Drifting Toward Disaster

How Dicamba Herbicides are Harming Cultivated and Wild Landscapes

National Wildlife Federation

prairie rivers network

XERCES SOCIETY for Invertebrate Conservation

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***Cover images: Front cover (left to right):** Symptoms of herbicide injury on showy milkweed. Credit: Xerces Society/Brianna Borders, Wetland habitat between corn fields. Credit: Will Parson/Chesapeake Bay Program - Flickr, Brown belted bumblebee on purple prairie clover. Credit: Xerces Society/Katie Lamke, Natural habitat bordering agricultural field. Credit: Rick Herrmann - Flickr, Blue-grey Gnatcatcher with Insect. Credit: Rob Kanter - Flickr, Narrow-leaved purple coneflowers in mixed-grass prairie. Credit: USFWS Mountain-Prairie - Flickr. **Back cover (left to right):** Eastern American toad. Credit: Steven Kersting/Flickr, Diverse Midwestern prairie. Credit: Michael Ware, Viceroy. Credit: Rob Kanter, Common milkweed in soybean field borders. Credit: Courtney Celley/USFWS, Cellophane bee on pussy willow. Credit: Jason King/Flickr, Farmers and technical advisor in soybean field. Credit: Lance Cheung/USDA/Flickr.*

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Redbud with irregular margins and cupping. Credit: Martin Kemper.

Executive Summary

Widespread Use of Dicamba Threatens Ecosystem Health

More than five million acres of crops, an area roughly the size of New Jersey, have been injured by the herbicide dicamba since the U.S. Environmental Protection Agency (EPA) conditionally registered three new formulations for in-crop applications in dicamba-resistant soybeans and cotton in 2016. Damage from this highly mobile herbicide does not stop at the field edge: dicamba drift places tens of millions of acres of wild and ornamental plants—and the wildlife these plants support—at risk.

Dicamba is highly volatile, easily evaporating from plant and soil surfaces, and can continue volatilizing days after application. Thousands of pesticide injury complaints over the past three years in states across the Midwest and South demonstrate that increasing dicamba use is causing injury thousands of feet from treated crop fields, especially during temperature inversions and in warm weather. Much of this damage is difficult to monitor, document, and investigate—and is not covered by federal crop insurance.

"The drift has been trespassing onto our land and damaging both our crops and conservation land, which is damage to taxpayers' dollars. However, the way the system currently works, it just pegs farmer against farmer, neighbor against neighbor, and leaves the whole area damaged both physically and socially."
Dallas Glazik, Cow Creek Organic Farm co-owner and operator

Investigating claims of damage can be intrusive, time-consuming, and damaging to community relationships, resulting in both social strife and economic loss for farmers.

States have implemented a patchwork of regulations to address off-target injuries, but changes to already complex label language and increased applicator training requirements have not been effective in preventing off-site dicamba movement and injury. The majority of reported injuries clearly coincide with the widespread planting of dicamba resistant soy and cotton and the associated increases in mid-season over-the-top applications. There are also some concerns with other uses of dicamba and related phenoxy herbicides throughout the growing season.

The use of the new formulations of dicamba that allow for over-the-top use has not gone unchallenged. The EPA was forced to cancel the registration of three dicamba products in 2020 after a federal appeals court ruled that the EPA's approval of them had "substantially understated" or "entirely failed to acknowledge" multiple risks associated with dicamba. Despite this court ruling, along with a recent $400 million settlement that compensates farmers for dicamba-related crop damage, the manufacturers are pursuing new registrations for these products for the 2021 growing season. As dicamba herbicides move off their intended application site, they pose threats to wild plants and the wildlife that depend upon them. Loss of native plants and declines in forage quality poses risks to bees and other beneficial insects that rely on pollen and nectar for food. These risks ripple through numerous food webs, including those of birds, which rely on a wide variety of plants and invertebrates for food resources. This report will discuss what's known about the wider ecological impacts of dicamba and related herbicides to native plant communities and the wildlife they support, and provide a few short-term and long-term recommendations for reducing environmental harm from these volatile herbicides.

Post oak with deformed and stunted leaves. Credit: Martin Kemper.


Short-eared owl in corn field. Credit Rob Kanter.

Recommendations

Mounting evidence suggests that current dicamba products and uses are causing unreasonable adverse effects on the environment, even when used exactly as specified on the labels. Based on what is known of the impacts of dicamba on off-target species, we have the following recommendations for any future decisions on reregistering dicamba for agricultural use:

- The EPA should not renew over-the-top product registrations unless and until independent research shows with certainty that dicamba formulations will not cause off-target injury to crops and wild plants, including from vapor drift.

- The EPA should include a full risk assessment for animal and plant species listed under the Endangered Species Act, migratory birds, native pollinators, and aquatic life that includes direct and indirect effects from exposure to dicamba due to drift, volatilization, and runoff.

- The USDA should reject petitions for the deregulation of additional dicamba-resistant crop varieties that would result in increased use of dicamba, unless and until independent research shows with certainty that associated dicamba formulations will not cause off-target injury to crops and wild plants, including from vapor drift.

- Sustainable weed management includes adoption of multiple approaches to managing weeds rather than an overreliance on herbicide-only weed control. Greater investment is needed to support research on integrated weed management and the ecological impacts of herbicide use. Financial resources are also needed to support the development of economic and behavioral drivers that will increase adoption of these multi-tactic approaches to weed management.

For a comprehensive list of all our recommendations please refer to page 34.

Introduction

Since their introduction in the mid-20th century, herbicides have largely replaced other weed management strategies on American farmland. Starting in the 1990s, certain crops were genetically engineered to withstand the herbicide glyphosate (i.e. glyphosate resistant) which was found to be extremely effective in controlling perennial weeds. Herbicide-based weed management was simple and cost-effective, and by 2015, glyphosate-resistant corn, cotton, and soybean varieties were planted on more than 85% of their respective crop acreages.[1] However, the near-universal adoption of glyphosate-resistant crop technology for weed control led to the development of substantial weed resistance to glyphosate. Glyphosate-resistant weed species have emerged in at least 120 million acres of row crop fields, particularly in the Midwest and mid-South.[2] Loss of efficacy has fueled farmer demand for new herbicide options to combat resistant weeds in crop fields.

Palmer amaranth, a highly competitive annual weed in row crops like soybean. Credit: United Soybean Board/Flickr.

Dicamba was first introduced in the 1960s and has been widely used for broadleaf weed control in crops, lawns, and turfgrass. Dicamba and the similar herbicide 2,4-D are synthetic auxins, or growth regulator herbicides that mimic plant hormones and disrupt growth in broadleaf plants, including many weeds. In crops, these pre- and post-emergent herbicides have historically been used at the beginning of the growing season to "burn down" annual broadleaf weeds to prepare crop fields for planting.

Dicamba and several other related growth regulator herbicides are volatile compounds with a relatively high vapor pressure—meaning they are more likely than other herbicides to evaporate and move away from the site of application as vapor drift. Nontarget crop and wild plant injury from dicamba vapor drift has been a recurrent issue for over five decades, and has generally limited the allowable uses and popularity of dicamba in or near broadleaf crops until new products marketed as lower volatility were released in the past few years.

Since 2015, several companies, including Monsanto (recently acquired by Bayer), BASF, Dow Agrosciences and DuPont (now DowDuPont, with the agricultural division Corteva Agriscience), have released proprietary crop seeds resistant to dicamba (Xtend soybeans, XtendFlex cotton) or 2,4-D (Enlist), and/or new formulations of dicamba or 2,4-D herbicides intended for in-crop use with these seed technologies.[3] The seeds are generally dually resistant to glyphosate as well as dicamba or 2,4-D, with some seed products also resistant to the herbicide glufosinate (Liberty, *While early season burndown use of dicamba herbicides has always posed some concerns, the level of drift injury has spiked since the introduction of new in-crop formulations used later in the season, when temperatures are higher.*

Dicamba is commonly applied early in the season to control emerging weeds. Credit: Chafer Machinery/Flickr.

manufactured by Bayer). The new herbicide formulations, released in time for the 2017 growing season, were marketed as being able to reduce ***vapor drift,*** or the movement of the gaseous form of an herbicide that has ***volatilized*** from its liquid or solid form to a vapor. In order to reduce ***particle drift,*** or the movement of solid droplets of herbicide solution away from application equipment, the labels of the new formulations were modified, outlining more strict application guidelines than those of older formulations.

Since the U.S. Environmental Protection Agency (EPA) conditionally registered three formulations of dicamba—Bayer-Monsanto's XtendiMax, BASF's Engenia and Corteva's FeXapan—for over-the-top crop applications in dicamba-resistant soy and cotton in late 2016, there have been widespread reports of dicamba drift and damage to both crops and natural areas. The amount of dicamba applied to all US crops more than doubled in 2017 relative to 2016, driven by the increased use in soybeans and cotton, and an estimated 3.6 million acres of non-dicamba resistant soybeans were injured at some point during the year.[4-6] No estimates are available for the acreage of vulnerable wild plants injured by off-target herbicide movement, but complaints to weed scientists and state departments of agriculture about suspected dicamba injury to trees, vegetables, ornamental plants and commercial nurseries were higher in 2018 than previous years.[7]

Dicamba-resistant crops are a self-reinforcing technology. As soon as some growers in an area adopt the new technology, nearby soybean growers are pushed to also purchase and plant resistant seeds to avoid the risk of off-target injury to their vulnerable soybean crops.[8] These growers may not be intending to use over-the-top (mid-season) herbicides for weed management, but plant the resistant seeds to avoid yield losses from herbicide use in nearby fields. However, after planting the seeds—having paid for the genetic trait—growers may become more inclined to start using the herbicides that are marketed for use with those seeds.

