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The Science of Dicamba and Past Experiences: What We Know Today

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The University of Arkansas System Division of Agriculture (Division) is dedicated to supporting the Arkansas agricultural community, the agricultural industry and consultants, and the general public by providing unbiased research-based information for anyone involved in agricultural activities. In the area of dicamba labeling and off-target movement management, Division scientists have spoken to the Arkansas State Plant Board Committee many times over the past 10 years. The Division has always provided consistent up-to-date counsel based on our clearest understanding of past and present research.

A petition for rulemaking was filed asking the Plant Board to follow the federal label on dicamba and repeal the previous date and buffer restrictions placed on that technology. Many statements were made regarding a number of scientific principles and thoughts about dicamba. The attached summary provides detail on each of these statements with literature citations of published research. The main scientific points are as follows:

- The small-plot, peer-reviewed research model is accepted by all major research publications and institutions as an acceptable method for conducting agricultural research and is the foundation for all variety and technology trials currently conducted, including other production recommendations associated with crop pest management and fertilization. In addition, large-scale studies are cited and have been conducted during university dicamba evaluations. Both replicated small-plot research and larger plot observational data have a place in the decision-making model.
- Low rates of dicamba do not increase soybean yields (Kniss 2018; Castner et al. 2021a). Research shows that more often the effect of dicamba injury is negative (Kniss 2018; Meyeres et al. 2021; USB funded unpublished research).
- Dicamba is not the only option for control of Palmer amaranth in Arkansas. Dicamba, 2,4-D, and glufosinate are all potentially effective postemergence herbicides for controlling Palmer amaranth. In addition, there are a number of residual options that can be utilized (Houston et al. 2020; Lingenfelter 2021).
- University weed scientists are neither aware of nor have researched any new additives or volatility reducing agents that prevent dicamba volatility that are available to growers in 2021.
- Research shows dicamba volatilizes and is frequently detected in rainwater and air samples at sufficient levels to cause injury to soybean at dates beyond a May 25th cutoff (Behrens and Leuschen 1979; Brabham et al. 2019; Egan and Mortensen 2012; Jones et al. 2019; Oseland et al. 2021; Soltani et al. 2020).
- An analysis of the number and type of plant injury complaints investigated by the Plant Board indicates that dicamba secondary movement is responsible for most injury complaints received from 2016 to the present. Furthermore, the numbers reveal that

many of these applications were made after the May 25th cutoff date. The May 25th cutoff date initiated in 2018 reduced the 1014 alleged dicamba complaints that occurred in 2017 to a total of 200 in 2018, 210 in 2019, and 218 in 2020 (Figure 1). Research confirms that volatilization occurs more at higher temperatures (Hartzler 2017; Behrens and Leuschen 1979; Mueller and Steckel 2019a).

- Research shows that volatility is a major contributor to off-target, landscape movement of dicamba. In addition, some of this same work has shown the detrimental effects of off-target movement to sensitive species other than soybean, such as vegetable, nut, fruit and vine crops (Knezevic et al. 2018; Bish et al. 2019; Dintelman et al. 2020; Oseland et al. 2020; Johnson et al. 2021).
- University weed scientists in a number of other states have observed and reported on the widespread dicamba injury in other soybean-producing states, showing that this is not just an Arkansas problem (Hager 2017; Hartzler, 2017; Bradley 2017, 2018).
- Weed scientists are seldom able to trace dicamba-induced symptomology to a source, indicating a means other than physical drift is responsible for the movement. These observations are consistent with Plant Board findings.
- Detrimental effects of sub-lethal dicamba doses dicamba to trees and other perennials have been well documented and are presented in this report (Dintlemann et al. 2019; Wells et al. 2019). This injury has been associated with an increased susceptibility to further abiotic and biotic stresses (ex. Insect feeding/disease) (Campbell and Valentine 1972).
- There are no scientific data that shows dicamba can be used throughout the year in Arkansas without substantially injuring crops. Analysis of complaint data indicates that applications in the summer months have caused a substantial number of complaints.

