicide drift. If the buffer is included as part of the production area, it should be treated with different products that will not affect the sensitive crop and/or be sprayed at a different time to avoid injuring the sensitive crop. Another option is to plant a cover crop in the buffer zone that can be injured or killed without economic loss if spray drift occurs.

NEIGHBORING FIELDS AND PRODUCTION SYSTEMS
While not necessarily a drift-reducing practice, scouting neighboring fields and understanding the local management systems and types of commercial crop production will help to determine whether herbicide-sensitive plants are grown nearby. A free online tool is available called DriftWatch that helps to identify nearby sensitive crop production systems (https://driftwatch.org). On the site, growers of herbicide-sensitive crops can enter their information to alert those who plan to apply herbicides (who should consult the platform before applications are made) where their crops and production systems are located.
Herbicide Drift
Considerations for Vineyard Managers

Vineyard owners and managers should be aware that grapevines are highly sensitive to herbicide damage (Culpepper et al. 2018). Thus, vineyard managers should be aware of nearby industries that use auxin herbicides in their management systems, including but not limited to row crop farms, right-of-way/roadside management, pastureland, and residential and commercial turfgrass and ornamental landscape management.

Herbicide drift damage can happen throughout the grapevine growth cycle but is typically observed by grape growers in May, June, and early July in Pennsylvania. The growth stage at which grapevines are most sensitive to herbicide drift damage is unclear because the large number of variables involved (cultivar genetics, environment/weather, the health and age of the vine, the type and concentration of the herbicide, and disease pressure, to name a few) make this question difficult to settle using applied science and experimental designs.

Collective observations and logical scientific reasoning suggest that the growth stages between bud break and fruit set (Figure 5) are sensitive to herbicide damage in the current season. This is the time when vines have relatively low vegetative biomass and sensitive tissues (e.g., buds, inflorescences) are developing into the current season’s crop. Unfortunately, it is during these stages (which typically occur from April through June) when auxin herbicides are often used to manage weeds in other production systems. Given their low biomass, it seems likely that newly planted and/or low-vigor vineyards are more susceptible to herbicide damage of any type or stress than mature and/or highly vigorous vineyards.

Observations from the field suggest that the damage caused by particle drift, which, again, occurs when the movement of air channels large herbicide particles off-target at the time of application, is easier to diagnose and observe than the damage caused by vapor drift. The damage from particle drift is often intense on one side or edge of a vineyard block and fades farther toward the center of the block whereas damage from vapor drift tends to be spottier throughout the vineyard.
FIGURE 5

The growth stages between which herbicide damage can have remarkable impact on current season vine growth and crop yield. Figure adapted from UGA Extension Circular 1151: https://extension.uga.edu/publications/detail.html?number=C1151. Graphic by Megan McCoy.
and with less of an identifiable pattern. In one case, grapevines that sustained extensive particle drift damage in a vineyard in Pennsylvania (Figure 6) were able to recover the following growing season and produce a typical commercial crop. Notably, these vines were well-managed, relatively vigorous, and approximately eight years old; results may vary in the case of suboptimal vine management and health status, or in young vines. The authors have not evaluated the impacts of herbicide damage in year one on vine productivity and health in year two; results would likely vary by herbicide damage extent and timing, vine age and health status, and other factors.

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**Scouting for and reacting to herbicide damage to vineyards**

**WHEN TO SCOUT**

Vineyard managers should scout their vineyards at least weekly for pests and abiotic stress symptoms. Scouting is especially important during the growing season (April through October). Herbicides are used across a wide spectrum of management systems with various goals and targets, and auxin herbicides are generally and variably sprayed from April through October throughout Pennsylvania. When scouting for herbicide damage in vineyards, the phenomena to be considered include (1) the critical timeframe between bud break and fruit set, (2) the emergence of weeds and their management through the application of auxin herbicides across several management systems, and (3) the air temperature and, thus, potential volatility of the herbicides. Taken together, these considerations indicate that it is important to scout vineyards for herbicide damage from April through October, but especially from May through July in Pennsylvania.

**WHAT TO SCOUT FOR**

Symptoms vary highly depending on factors such as the active ingredient causing the damage and its concentration, the severity of the drift, the grapevine cultivar, and the growth stage. Moreover, many tank mixes contain multiple active ingredients, so it may not be obvious which active ingredient(s) caused the
Figure 6. Herbicide damage (likely from particle/droplet drift) effects on Chardonnay. Symptoms were most evident near the edge of the block immediately adjacent to the field where herbicide was applied. A “commercially acceptable” crop yield was harvested from this same block the year following herbicide damage.

Figure 7. Herbicide damage in grapevines. Symptoms resemble those associated with 2,4-D damage (left) and dicamba damage (right). Photo on right courtesy of Dr. Rob Crassweller.
symptomology. Typically, particle drift causes severe, “textbook” damage symptoms (Figure 7) while the symptoms of vapor drift are often less obvious and scattered throughout sections of vineyards (Figure 8). The symptoms of herbicide drift damage may occur on the foliage and clusters and are generally not seen throughout the entire canopy unless the damage is from severe particle drift and/or occurs early in the season when the canopy is small. The less obvious symptoms often require training to identify.

Herbicide drift and sensitive plants: what to do if drift is suspected

A recent article by Lingenfelter (2019) noted that herbicides are commonly used in Pennsylvania to control weeds and vegetation and are a valuable tool when applied correctly. Sometimes, though, they move off-target for various reasons and can injure or kill desirable crops or other plants. When this happens, it is critical to act quickly to determine the cause, and it can be useful to report it immediately. Below are some key points to consider if you suspect herbicide has drifted onto your property.