While dicamba application has typically been limited to early in the season, before sensitive crops have emerged and before many wild plants have leafed out, injuries do occur when spring temperatures are warm and farmers are spraying for pre-emergent weed control. Many trees, shrubs, and other plants that are critical sources of nectar, pollen, nuts, seeds, and cover for wildlife are very sensitive during this springtime spray, when they are in stages of bud-swell and leaf emergence.[9] Instructions from dicamba product labels confirm the risk to sensitive plants during growth and development stages; for instance, the Clarity® product label states, "Clarity may cause injury to desirable trees and plants, particularly beans, cotton, flowers, fruit trees, grapes, ornamentals, peas, potatoes, soybeans, sunflowers, tobacco, tomatoes, and other broadleaf plants when contacting their roots, stems, or foliage. These plants are most sensitive to Clarity during their development or growing stage".[10]

However, while early season burndown use of dicamba herbicides has always posed some concerns, the level of injuries has been unprecedented since the adoption of the new herbicide-resistant technologies that allow for the use of these volatile herbicides to continue later into the growing season when temperatures are higher. The spike in complaints related to dicamba injury in 2017 was clearly linked to increased use of the new over-the-top formulations, with 93% of dicamba complaints in Indiana tied to use in soybeans.[11] Volatility of dicamba increases with temperature. Mid-season over-the-top use of dicamba, when temperatures are higher, increases volatilization and risk of injury to sensitive crops and wild plants.

Early reports from 2020 suggest that dicamba injury may be even more widespread than in 2017–2019. Weed scientists from Iowa State University reported that "dicamba injury across the Iowa landscape in 2020 is the most extensive it has been since the introduction of dicamba in the 1960s."[12] The authors point to the short window for over-the-top applications that met label instructions, followed by high temperatures and low rainfall the week after the application window. Dicamba applications were made across the landscape at roughly the same time and then residues volatilized under high temperatures, leading to high 'atmospheric loading' of dicamba and near-universal damage across thousands of acres of non-resistant soybeans. The authors go on to acknowledge that while the focus is on damage to soybeans, "it is not difficult to find injury symptoms on other plants in the landscape."[12]

It is important to recognize that the use of the new formulations of dicamba that allow for over-the-top use have not gone unchallenged. In June 2020, a federal appeals court vacated the conditional registrations for three over-the-top dicamba herbicides, stating that EPA's approval of them "substantially understated" or "entirely failed to acknowledge" multiple risks associated with dicamba.[13] While unregistered products generally cannot be legally sprayed on crops or sold for use, the EPA's cancellation order allowed for use of existing stocks of the three herbicides through July 2020. The manufacturers will likely be pursuing new registrations for these products for the 2021 growing season.

The use of dicamba—from pre-planting weed control to mid-season application—presents unreasonable risks to wild plants as well as the pollinators and other wildlife in agricultural landscapes that depend on them. The lack of research and attention paid to non-crop impacts of this herbicide use is alarming. In this report, we outline the current understanding and the need for further research on impacts to various species from dicamba. While concerns around drift apply to other phenoxy herbicides such as 2,4-D— which has also seen increasing use and associated off-site injury complaints in the past year—this report is focusing on dicamba, given the upcoming registration decisions for over-the-top dicamba products in 2020. This report highlights the threats to non-target crops, wild plants, and other wildlife from the use of dicamba herbicides, and provides a few short-term and long-term recommendations for reducing environmental harm from these volatile herbicides.

Damage from volatile herbicides does not stop at the field edge. Dicamba drift places wild plant communities and the wildlife that depend on them at risk. Credit: J. Franklin Egan, Penn State University.

Soybean spray. Credit: United Soybean Board/Flickr.

Dicamba: What's the Problem?

Dicamba evaporates easily from plant and soil surfaces, even at lower temperatures, and can continue volatilizing days after application. High temperatures (of air, leaves, and soil) and low humidity—common during mid-season months—exacerbate the risk of volatilization. Temperature inversions, or conditions where there is a layer of cool air close to the earth's surface with warmer air above, can allow droplets containing herbicide to remain suspended in the air and travel long distances before being deposited on the surface of unintended plants.

Growth regulator herbicides can injure plants at very low doses—even at 0.005% of the labeled use rate on soybeans, which are highly susceptible. Plant injury symptoms include twisting, leaf curling, cupping, stunting, vein discoloration, fruit delay or abortion, and in extreme cases dieback and death. Expression of injuries can vary widely due to many factors including but not limited to species, plant age, growth stage, and herbicide exposure rate.[14] Numerous trees, vines, shrubs, and herbaceous broadleaf plants have shown sensitivities to volatile growth regulator herbicides including dicamba and 2,4-D.

Off-target herbicide damage to crops, trees, and native plants has been occurring for decades. In fact, when dicamba-resistant seeds first hit the market in 2016, early reports of off-target damage were largely assumed to occur due to applications of older herbicide products to dicamba-resistant soybeans, as the Xtend seed technology was approved by the U.S. Department of Agriculture (USDA)—and planted—before the EPA had approved corresponding 'low-volatility' herbicide formulations intended for in-crop rather than early season use.[15]

However, the new products formulated for over-the-top use did not solve the problem with dicamba volatility. Despite implementation of stricter label language, and required applicator training on minimizing off-target movement for the 2018 growing season, plant injury from off-target movement of dicamba remained a significant issue.[16] Even with several states having made efforts to reduce injuries through the use of stricter 24(c) labels for dicamba applications, there continued to be an increase in injury complaints, with a high level of injuries reported across many states in 2019.[17] These documented cases of injuries from dicamba drift are likely just the tip of the iceberg, as many more cases—particularly of wild plants—go unreported.

Many pesticides can have a synergistic effect when they interact, with one another, either in the air, in water, on a plant surface, or when mixed in a tank at the time of application. There are also the additive impacts of plants that experience drift exposures of multiple herbicides as a result of tank mixing or from separate exposures occurring throughout the growing season. Additionally, how pesticides are mixed can have a large impact on their behavior and efficacy. Farmers and applicators often mix multiple pesticides in a tank for a single application to reduce costs or to improve efficacy across a wider range of target species. However, tank mixing with certain chemicals may increase the risk of dicamba volatilization. Tank mixing dicamba with glyphosate or ammonium sulfate, as is often recommended on labels and by crop consultants or Extension services to improve herbicide efficacy or uptake by weeds, decreases the pH and increases the volatility of these dicamba products.[18] Tank mixing with glyphosate increases dicamba concentrations in the air by 2.9 to 9.3 times relative to dicamba applied alone, with higher concentrations at higher temperatures.[19]

In addition to the widespread adoption of the new in-crop dicamba products (FeXapan, XtendiMax, Engenia, Tavium), farmers are increasingly applying dicamba-based herbicides (e.g., Clarity, DiFlexx, Status) over the top in corn to control glyphosate-resistant broadleaf weeds such as waterhemp and Palmer amaranth. These herbicide applications also raise concerns about volatility, drift, and off-target injury to susceptible crops and wild plants, although the number of dicamba injury reports related to use in corn was much lower than those tied to over-the-top use in dicamba-resistant soybeans in states that reported those figures.[11,20]

Many pesticides can have a synergistic effect when they interact with one another, either in the air, in water, on a plant surface, or when mixed in a tank at the time of application.

Farmers and applicators often apply multiple pesticides in a single application to reduce costs or improve efficacy. However, tank mixing dicamba herbicides may increase their potential for volatility and drift. Credit: United Soybean Board/Flickr.

Damage is Under-Reported and Under-Documented

The US EPA usually works with one agency in each state to regulate and monitor pesticide use. The typical method of documenting pesticide incidents—such as drift, overspray, or injury to unintended crops, animals, or contamination of facilities—is through a complaint process overseen by a state plant board, department of agriculture, or similar regulatory agency. Pesticide enforcement on tribal lands is typically overseen by either the EPA or a tribal designee. Injuries to non-crop plants and ecological areas can be reported to the Ecological Pesticide Incident Reporting Portal at http://npic.orst.edu/eco/. However, little is known about how frequently this portal is used, or how well known this resource is to the general public.

If a farmer or landowner suspects that the injury to their plants is herbicide related, they may choose to file a complaint with their state's pesticide regulatory enforcement agency. A formal complaint, outlining what is known about the injury (timing, physical description, weather, location, etc.) is submitted. Typically, a field visit occurs, and an agency representative will evaluate the injury and if necessary, further investigate the claim by taking a tissue sample and inquiring with surrounding landowners about pesticide use. Inquiries often include examinations of surrounding landowners' records of pesticide

The EPA's definition of drift excludes volatility or vapor drift because it can occur days after application and cannot be fully controlled by the applicator. As a result, little is being done to protect crops and wild plants from injury due to volatilization.

Curled and cupped Northern catalpa leaves. Credit: Landowner in Eastern Nebraska.

application and disposal. If no application or disposal regulations or guidelines were broken, and the applicator(s) were not found to have applied the pesticide illegally, then generally no fault is found. This is frequently the case with instances where volatility, or vapor drift are the cause of off-target injury. When injury is caused by vapor drift and the applicator followed all guidelines, no fines or penalties can be given.

Currently, the EPA's official definition of drift excludes volatility or vapor drift because it can occur days after application and it is inherently uncontrollable by the applicator. While applicators should not be penalized for following guidelines, the end result is that very little is being done to protect specialty growers, natural areas, and wildlife habitat from herbicide injuries that are a result of volatilization.

It is widely acknowledged that only a small percentage of actual damages to crops and private lands are reported to agencies and that the current uptick in reporting has overwhelmed many offices; one survey of Missouri farmers, pesticide applicators, and crop advisors estimated that over 70% of dicamba injury in 2019 went unreported.[21] Another study that surveyed growers for dicamba injury on non-dicamba resistant soybeans, found that of the survey respondents reporting injury (51%) only 7% actually filed a complaint.[20] The majority of the complaints being received are crop-related. The injuries to non-crop species, such as trees in private residences, forested lands, and other natural areas that provide crucial habitat for wildlife, are likely not often recognized and are therefore even more underreported. It is unknown how many of the formal complaints submitted are for trees and other non-crop broadleaf plants.

There are numerous reasons why suspected pesticide injuries are not reported. Perhaps the most common reason is the reluctance of farmers and landowners to file a complaint against a neighbor. There is often intense social pressure against complaining about the way your neighbor is farming or accusing them of wrongdoing, even if one's own crop or property is damaged. Many farmers and landowners make an effort to have good communication and strong relationships with their neighbors. Investigating claims of damage can be intrusive, time-consuming, and harmful to community relationships, resulting in both social strife and economic loss for farmers.[20]

With the increase in the use of these highly volatile herbicides, symptoms of off-target impacts are being observed far from agricultural fields, well beyond the distance of recommended set-backs printed on the herbicide labels. Therefore, a lack of information and awareness is another reason for underreporting. Many landowners and managers that are not in an agricultural community are not aware of the pesticide injury reporting process for their state, and once they find it, they are often perplexed and intimidated by the process and simply decline to proceed. Compounding this issue is the fact that many rural and residential landowners are also not aware of the common symptoms of growth regulator herbicide injury and therefore symptoms go unnoticed, or may be mistaken for disease, pests, or other injuries.

This underreporting means the extent of the problem is widely underestimated, and data are lacking on the frequency, timing, patterns, and geographic range of injuries.

This underreporting means the extent of the problem is widely underestimated, and data are lacking on the frequency, timing, patterns, and geographic range of injuries. This is particularly troubling since state regulatory agencies often use the number of documented cases of herbicide injury as a tool for decision making, regulatory action, and gauging the efficacy of certain restrictions on the use of a pesticide.

The rise in these injuries is also occurring during a time when many state and federal ecological monitoring programs are being cut back or eliminated for budgetary reasons. Many agencies are also understaffed and/or do not have funds to do the critical ecological monitoring required to protect ecosystems under the threats of climate change, increased pesticide use, and disease and pest pressures.

Monitor, Report, Protect: How Can You Help?

Rosinweed twisting. Credit: Kim Erndt-Pitcher/Prairie Rivers Network.

Curling, stunted and deformed leaves. Credit: Martin Kemper.

Elongated leaves in Burr oak. Credit: Martin Kemper.

Dicamba damage — recognizing it. If you suspect your trees may have herbicide damage, first become familiar with the most common leaf symptoms: cupping, curling, twisting, elongation, or stunted, smaller leaves. You may also see some branch dieback. There are many places where you can find photographs of trees and plants that have received herbicide damage, such as university extension plant health guides and reputable tree and plant health resources on the internet.

Dicamba damage — reporting it. The EPA has a short overview of dicamba complaint reporting here. If you suspect the off-target movement of dicamba has caused damage to a crop or other landscape or garden plants, submit a complaint over the phone or using the online reporting form (if available) through your state Department of Agriculture or your state Pesticide Regulatory Agency. See this example reporting form from the Minnesota Department of Agriculture for an idea of the information to have on hand before submitting a complaint. Some states have forms that are a bit outdated or ask for very specific information about the incidence, some of which you may not know. If you are unable to answer some of the questions, you can call your local agency representative for assistance or do your best and send in the report. A field representative will likely get in touch with you shortly regarding your complaint.

Document symptoms in addition to reporting. While it is important to report symptoms to your local agency that regulates pesticide use, it is just as important for you, the landowner to document suspected injuries. First be sure the injury is not something you caused yourself! Many lawn care products contain herbicides that kill broadleaf plants and these chemicals can move through the soil or volatilize and injure your trees and plants. If herbicide injury has occurred to your property, symptoms will likely be present on more than one plant type or species in the area. It is good practice to examine trees, vines, shrubs, and/or several types of herbaceous plants in the area for symptoms, this can help rule out other causes of injury. When you notice symptoms, document them immediately, noting the date, plant name, location, and any important notes. Also include several photographs. It is best to get a couple close-up photos of symptomatic leaves as well as one or two of the whole plant or tree. Be sure to also take note of the symptoms you observe such as leaf cupping, stunting, elongation, twisting, or branch dieback, etc.

Yellow-breasted chat with insect. Credit: Rob Kanter.

Communicate with your neighbors as much as possible. If you have plants and trees that you think are showing symptoms of herbicide exposure it is always a good idea to speak with your neighbors and let them know. They may not be aware your plants are showing symptoms and would be willing to modify their weed control methods. There are many alternative methods of weed control that not only reduce off-target injuries, but that also help build healthy soil, diversify farm income streams, and protect overall environmental health.

Risk to Crops

Soybeans, grapes, tomatoes, and many vegetable and tree fruit crops are very sensitive to dicamba and similar herbicides. In soybeans, mid-season injury from dicamba (e.g., from late vegetative growth stages through flowering of soybean plants, or typically June through early August, depending on location) is much more likely to cause yield losses than early or late season injury.[22] Once soybeans reach more developed stages, including post-flowering when the plants begin to form pods, they are less susceptible to plant injury. However, dicamba use during pod fill can reduce germination of seeds from treated plants.[23] Crop insurance does not cover either of these types of injury.

In addition to its potential to reduce plant health, survivability, and yields, dicamba drift can render entire crops unmarketable simply from cosmetic damage. Herbicide residue can also cause an organic farmer to lose the organic certification of that crop or field. Property owners on the receiving end of dicamba injury to fruit and vegetable crops or ornamental plants can face large economic losses with little opportunity for compensation.[24]

The widespread reports of dicamba volatilization and injury to fruits and vegetables over the past few years prompted the U.S. Department of Agriculture's Fruit and Vegetable Industry Advisory Committee, which represents the retail and commercial produce industry, to "strongly recommend the registration for XtendiMax, Engenia, FeXapan and Tavium or any other new formulations for in-crop use in soybeans and cotton not be renewed when the current registration expires" in its set of recommendations released in spring 2020.[25]

Many fruit and vegetable crops, like this peach tree are very sensitive to plant growth regulator herbicide drift. Credit: Kim Erndt-Pitcher/ Prairie Rivers Network.

While the new over-the-top formulations in soybean and cotton appear to be the main source of dicamba-related pesticide injury reports over the past few years, other dicamba formulations used for post-emergent weed control in corn also pose concerns. According to a survey of Nebraska farmers in 2017, about 30% of dicamba injury observed on non-dicamba resistant soybean may have been attributable to use in corn.[20] Mid-season applications of dicamba products in corn have increased in recent years to control glyphosate-resistant weeds.[26] Weed scientists from Iowa State University echoed this and reported an increase of dicamba use in corn both in acreage and rate of application.[12] Label guidance and Extension recommendations around the use of these products is highly variable and often does not adequately reflect concerns with drift and volatility.

Tomato plant with symptoms of herbicide injury. Credit: Louis Nelms.

Ecological Monitoring: Critical, but Costly

Monitoring an insectary strip. Credit: Xerces Society.

The frequency of symptoms occurring to non-crop species across large areas of the landscape has prompted some non-governmental organizations, such as Audubon Arkansas and Prairie Rivers Network in Illinois, to use volunteers to help monitor and document symptoms of possible herbicide injury to trees and other plants that wildlife depend on. State and federal forest and natural resource management professionals have also begun to monitor and document symptoms of herbicide injuries to public lands. However, all of these monitoring efforts are limited by numerous factors.

It is difficult to gauge the impacts to trees and other plants in backyards, conservation lands, forests, and public lands without extensive monitoring throughout the growing season. Monitoring and documenting symptoms takes trained personnel, time, and financial resources. Herbicide applications occur numerous times throughout the growing season. Due to the variability of the timing and location of applications, as well as differences in weather patterns, sites that were not symptomatic early in the growing season may be affected by applications later in the season—so monitoring sites must be visited to assess damage regularly throughout the growing season. Locations may also experience more than one episode of off-target herbicide exposure, potentially increasing the severity of injuries.

Analyzing plant tissues for herbicide residues can be a useful tool for verifying symptoms. However, these tests are costly and must be performed before residues have been degraded from the plant tissue. This can be challenging, since it can take up to three weeks for exposed plants to show signs of injury. While symptoms of growth regulator herbicide injury may last for weeks or, in the case of many trees, for the entire growing season, actual chemical residues may be hard to detect without prompt sampling after exposure. All these factors make monitoring arduous and resource intensive with the result that such efforts are few and far between.

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Risk to Native and Other Non-Crop Plants

As key primary producers, plants are vital to ecosystem health and function. Entire food chains depend on plant food resources. There are numerous complex relationships that exist between plants and animals; these relationships between species play key roles in helping stabilize ecosystems.[27] Stressors or repeated disturbance to ecosystems can interrupt or destabilize their functions. The widespread use of volatile herbicides like dicamba pose unreasonable risks to wildlife habitat. The enormous variance in possible rates, frequency, and timing of exposure to herbicide drift, combined with variable species susceptibility to herbicides, individual plant health, and interaction with other environmental stressors poses many unknown risks to ecological health.

Off-target herbicide injuries are not a new phenomenon. Numerous tree and plant disease manuals published by state university extension units or federal agencies have sections on identifying the symptoms of herbicide exposure.[28] While the typical visual symptoms of dicamba exposure such as stunted, twisted, curled, and cupped leaves and twig or branch dieback may be commonly recognized, it is important to acknowledge that there is much to learn about the unseen physiological injuries occurring to native species. Additionally, the incidence of injuries to native trees, shrubs and other plants is likely much higher than is documented through existing research or the pesticide misuse complaint processes, as outlined earlier.