I SUSPECT HERBICIDE DRIFT . . . NOW WHAT?
The Bureau of Plant Industry at the Pennsylvania Department of Agriculture (PDA) regulates pesticides (herbicides, insecticides, fungicides, etc.), their application, and those who apply them. If you believe that the drifting of a pesticide has adversely affected plants on your property and want to initiate an investigation, please do not wait to call the PDA. Some pesticides break down quickly in sunlight or are metabolized rapidly by vegetation, so, the sooner after the pesticide application the department can collect samples, the better the chances are of identifying the pesticide through laboratory analysis.

To report a pesticide drift incident, contact your regional PDA office (Figure 9) or visit http://www.agriculture.pa.gov/regional-offices/Pages/default.aspx and ask for “Plant Industry.” Alternatively, contact your local Penn State Extension office for additional help: https://extension.psu.edu/county-offices
Figure 8. Herbicide damage on cultivated grapevines; note that the causal active ingredient in these situations may be less obvious.
The steps of a typical pesticide investigation to determine whether drift has occurred are as follows:

- a complaint is filed with the PDA,
- an inspector contacts the complainant to gather facts about the incident,
- the inspector may take environmental samples and send them to the PDA lab for pesticide analysis,
- the inspector contacts the party suspected of pesticide misuse to conduct an investigation and inspect records,
- regulatory action is taken if pesticide violations are found, and
- the case is closed once the action is settled or if no pesticide violations are found.

Other steps to consider include

- taking notes to document the date and growth stage of the affected plants when the symptoms first appear,
- taking good-quality (high-resolution) photographs of injury symptoms at least weekly until the symptoms subside, and
- identifying the area affected and flagging both affected and unaffected plants for future reference.

What are the options for receiving compensation for damaged plants?

While agriculture and pesticide laws vary by state, the general goal should be to limit herbicide drift. In Pennsylvania, it is unlawful to cause unwanted pesticide to drift or trespass onto another person's property, but enforcement is complicated by the difficulty of determining the responsible party.

So, again, if drift is suspected, the first step is to contact the PDA and request an investigation. If the department determines that drift has occurred, the offending party is subject to penalties. Notably, the penalties issued and fees charged by the PDA are not conveyed to the injured party. In other words, even when it is proved that drift occurred, the landowner with damaged crops does not receive financial compensation for the damage from the department. Landowners who wish to be compensated for damage to their plants and
Figure 9. Regional PDA Office map and corresponding phone numbers.
property must take additional steps, either initiating a lawsuit or resolving the matter informally.

In both cases, the landowner with damaged crops should initially contact the PDA and also consider paying a private testing facility to provide a full data report for use in court or in negotiations with the party responsible for the pesticide drift. Such testing can be expensive, and the cost should be weighed against the losses when making the decision to initiate a lawsuit. The next step in initiating a lawsuit is to contact an attorney. Agricultural attorneys can be found online, and the local county bar association is a good place to start. The Pennsylvania Bar Association lists these associations on its website here (https://www.pabar.org/public/legalproflinks/lcbassociations.asp). The attorney estimates the losses and provides guidance through the lawsuit. Pesticide drift can be difficult to prove in court, especially if multiple nearby farms utilize pesticides. In addition to being costly, lawsuits are often time-consuming. The landowner with damaged crops should, therefore, estimate the costs with their lawyers and clarify what they hope to achieve with a lawsuit.

Alternatively, a landowner with damaged crops may resolve the matter informally with the responsible party by negotiating compensation for the damaged property. In many cases, however, these efforts become combative.

Landowners with damaged crops who wish to avoid expensive litigation but have concerns about attempting informal negotiations on their own may choose to negotiate through a mediator. In Pennsylvania, landowners affected by pesticide drift can turn to the Pennsylvania Agricultural Mediation Program; requests for mediation can be filed and questions asked through the website (www.PAAgMediation.com). When a request has been received, a neutral third-party mediator is assigned to the case who reviews the details and works with the parties to select a mutually agreeable time to meet, whether in person or online through Zoom. The mediator does not act as a judge but, rather, helps the parties come to a compromise. This program is currently free for the participants.
Other resources

Pennsylvania Department of Agriculture: http://www.agriculture.pa.gov

Bureau of Plant Industry: http://www.agriculture.pa.gov/Plants_Land_Water/PlantIndustry/Pages/default.aspx

PaPlants: https://www.paplants.pa.gov/Index.aspx

Herbicide Drift and Drift Related Damage: https://extension.psu.edu/herbicide-drift-and-drift-related-damage

Burndown Herbicides, Drift, and Vineyards: https://extension.psu.edu/burndown-herbicides-drift-and-vineyards

Herbicide Drift and Sensitive Plants: What to do if Drift is Suspected: https://extension.psu.edu/herbicide-drift-and-sensitive-plants-what-to-do-if-drift-is-suspected

Pennsylvania Agricultural Mediation Program, operated by Penn State: https://aglaw.psu.edu/pennsylvania-agricultural-mediation-program/


Leaf Index and Severity Rating & Leaf Index Report: http://feql.wsu.edu/eb/

Herbicide Injury and the Problem of Spray Drift: https://ohioline.osu.edu/factsheet/anr-0137
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