While off-target injuries to trees and other plants have been occurring for decades, the widespread increases in herbicide injury complaints throughout the Midwest in recent years underscores the fact that volatile herbicides such as dicamba and 2,4-D are causing injury far beyond mandatory buffer zones.[17,29,30] Recent news articles have documented the widespread symptoms of off-target herbicide damage to trees, including oaks, which are keystone species in many North American woodlands and provide critical resources for wildlife.[31] In 2018, countless cypress trees were reported to be damaged by dicamba at Reelfoot Lake in Tennessee, a valuable recreational attraction and refuge for wildlife.[32] The symptoms are also being observed in rural towns, threatening private property and landowners' efforts to bring nature into their backyards.

Volunteer monitoring efforts in Illinois documented the prevalence and severity of symptoms of potential off-target herbicide injury to trees and plants in 2018 and 2019. Symptoms were widespread in numerous native species including redbud, oaks, hickory, elm, sycamore, box elder, and maples. Symptoms were observed well beyond the recommended buffer zone in numerous settings including woodlands, pastures, and private residences.[33]

Wild plants are at risk of a range of injuries from particle and vapor drift. Unsightly injuries can occur from very low doses of dicamba and some other herbicides. Drift rates of dicamba and 2,4-D on ornamental plants can reduce flower production, and cause foliage injuries such as leaf twisting, stunting, and curved stems.[34] In pecan trees, dicamba and 2,4-D drift can cause severe injuries including deformed foliage, branch dieback and arrested nut development.[35] Depending on the developmental stage of exposure and growing conditions after exposure, some annual and

Redbud curling and cupping. Credit: Prairie Rivers Network.

Wild grape stunted, with irregular margins. Credit: Martin Kemper.

Sycamore curling and cupping. Credit: Louis Nelms.

White oak with symptoms of growth regulator herbicide injury. Credit: Martin Kemper.

Sycamore leaves showing symptoms of dicamba injury. Credit: Louis Nelms.

perennial herbaceous plants may be able to "grow out of" visible symptoms. However, the same does not appear to be true for woody plants. Studies of woody perennial species have shown symptoms of injury remain visible long after exposure.[14] Visual symptoms can remain for the entire growing season and can be observed in fallen leaves.

Many plants that are critical to wildlife and ecosystem health are in reproductive stages from early spring to mid and late summer, when most herbicides are being used. Herbicide injuries during these times can have impacts at the community and ecosystem level. Studies have demonstrated that low doses of dicamba can cause delays and reductions in flowering in some wild plants and that low levels dicamba and glyphosate can negatively impact the reproduction of wild plants.[36,37] Both seedlings and plants in reproductive stages can experience impaired fertility such as reduced seed production and delayed flowering when exposed to drift rates of herbicides.[38] Reduced plant reproduction and compromised plant health could cause shifts in plant communities that threaten wildlife.

Not all plants respond to stressors, including herbicide exposure, the same way. Studies have shown that some native plants experience visible harm at a fraction of the application rate.[37] This sensitivity increases the risk that off-site movement of dicamba would cause harm at a community or ecosystem level. Many native and ornamental tree species have different sensitivities to herbicides. Recent research examining responses of common fruit, nut, and ornamental species to drift rates of dicamba and/or 2,4-D demonstrated that the expression of visual symptoms varies with herbicide, drift rate, and plant species, and that symptoms in many tree and shrub species generally worsened when glyphosate was added to higher rates of simulated drift of the herbicides.[14] Herbaceous plants also vary in their responses to dicamba and mixtures of dicamba and glyphosate.[39] These differences in individual plant responses highlight one aspect of the complexities involved in evaluating pesticide impacts on ecosystem health.

It is not just broadleaf plants and trees that are sensitive to dicamba. Conifers are also sensitive to dicamba and herbicide exposure can negatively impact trees for several months.[28,40] Twisted, deformed and/or discolored leaves and branch tips to branch dieback and leaf loss are common symptoms of dicamba and other growth regulator herbicide exposure in conifers.[28] Whether in a backyard or a forest, conifers provide numerous resources for wildlife. They are excellent sources of shelter during inclement weather and a variety of animals rely on their cones, seeds, foliage, and bark for food.

There is a great need for a better understanding of how off-target herbicides are impacting native plant communities at a landscape scale. Injuries could be occurring that will shape the ecological landscape for decades to come. The following sections explore some of the known ecological risks.

Other Off Target Impacts

Pollinator and Beneficial Insects

Impacts from herbicide drift go beyond plants with visible symptoms of injury. Herbicide applications can have both direct and indirect impacts on the invertebrate communities that provide essential ecosystem functions from wild plant and crop pollination to pest control. Many groups of flying insects, including species of butterflies, bumblebees, and beetles, are experiencing severe population declines.[41,42] Drift injury from dicamba to wild plant communities could further stress these populations and have cascading impacts on other wildlife and ecosystem functions.

The quantity, quality, and diversity of floral resources can affect bee development, physiology, and immune response, with many potential impacts on individual bee and colony longevity and reproductive capacity.

Bees and other beneficial insects may be exposed to dicamba and other pesticides by direct contact (e.g., from a spray applied when bees are active), or by contacting or eating contaminated plant foliage or pollen and nectar. Older formulations of dicamba did not appear to have direct toxicity to adult honey bees or brood, but the similar herbicide 2,4-D was found to have some toxicity to honey bee brood.[43,44] A recent study found that dicamba significantly increased mortality of lady beetle adults.[45]

However, the largest risk of dicamba use to bees and other beneficial insects that rely on pollen and nectar for food is likely to be loss of food sources and declines in forage quality. The quantity, quality, and diversity of floral resources can affect bee development, physiology, and immune response, with many potential impacts on individual bee and colony longevity and reproductive capacity.[46-48] The increased use of these herbicides during the middle of the growing season for in-crop weed management threatens a wide array of flowering broadleaf plants that provide food and shelter for bees and other beneficial insects. Glyphosate use on glyphosate resistant crops led to an estimated 58% decline in milkweeds in the Midwest, and an associated decline in breeding monarchs between 1999-2010.[49] Dicamba has a greater potential to reduce flowering plant survival in areas farther from agricultural fields than glyphosate due to its greater volatility.

Lady beetles, which are important beneficial insects for controlling soft-bodied insects like aphids, are threatened directly and indirectly by dicamba herbicides. Here, a polished lady beetle feeds on an aphid. Credit: John Flannery/Flickr.

In addition to plant death from acute drift events, sublethal doses of dicamba can stress plants and reduce the quality of these plants as food sources for pollinators and other beneficial insects. Particle drift levels of dicamba can delay, reduce, or suppress flowering of wild plants and reduce pollinator visitation.[36] Multiple drift events during the growing season are likely to have a larger effect. Bees may have to travel farther to locate additional sources of forage to meet their nutritional requirements. Longer travel distances

Monarch butterflies on swamp milkweed. Credit: Xerces Society/Stephanie McKnight.

require more energy and increase the risk of mortality from predators, weather events, and pesticide exposure.

Because broadleaf plants vary in their susceptibility to dicamba, wild plant communities in agricultural areas will likely change as more vulnerable plants are eliminated and more resistant plants survive drift events. Shifts in the abundance and occurrence of wild plant species in agricultural landscapes are likely to impact wild bee communities. The loss of floral hosts for specialist or univoltine bees (e.g., bee species with a single generation per season) may lead to declines in bee species richness.[50] Loss of central species in plant-pollinator networks, such as particularly rewarding woody or forb species like willows, maples, sunflowers, milkweeds, or goldenrods, could lead to more catastrophic loss of function in these networks.[51]

Other beneficial insects are likely to experience similar negative effects of the loss of forage quantity and quality. Sublethal rates of dicamba applied to butterfly host plants reduced larval and pupal mass of painted lady butterflies (Vanessa cardui) feeding on these plants in a cage experiment.[52] The affected plants were lower quality than untreated plants, with lower nitrogen content in the remaining foliage. If wild plants in a field setting were similarly affected by dicamba exposure, leading to smaller caterpillars and smaller adults, this could have a variety of possible negative consequences for the fitness of host-dependent insects like monarch butterflies, whose populations have declined sharply in recent decades from a variety of factors, including habitat loss from extensive herbicide use.[53]

Birds

Losing plant and insect diversity will likely have cascading negative impacts on populations of birds and the other terrestrial wildlife that depend on primary producers (plants) and invertebrates for food. Agricultural intensification over the past 50 years, including conversion of grassland to cropland and increasing use of tillage and pesticides, has been accompanied by severe declines in farmland bird abundance and diversity in North America and Europe. Much of the Mississippi Flyway, one of the primary bird migration routes in North America, travels through areas dominated by corn, soy, cotton, and wheat production. Protection of remaining habitat areas from herbicide drift damage will be critical for sustaining bird populations.

Like beneficial insects, dicamba has the potential to impact birds directly. While the acute toxicity of dicamba to birds appears generally to be low, consumption of large amounts of contaminated seeds, vegetation, and insects can cause reproductive issues and other sublethal effects.[54] For example, mallards fed relatively high doses of dicamba in lab studies had decreased hatchability and survival of young.[55]

Herbicide drift injury could potentially reduce the population of plants that host invertebrates and/or plants that produce seeds, both of which are important sources of food for farmland birds. Dicamba has been found to reduce seed production in both target and non-target plants.[37,56,57] Non-game birds that depend on seeds are known to be particularly vulnerable to increased use of herbicides due to declines in food availability.[58] By reducing the availability of seeds that birds depend on, growth regulator herbicide drift could limit food resources and impact bird populations.

Additionally, many native trees provide critical forage and shelter for caterpillars (the larvae of moths and butterflies)—essential food resources for birds. Over 90 percent of terrestrial

Carolina chickadee brings a caterpillar to its nest. Credit: Will Parson/Chesapeake Bay Program/Flickr.

bird species feed their young on insects, and caterpillars are one of the main sources of protein for young birds.[59-63] Native trees host thousands of species of larval moths and butterflies; oaks, willows, birch, poplar, and cottonwoods each support more than 300 species of moths and butterflies.[64] Research has shown that even subtle changes in insect prey availability in agricultural landscapes caused by pesticides can have harmful effects on insectivorous birds, including altered behavior and physiological costs.[65] Caterpillars feeding on host plants treated with sublethal drift-level doses of dicamba had reduced larval and pupal biomass, potentially due to alterations in plant nutritional content.[52] Reduced caterpillar biomass or survival on herbicide-affected plants could have cascading impacts up the food chain; insectivorous birds might need to travel farther or collect many more caterpillars in order to feed their young.

Dicamba could also impact birds through its effect on bird habitat. The use of herbicides in farming has dramatically altered habitat patterns in North America, and strong evidence exists for adverse effects of changes in habitat pattern on birds.[66] Based on a thorough literature review and analysis, there is a strong argument to be made that the decline of ducks nesting in the prairie pothole region of North America was likely related, at least in part, to adverse alteration of food, nesting, and protective cover in uplands, pothole, and pothole margins from repeated, broad scale use of herbicides.[67] Non-game species dependent on weeds and their seeds are especially vulnerable to more intensive and extensive use of herbicides because of the loss of weedy foraging and nesting sites in fields and adjacent habitats such as hedgerows.[58] In addition to reduced availability of food for chicks, gray partridge declines have also been linked to loss of suitable nesting cover from removal of field margin habitats, particularly hedgerows.[57]

Box elder maples provide important food resources for birds but are sensitive to dicamba. Credit: Julia Adamson/Wikimedia.

Although little research has been done on the specific impacts of dicamba on bird habitat, herbicides like dicamba and 2,4-D are known to harm plants that birds depend on. For example, box elder trees *(Acer negundo)* are highly sensitive to growth regulator herbicides like dicamba.[68] In riparian areas, box elder communities provide important habitat for many wildlife species, food resources, and valuable cover for upland game birds and small nongame birds.[68-71] The effects of herbicide drift on native plants in general can include increased mortality, reduced biomass, lower fecundity, and modifications in morphology and development.[66,72] At drift-level concentrations, these herbicides can result in deformed or dead foliage, dead limbs and branches, delayed onset of flowering, and reduced number of flowers in non-target plants.[35,36,73,74]

Recently, some efforts have begun to assess dicamba impacts on the landscape. Audubon Arkansas launched a community science project in 2019 to investigate the impacts of dicamba on natural areas in the state. They found signs of probable or possible dicamba injury symptoms on a wide variety of plants, including Carolina buckthorn, catalpa, elms, hackberry, hibiscus, morning glory, magnolias, maples, mulberry, muscadine, oaks, pears, pecan, peppervine, pokeweed, redbud, smooth sumac, sweetgum, sycamore, trumpetvine, tuliptree, and white poplar, most of which are listed in National Audubon Society's "Plants for Birds" database as providing food for birds, including insects that most landbird species need to feed their young.[75] However, no large-scale research has been done to examine whether the magnitude of effect of dicamba and other herbicides on sources of food will result in adverse effects on terrestrial bird survival or reproductive success.

Many pesticides, including the herbicides dicamba and 2,4-D, are water soluble and can readily enter surface water bodies, where they may also pose risks to aquatic life.

Like many other pesticides, dicamba is water soluble and can easily move into and contaminate aquatic ecosystems, posing risks to aquatic life. Here, the lead Freshwater Mussel Biologist for the Xerces Society surveys a stream for freshwater mussels, which are highly susceptible to environmental contaminants. Credit: Xerces Society/Justin Wheeler.

Other Wildlife

There is still much to learn about the ecological impacts of herbicides like dicamba. Pesticides sprayed over large areas of land put wildlife and their habitat at risk. Whether they are intentionally mixed at the time of application, or encounter one another in the soil, water, or air, additive or synergistic effects can occur.[76,77]

In addition, many pesticides, including the herbicides dicamba and 2,4-D, are water soluble and can readily enter surface water bodies, where they may also pose risks to aquatic life. Aquatic and terrestrial ecosystems alike provide key habitats for many species at risk, including some species that may move between them.

Many invertebrates have an aquatic stage to their lifecycle and are highly dependent on plant material that grows in or falls into water bodies.

Amphibians are of unique interest in regards to environmental pesticide exposures due to their complex lifestyle and metamorphoses. They inhabit the water and land, and undergo dramatic physiological changes throughout their lifecycle. They also have permeable skin, which can allow for rapid exposure and uptake of environmental contaminants.[78,79] Research

Amphibians can be highly susceptible to environmental contaminants. Credit: Rob Kanter.

has shown that dicamba and 2, 4-D can damage amphibian DNA and enzymatic systems and that dicamba and glyphosate can have impacts, singly and synergistically, causing primary DNA breaks in amphibians [80-82]. This can result in abnormalities in growth, cell death, and organism illness. Additionally, dicamba and glyphosate have been shown to harm tadpole development in the Argentine common toad, which may also have implications for similar toad species in North America.[77]

A full assessment of risks to aquatic and terrestrial life is beyond the scope of this report, but the widespread use of dicamba and other growth regulator herbicides—and the clear harm that has resulted for sensitive crops and other non-target plants—raises significant concerns about the potential ecological ramifications of continued use.

Farm workers, pesticide applicators, and their families are the most likely among the general population to have repeated exposures to agricultural pesticides, including dicamba. Credit: United Soybean Board/Flickr.

Human Health

While it is not the main focus of this report, it should be noted that little is known about the environmental impacts of widespread use of dicamba on human health. There is very little published information on the environmental loadings from the recent increased use of this herbicide. Among the general population, farmers, farm workers, pesticide applicators, and their families are the most likely to have repeated exposure to agricultural pesticides, including dicamba.[83–85] Communities living near agricultural lands also experience higher exposure to pesticides than the general population.[86]

Studies of occupational exposure to dicamba among farmers and pesticide applicators have found some associations with different cancers, including lung cancer, non-Hodgkin's lymphoma, and bile duct cancer, but others have not found clear associations between exposure and cancer incidence.[87–91] There may also be an association between an increased risk of hypothyroidism and exposure to several pesticides, including dicamba.[92]

In vitro studies of mammalian cells indicate that dicamba can inhibit cell division activity and induce cellular and DNA damage at the highest tested doses.[93] While these doses are likely much higher than environmental exposures, these in vitro studies suggest mechanisms by which prolonged or multiple exposures to dicamba could be harmful to mammalian wildlife and human health.

Tulip poplars are important spring resources for bees, but buds, leaves, and flowers can be heavily impacted by dicamba injury. Credit: Jane Shelby Richardson/Wikimedia Commons.

The lack of information about the impacts of this widespread use, combined with the reduction in many state and federal monitoring programs, makes it difficult to gauge the impacts of pesticide use in ecosystems that already face many stressors.

Knowledge Gaps

Many Questions Remain Unanswered

The expansion of dicamba use to over 60 million acres, with applications from early spring throughout the growing season, raises numerous questions and concerns about the ecological impacts of such exposures. There is a lack of current, publicly available information on dicamba distribution and use; USGS estimates of county-level pesticide use lag by several years and are currently available only through 2017.[4] The lack of information about the impacts of this widespread use, combined with the reduction in many state and federal monitoring programs, makes it difficult to gauge the impacts of pesticide use in ecosystems that already face many stressors, including climate change, invasive species, disease and habitat loss. In many cases, we are causing harm to systems for which we have little to no baseline ecological information.

The ecological and human health impacts of this widespread use of dicamba and similar herbicides are largely unassessed and extremely understudied. Decision makers rely on laboratory simulations that are very different from field conditions. New ecological assessment frameworks need to be established to address the cumulative impacts of agrochemicals on wildlife.[94]

While the limited studies available provide important insights, many questions remain: How much herbicide is volatilizing into the atmosphere? Where and how far are these herbicides travelling, and at what rates are these chemicals landing on unintended plants? Are they combining with other chemicals during inversions which increase their toxicity? What are the short and long-term impacts to herbaceous and woody plants? How are nectar and pollen production, seed/fruit production, and plant fitness being affected? If current rates of use continue or increase, will species composition in critical habitat areas shift?

To what degree are invertebrate and seed food resources being shifted or eliminated due to changes in plant health, distribution, palatability, and nutrient content? What are the exposure rates and frequencies of birds to these herbicides via food and water resources or inhalation? How are invertebrates, birds, and other wildlife responding to changes in habitat and food?

To what degree are the plant food and habitat resources in or entering aquatic systems contaminated with plant growth regulator herbicides? What is the environmental loading of dicamba in water resources and aquatic ecosystems? How does this impact the emergence of insects with an aquatic life stage—a critical food resource for numerous wildlife, including migratory birds?

To what degree are the plant food and habitat resources in or entering aquatic systems contaminated with plant growth regulator herbicides?

What is the environmental loading of dicamba in water resources and aquatic ecosystems?

How does this impact the emergence of insects with an aquatic life stage - a critical food resource for numerous wildlife, including migratory birds?

Credit: Robert Hirschfeld/Prairie Rivers Network.

Examples of Landowners and Managers Experiencing Impacts

News stories about the destruction dicamba has wrought in the last few years have mostly featured farmers suing other farmers or neighbors getting into arguments about damage to their commercial row crops, including non-resistant soybeans. For this report on impacts to other plants and wildlife, we spoke with a few people who are experiencing damage to their property and livelihoods, including their organic farms, forests, and apiaries.

Young white oak tree showing symptoms of potential growth regulator herbicide injury. Credit: Kim Erndt-Pitcher/Prairie Rivers Network.

Cow Creek Organic Farm, a 1000-acre organic farm in East Central IL, is currently operated by fifth-generation owners, who have reported a large increase in herbicide damage in multiple locations every year for the last three years. Current co-owner and operator, Dallas Glazik says, "We have seen both support and criticism for our farming practices by our neighbors and surrounding communities, with the most backlash coming from our neighbors using dicamba and other volatile herbicides. The drift has been trespassing onto our land and damaging both our crops and conservation land, which is damage to taxpayers' dollars. However, the way the system currently works, it just pegs farmer against farmer, neighbor against neighbor, and leaves the whole area damaged both physically and socially."

IL state record post oak, Credit: Robert Hirschfeld/Prairie Rivers Network.

Shelley Harper in Washington County, IL, has land that has always been pasture and is surrounded by large farm fields of soybeans, corn and wheat. "Since 1968 and going on three generations, we have lived on this 23 acres of old growth pasture with oak trees (white, post, pin, burr), growing on it along with hickory, walnut, pecan, sycamore, redbud, persimmon, cypress, cedar, maples, dogwood and wild cherry." They also have the Illinois Grand Champion Post Oak Tree (awarded since 2012), which has been growing in this pasture for over 150 years. "My 90 year old dad noticed 'something wrong' going on with our trees around 2015. After he passed away in 2017 we kept seeing all of our trees, including the Champion Post Oak looking worse. They all had irregular or smaller, curled leaves, sparse crowns, thin foliage and dead branches. Our neighbors also talked to us about their own trees being in distress and dying."

Shelley reports that this tree damage is now a widespread problem which they see everywhere, and think this points to the use and drift of 2,4-D and/or dicamba. "Leaves from our Champion Post Oak have been tested for herbicides four times. Two tests found 2,4-D and two found both 2,4-D and dicamba. We have filed two formal complaints with the Illinois Dept. of Agriculture, with this year (2020) to be the third. There has been no outcome and no action taken by them." Since there is no information on such tree damage being cumulative and if such impacts can be stopped and reversed, time is running out to try and save these trees.

Raymond Nabors, a retired agricultural biologist and former apiculture specialist at the University of Missouri, has been keeping bees for over 40 years in the Missouri Bootheel, the southeasternmost corner of the state. “Everything from here south to Louisiana, it’s flat as a pancake,” Ray explains. “This area was all swamp in 1900—it was all Tupelo gum and cypress trees and things that grew well in water. But then they drained it, and there’s ditches everywhere. Every mile of road has 25–30 acres of ditch bank that used to have acres of wildflowers. Over the last decade, the wildflowers there have declined. Since dicamba, it’s taken a nosedive. When this stuff gets volatilized and up in the air, it comes down and kills everything. Dicamba killed the plants in the past two years, and they didn’t come back.”

Ray’s honey production has “dropped tremendously” in the past couple of years, and his bees are having a harder time surviving, with fewer resources in the spring and fall. “Dicamba is the worst thing I‘ve seen hit bees because you can’t do anything about it. We can treat for *Varroa* mites and diseases. It used to be unusual to replace more than 10% of my colonies in any given year. Now, it’s typically half.”

He keeps his bees on the family farm, where he’s planted many different kinds of bee-friendly trees for nectar and pollen in the spring, including maples, tulip poplars, and linden. “But,” he says, “the tree buds and leaves are distorted with dicamba in the spring. The maples bloom earlier and are less affected, but the tulip poplars come in later and they get hit hard.”

The loss of forage due to early season and mid-season dicamba use has made the business of keeping bees much more expensive. Ray is seeing “half as much production because we have half as much forage. And we have to feed the heck out of them.” This past year, Ray decided to buy more queens and split out the survivors, and not to add more bees as would have typically done, because “it was just getting unaffordable.”

“They’re trespassing their herbicide on my property, and I can’t do anything about it,” Ray says, the frustration evident in his voice. “I can’t even grow tomatoes in my garden. I don’t blame the growers, because they’re over a barrel. You can’t not plant it. But it should be banned because it’s trespassing on other people’s property. Or maybe you don’t need to ban it for everything, but it shouldn’t be in such widespread use.”

Honey bee nectaring on highbush blueberry. Spring-flowering trees and shrubs are important food resources for many pollinators. Credit: Emily May.

There are similar stories of widespread and dramatic tree damage from other parts of the country. Justin Evertson, a coordinator with the Nebraska Forest Service, reports seeing symptoms of herbicide damage to trees increase in recent years. He started noticing “damage early in spring burndown and post emergent spray as a second wave [of damage]”. What has been difficult, he reports, is the lack of awareness of the type of damage they are seeing and what it means, alongside the state department of agriculture being overwhelmed with injury reports to crops, with no time to also investigate non-crop damage.

Pitfalls in the Regulatory Process

Pesticides that are sold or distributed in the United States must be registered by the EPA under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Before the EPA will register a pesticide, the applicant must prove that the pesticide meets certain criteria, including that, when used according to label, the pesticide "will not generally cause unreasonable adverse effects on the environment." States often have one agency that is responsible for regulating and enforcing agriculture-related pesticide use, distribution, and disposal within their boundaries.

In 2016, the EPA approved two-year conditional registrations for three dicamba herbicide formulations for over-the-top use in dicamba-resistant soybeans and cotton. "Conditional" approval is allowed for new products that are substantially similar to previously registered pesticides, even if there are gaps in the data showing that the new product will not cause unreasonable adverse effects on the environment. After weed scientists reported over 3 million acres of dicamba-damaged soybean in 2017, the EPA reportedly considered a growing season ban on dicamba in 2018, but did not implement the ban after pressure from manufacturers.[95,96] In October 2017, the EPA announced new rules on dicamba use created in collaboration with manufacturers.[97]

Soybean is highly susceptible to injury from phenoxy herbicides like dicamba and 2,4-D. Very small drift concentrations of these herbicides can cause visible symptoms, like this leaf cupping. Credit: United Soybean Board/Flickr.

The rules included label changes to the dicamba herbicides registered for in-crop use in cotton and soybeans.[98] These products were updated to be classified as restricted use, permitting only certified applicators and those under their supervision to apply them. The labels became increasingly complex, including language to prohibit applications when wind speeds are above 10 mph or below 3 mph, reduce the time period during the day when applications can occur, and increase record keeping requirements especially in areas near sensitive crops (e.g., orchards, vineyards, and vegetable fields). Applicators were also required to attend dicamba-specific trainings.

The updated labels included downwind buffer requirements for over-the-top dicamba and 2,4-D products, which differ by product and rate.[99] Applicators must leave a 110-foot or more unsprayed buffer from the downwind field edge for dicamba products (e.g., XtendiMax, FeXapan, Engenia) and a 30-foot buffer for 2,4-D products (e.g., Enlist One and Enlist Duo). According to the label, applications cannot be made if the wind is blowing toward an adjacent susceptible crop field.

A few states took regulatory actions that went beyond the federal requirements in order to reduce drift injury, ranging from state-specific application restrictions that go beyond the label language, to a ban on mid-season use of dicamba in 2018 in Arkansas. However, changes to label language were not effective in preventing off-target dicamba movement and injury. Plant injury from dicamba volatilization remained a significant issue in 2018 despite implementation of stricter label language, applicator training, and individual state regulations.

While the complex set of label restrictions, if followed, may help reduce particle drift from dicamba application, vapor drift can travel much farther than the required downwind buffer distances during temperature inversions or at higher temperatures. Some states have implemented 24(c) labels, which allow them to modify or change uses and guidelines for use of a pesticide to better accommodate their needs locally or regionally. In order to reduce off-target movement caused by volatility that is increased during warmer temperatures, some 24(c) labels for dicamba have included application cut-off dates or temperature restrictions. However, leaf and soil temperatures are frequently higher than air temperatures and these factors are not taken into account in the added restrictions.

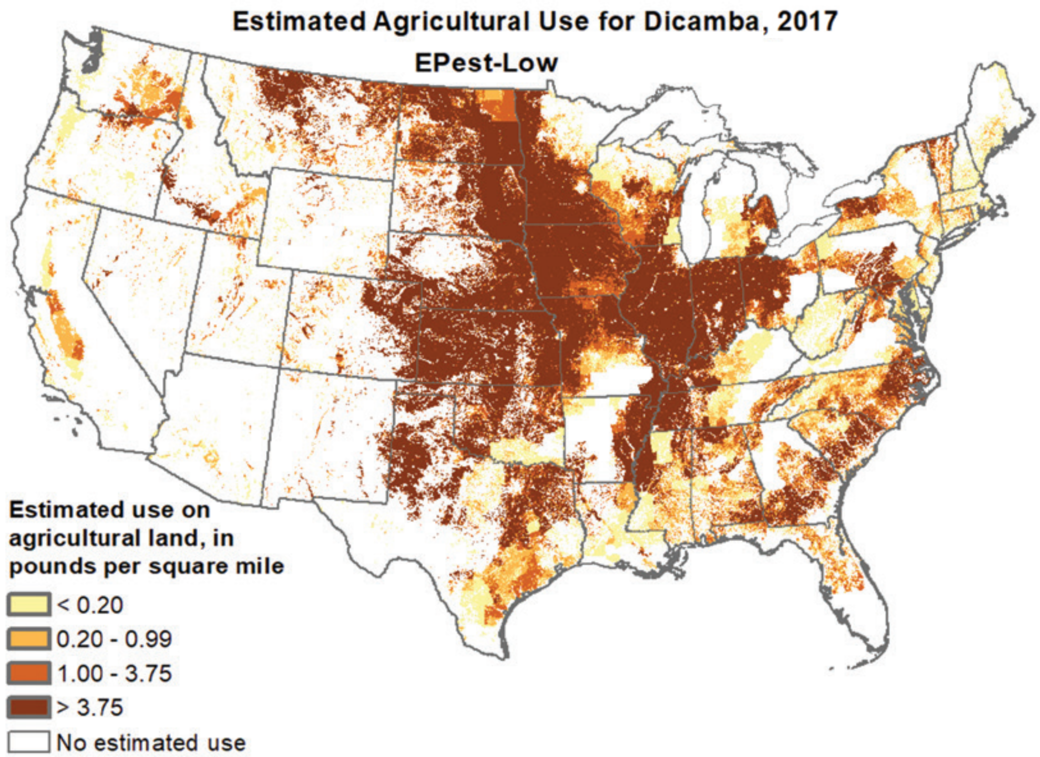
What's more, weed scientists and farmers are finding that the label restrictions are nearly impossible to follow.[100] Increasingly, university extension weed scientists are speaking out on the difficulties of complying with all the label requirements after the numerous changes to label language put forth by manufacturers.[101] In fact, they have found that weather conditions were largely unsuitable for dicamba application, with only two days of the week having more than five suitable hours to spray in one example from Iowa.[102] Weed scientists from Purdue estimated that dicamba could not be applied according to label instructions over half the time in June or July 2017 in Indiana.[103] By creating label restrictions that are nearly impossible to follow to the letter, manufacturers have a convenient scapegoat for future damage. Blame for damage events is likely to focus on application methods and how well applicators have adhered to the label standards, rather than the inherent volatility of the herbicide products.

Despite the evidence that these over-the-top dicamba herbicides had caused substantial, widespread damage since their conditional approval, the EPA decided to extend the conditional registrations for three over-the-top products for an additional two years in late 2018. Dicamba related pesticide complaints remained high again in 2019, despite many states taking extra precautions to reduce risks.[17]

In June 2020, a federal appeals court vacated the 2018 conditional registrations, citing EPA's flawed approval process and failures to acknowledge evidence of "substantial and undisputed damage" in 2017 and 2018, as well as evidence that increasingly onerous label restrictions would not be followed.[13] In addition, the Ninth Circuit Court ruling continued, "the EPA entirely failed to acknowledge the risk that over-the-top dicamba use would tear the social fabric of farming communities."[13] Another in-crop dicamba product, Tavium (Syngenta), was registered with the EPA in early 2019 and was not included in this court ruling.

While unregistered pesticides cannot be sold or distributed for use, the EPA's final cancellation order for the three dicamba products following the court ruling allowed commercial applicators and growers to use existing stocks that were in their possession by the date of the court ruling through the end of July 2020. Many states are adhering to their previously agreed upon 24(c) labels in light of the EPA's clarification of how the court ruling would be enforced.

While individual states grapple with the backlog of injury complaints and many more injuries are going unreported, all eyes are on the EPA's authorization decision permitting dicamba for soybeans and cotton, which is likely to come out by the end of 2020. In addition, the EPA is currently considering new applications for dicamba resistant corn, though the technology is still a few years from market. Dicamba products are already applied to several million acres of corn annually, but the resistance trait would likely result in much more widespread use, and later in



Dicamba use more than doubled from 2016 to 2017, which is the last year of use data currently available. Credit: U.S. Geological Survey.

The prospect of 80 million more acres receiving applications of dicamba herbicides — opening up many millions more acres of wild, ornamental, and crop plants to off-target dicamba injury — without the proper scientific and ecological risk assessments is very alarming.

the season. In 2015, Monsanto estimated that the technology might be adopted on as many as 9 out of every 10 acres of corn, or around 80 million acres. Currently, manufacturers have requested an increase that would more than double the maximum allowable annual application rate in corn. The prospect of 80 million more acres receiving applications of dicamba herbicides—opening up many millions more acres of wild, ornamental, and crop plants to off-target dicamba injury—without the proper scientific and ecological risk assessments is very alarming.

Recent settlement announcements by Bayer for crop damage claims from farmers on the use of dicamba herbicides developed by Monsanto and BASF are another example of ongoing legal developments. However, these legal decisions do not fully address the impacts of dicamba to native plants, trees, and wildlife and as we describe in this report, there is much cause for concern. Given pending court challenges to the registration of new 2,4-D products and upcoming registration decisions for dicamba products, research on these off-target impacts is critically important.[31]

Legal avenues may help halt the use of dicamba herbicides until ecological risk has been more fully assessed, given the widespread damage and lack of thorough scientific review outlined above. Over the longer term, however, the problems with dicamba injury—as well as growing weed resistance—highlight the underlying structural issue of overdependence on herbicides for weed management across millions of acres of American cropland. We outline how the weed resistance treadmill makes sustainable, diversified weed management a critical investment for the long term.

Long-Term Solutions

Building Resilience in Weed Management Systems

Herbicide control of agricultural weeds is simple, time-saving, and cost-effective, which is why it has been widely adopted—and often used exclusively over other weed management strategies. However, widespread resistance among weed species to glyphosate and increasing emergence of weeds resistant to other widely used herbicides underscores the fragility of this management system. Repeated herbicide application to a plant population can lead to the development of herbicide resistance in those plants over time. Once traits that confer resistance appear in a population, a small patch of resistant weeds can quickly colonize an entire field. Certain modes of action are less prone to the development of resistance, but glyphosate is only one of many herbicides facing a loss of efficacy against weed species. Palmer amaranth, waterhemp, and several other row crop weed species have developed resistance to multiple herbicide modes of action, including volatile growth regulator herbicides.[104] Weed scientists in Kansas identified populations of Palmer amaranth resistant to dicamba and 2,4-D in 2018.[105] Dicamba resistance has also been reported in Tennessee and other areas of the mid-South, which saw widespread performance failures of dicamba in 2019.[106]

Herbicide-resistant weeds can spread quickly—moving from a single introduction to over 20% of a field area within 2 years—when managed only with the herbicides to which they've developed resistance. Palmer amaranth and waterhemp are prolific seed producers and have a zero tolerance threshold, as individual plants can deposit thousands of seeds into the seed bank.[90] Surveys estimates that glyphosate-resistant weeds infest around 120 million acres of U.S. farmland, including over half of soybean acreage.[2,107] With millions of acres of row crops planted to dicamba-resistant varieties, weed resistance to dicamba will likely spread quickly in the absence of other management strategies.

Buckwheat can help improve soil health, suppress weeds, and provide resources for pollinators. Credit: Xerces Society/Karin Jokela.

Herbicide-only weed management puts growers on a resistance treadmill that is not sustainable. Over reliance on herbicides, especially individual herbicide modes of action, leads to the development of resistant weeds, which in turn leads to more intensive use of the same or additional herbicides and eventual failure of the products.

With millions of acres of row crops planted to dicamba-resistant varieties, weed resistance to dicamba will likely spread quickly in the absence of other management strategies.

Field edges can be important wildlife habitat.
Credit: Xerces Society/Mace Vaughan.

Ecological weed management practices include choosing crop varieties that are competitive with weeds, adjusting planting dates and depths of crops to help get ahead of weed growth, and managing nutrients in ways that give crops the competitive edge.

The short-term problem with dicamba and other volatile herbicides used for controlling broadleaf weeds is the increased risks of off-target injury to sensitive crops and wild plants, with potentially widespread ramifications for insect, bird, and other wildlife populations that interact with and depend on these plants. Over the long term, the issues are broader: weed management systems dependent on broad-spectrum herbicide applications are contributing to biodiversity loss across millions of acres of agricultural land.[108] Adoption of herbicide-resistant technology and the associated widespread use of broad spectrum herbicides has led to decreased diversity in intensive agricultural systems (of crops, weeds, other wild plants, soil microbiota, beneficial insects including pollinators, etc.), both from reduced use of mixed rotational cropping systems and from indirect effects of herbicide applications on wild plants and animals.

Integrating ecological weed management strategies that help eliminate seed production and reduce the soil seed bank (e.g., not allowing Palmer amaranth, waterhemp, and other prolific seed producing weeds to go to seed) will be critical for building resilience into weed management systems in row crops.[109]

More growers and companies need to be looking for longer-term sustainability of weed management systems, starting with approaches that are based on ecological principles and reduce reliance on herbicides. Multi-tactic strategies that incorporate diverse weed management techniques such as weed seed prevention, as well as cultural, mechanical, and biological strategies, can help farmers achieve more effective and sustainable weed management.[110,111] By focusing on prevention, growers can reduce the need for chemical inputs to control weed populations, but also prolong the lifespan of chemical products for when they may be needed, slowing the progression of herbicide resistant weeds.

Ecological weed management (EWM) emphasizes preventive and non-chemical control tactics—the “many little hammers” of weed prevention and control over the “large hammers” of cultivation and herbicide.[112,113] Ecological weed management practices include choosing crop varieties that are competitive with weeds, adjusting planting dates and depths of crops to help get ahead of weed growth, and managing nutrients in ways that give crops the competitive edge. Adopting multiple strategies for weed control can help reduce or eliminate the need for herbicide applications. On farms where herbicide-resistant crops are used, the use of additional physical, cultural, and biological weed control techniques can help delay the development of herbicide-resistant weeds.[114,115] Used together with other farming practices that build soil health and protect water quality, these practices can help improve on-farm biodiversity, including the diversity and abundance of pollinators and other beneficial insects.

The list of weed seed control options continues to grow, and includes increasing to four or more crops into a rotation, growing more than one crop per calendar year, using conservation tillage, tine weeding, using cover crops with other integrated pest management strategies to suppress weeds, interseeding cover crops, and using innovative weed management tools and practices such as weed zappers and harvest weed seed destructors, as well as by using nature’s natural weed seed eaters to help with the work by creating space for nature on the farm.[109] University researchers and private companies are working on new precision technologies, including drone-applied spot sprays and robotic weed control. Mechanical control with autonomous robots may play an important role in sustainable weed management in the future, but this technology is likely at least a decade away from commercial release.[116]

Roller crimping rye. Credit: Robert Hirschfeld/Prairie Rivers Network.

If using chemical methods of weed control, farmers should practice careful herbicide resistance management by rotating different herbicide modes of action and not continually applying herbicides in the same grouping.[120] Spot spraying and hand weeding in fields and field margins can also be important in a zero tolerance approach. Farmers can also burn collected piles of weeds that have already produced seedheads. However, even with careful resistance management, cross-resistance to multiple herbicides can sometimes develop.

Given that a multi-tactic approach with a strong emphasis on proactive and ecological weed management may be critical for building resilience into weed management systems, it is important to acknowledge there is considerable lag in adoption rates.[110] Changing behavior is rarely easy, particularly when social norms—as well as the ease and affordability of the current system—do not support such changes. IWM and EWM have greater uncertainties, compared to chemical methods, around efficacy, cost, and reliability of different cultural and mechanical methods.[121,122] There is a need for increased research to bridge these uncertainty gaps, as well as a need for technical support providers that are knowledgeable in these areas and that can help farmers best utilize alternative and more ecologically beneficial methods of weed control for their farm. A study of the progression of weed management systems concludes that short term fixes such as new herbicide technologies continue to perpetuate underinvestment in public domain research on weed management, which hinders the adoption of more complex but sustainable weed management systems.[123] Additional research has indicated that acknowledging and incorporating local knowledge and decision making stressors into the design of EWM can contribute to long term behavioral shifts, essential for adoption of these techniques.[124]

Harvest weed seed control is a proven approach to reducing weed seeds in the soil seed bank without relying completely on herbicide control.[117] These methods for removing weed seeds from fields at the time of harvest, to ensure that they cannot return to the soil are continually being fine-tuned. New research suggests that mechanical seed destruction can kill between 97-100% of weed seeds at harvest, reducing inputs of weed seeds into the soil seed bank.[118] Another harvest-time solution is creating narrow, 30-inch windrows of chaff and straw, then immediately burning the windrows to destroy remaining seeds, which can also achieve up to a 100% seed kill.[119] These harvest weed seed solutions can help provide non-chemical control of herbicide-resistant Palmer amaranth, waterhemp, and other weeds in the mid-South. Cover crops can also contribute to control of these herbicide-resistant weeds; for example, the excellent smother crop, cereal rye, which can be terminated by rolling and crimping instead of by herbicides.

Conclusion

Dicamba herbicides pose significant threats to wild plants and the wildlife that depend upon them—even when used as prescribed on their labels. Widespread use of dicamba herbicides throughout the growing season is leading to injury to sensitive crops and wild plants, with potentially sweeping ramifications for insect, bird, and other wildlife populations. These effects are rippling throughout numerous food webs and ecosystems.

Policymakers need to take a range of steps over the short and long terms to limit the destructive effects of dicamba.

Short term

Approving the use of new dicamba products without adequate ecological impact studies has proven to be short-sighted and has resulted in unacceptable harm to the environment. Short term regulatory fixes requiring stricter labelling information have not proven effective in preventing further harm. Given these findings and the many additional areas of research needed, the EPA should not renew dicamba product registrations unless and until further independent research shows with certainty that dicamba formulations will not cause off-target injury to crops, wild plants, and biodiversity, including from vapor drift. In fulfilling this research on injury to non-target plants, EPA should include a full risk assessment for animal and plant species listed under the Endangered Species Act, migratory birds, native pollinators, and aquatic life. The FIFRA Scientific Advisory Panel should provide recommendations to the EPA on how to update the current ecological risk assessment processes to better address the impacts to terrestrial biodiversity including community and population level plant and invertebrate abundance, persistence, and richness.

Additionally, the EPA should review and revise label language on products registered for over-the-top application in corn to better address drift and volatility concerns in line with the application and label requirements for products used over-the-top in soy and cotton. The USDA should reject petitions for the deregulation of additional dicamba-resistant crop varieties that would result in increased use of dicamba, unless and until independent research shows with certainty that associated dicamba formulations will not cause off-target injury to crops and wild plants, including from vapor drift.

Because the restrictions of a pesticide's use are based largely on the number and type of complaints received, state agencies that deal with specific aspects of their pesticide laws should work collaboratively to improve the pesticide incident reporting process and the effectiveness of their pesticide laws and regulations to ensure that pesticides are not causing unreasonable harm to crops, human health, and the environment. Injuries to agricultural and non-agricultural plants and animals should be investigated, recorded, and given equal consideration, even when it appears that the injury is a result of volatility. The reporting process should be easily understandable and accessible to growers, private landowners, and private and public land managers. States should also be given the adequate financial resources required to improve the reporting process, potentially through increased pesticide registration fees, as well as to investigate incidences and properly enforce their pesticide laws.

Finally, the lack of publicly available information on pesticide distribution and use, as well as pesticide injury claims, makes it difficult for scientists and policymakers to assess and make informed decisions about the potential harm to crops, biodiversity, and human health. California is the only state in the country with an extensive publicly available database of pesticide use reporting.[125] States should improve transparency in the injury reporting process and make data on pesticide use and distribution publicly available to better ensure public health and environmental protection.

Long term

A longer-term investment in sustainable weed management which includes adoption of multiple approaches is critical. Reliance on herbicide-only weed control is not effective or ecologically sound over the long term. We need to shift to sustainable, ecologically sound weed management systems that use multiple approaches to manage weed populations in crop fields. Greater investment is needed to support research on integrated weed management and the ecological impacts of herbicide use. Financial resources are also needed to support the development of economic and behavioral drivers that will increase adoption of these multi-tactic approaches to weed management. Additionally, training and the deployment of technical service providers and tools to support farmers making these transitions has to be prioritized to achieve these goals.

Greater investment is needed in research and technical support for integrated weed management systems. Credit: USDA NRCS South Dakota.

This report has outlined what little is known of the impacts of dicamba and similar plant growth regulator herbicides to herbaceous and woody plants and the wildlife that depend on them. It also summarizes the many unknown off-target impacts of these herbicides that need to be addressed in future research. While current dicamba injury claims, rulings, and settlements almost exclusively address crop damage, harm to wildlife and habitat cannot be ignored. To better address these concerns, we have provided recommendations on immediate policy actions to address research gaps before any decisions on re-registering dicamba herbicides for agricultural use can be made.

Beyond policy modifications and improvements, we have also included measures that farmers and other producers can take, including a variety of ecological weed management strategies that can help eliminate weed seed production and reduce the soil seed bank, reducing reliance on herbicides and building resilience into weed management systems. We recommend significantly increasing investment to facilitate the shift to diversified weed management and cropping systems that grow crops based on agro-ecological principles. These measures will ensure that we regenerate the soil and protect terrestrial and aquatic habitats for people and biodiversity.

Recommendations

- The EPA should not renew over-the-top product registrations unless and until independent research shows with certainty that dicamba formulations will not cause off-target injury to crops and wild plants, including from vapor drift.

- The FIFRA Scientific Advisory Panel should provide recommendations to the EPA on how to update the current ecological risk assessment processes to better address the impacts to terrestrial biodiversity (e.g., community and population level plant and invertebrate abundance, persistence, and richness).

- The EPA should include a full risk assessment for animal and plant species listed under the Endangered Species Act, migratory birds, native pollinators, and aquatic life that includes direct and indirect effects from exposure to dicamba due to drift, volatilization, and runoff.

- Based on these additional risk assessments, there should be consistent regulation to reduce off-target movement and volatility across all dicamba-based herbicides, including older formulations.

- The USDA should reject petitions for the deregulation of additional dicamba-resistant crop varieties that would result in increased use of dicamba, unless and until independent research shows with certainty that associated dicamba formulations will not cause off-target injury to crops and wild plants, including from vapor drift.

- State agencies that deal with specific areas of their pesticide laws should work collaboratively to improve the pesticide incident reporting process for their state. The reporting process should be easily understandable and accessible to growers, private landowners, and private and public land managers that desire to report crop or non-crop related injuries to plants or animals. States should also be given the adequate financial resources required to improve the reporting process, as well as to investigate incidences and properly enforce their pesticide laws.

Savannah sparrows will feed on seeds from field margin plants like goldenrods. Credit: Andrew Weitzel/Flickr.

- The lack of publicly available information on pesticide distribution and use, as well as pesticide injury claims, makes it difficult for scientists and policymakers to assess and make informed decisions about the potential harm to crops, biodiversity, and human health. States should improve transparency in the injury reporting process and make data on pesticide use and distribution publicly available in a timely manner, in order to better ensure public health and environmental protection.

- Sustainable weed management includes adoption of multiple approaches to managing weeds rather than an overreliance on herbicide-only weed control. Greater investment is needed to support research on integrated weed management and the ecological impacts of herbicide use. Financial resources are also needed to support the development of economic and behavioral drivers that will increase adoption of these multi-tactic approaches to weed management.

- We need greater investment in technical service providers and financial and technical assistance programs that facilitate the shift to agro-ecological systems that regenerate the soil and protect air and water for people and biodiversity.

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Fritillary butterfly on butterfly milkweed. Credit: Robert Hirschfeld/Prairie Rivers Network.

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