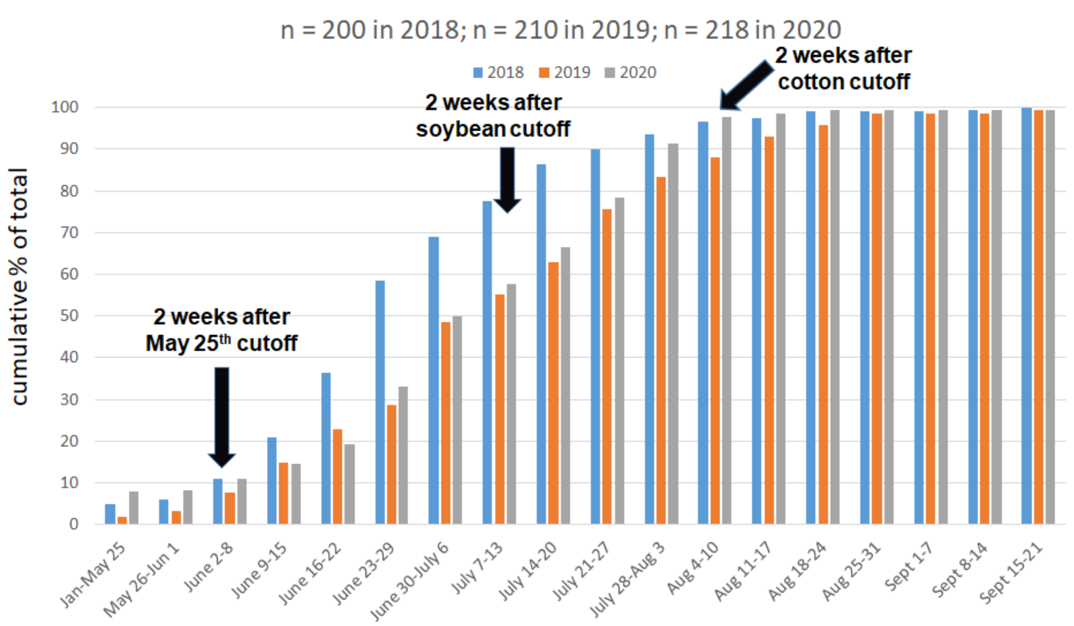

Figure 1. Cumulative percentage of alleged dicamba complaints in Arkansas in 2018, 2019, and 2020 with the assumption that these complaints occurred 2 weeks after application.

List of dicamba-related issues

The following numbered list of issues is supported by peer-reviewed literature. The term "peer-reviewed" means a scholarly process by which research is scrutinized by a group of experts in the appropriate field before publication, ensuring high scientific quality. Research published in peer-reviewed journals has gone through the rigors of the review process, and when it does not meet scientific standards, it is rejected (not published). Scientific findings on dicamba presented in this document are based on published research. Information from articles written by land grant university weed scientists and the media are included to document the expert opinions and observations from several soybean-producing states where dicamba injury has been observed in recent years.

1. ***Dicamba has historically been applied as a burndown herbicide or to corn and grain sorghum in early spring, which has minimized the risk for damage to nearby plants through volatilization.***
    - All herbicides have the potential to move off-target during and following their application; however, no herbicide has caused the extent of damage or the number of complaints in Arkansas or across the US comparable to dicamba (Bish et al. 2020).
    - Problems with dicamba volatilization were noted as early as the 1960s when Dr. Ellery Knake, extension weed scientist at the University of Illinois, discouraged the use of the herbicide on corn because of the risk for injury to soybean (Hartzler 2017).
    - Behrens and Leuschen (1979) published the widely cited, sentinel paper "Dicamba volatility", which was a major contribution to our understanding of the factors influencing dicamba volatilization and associated injury on soybean. Factors identified as affecting volatilization included formulation and rate, treated surfaces (plant vs soil), temperature, humidity, and rainfall after application. From field trials, Behrens and Leuschen concluded that abnormally high temperatures were not needed for sufficient dicamba volatilization to injure soybean.
    - Air temperature has long been recognized as a factor contributing to off-target movement of dicamba via volatilization, leading to a daily air temperature threshold of 85°F recommendation to limit off-target movement. Temperature-related movement of dicamba has directly led to another state (Illinois) implementing a temperature restriction (85°F) on over-the-top dicamba applications for the 2021 growing season (Hager 2021).
    - Egan and Mortensen (2012) demonstrated that field application of the diglycolamine salt of dicamba, the same salt form in Xtendimax, volatilizes at levels sufficient to injure soybean.

- Kniss (2018) and Castner et al. (2021a) showed low rates of dicamba applied to soybean do not increase soybean yields.

2. ***Division scientists were asked to provide the Plant Board an update on the latest scientific knowledge regarding dicamba and 2,4-D off-target movement as early as 2012 in anticipation of a request for use of dicamba in Xtend crops and 2,4-D in Enlist crops.***

    - Secondary movement is defined as volatilization, movement in water, re-lofting of herbicide molecules from treated surfaces, or suspension of herbicide molecules in air after deposition of the physical spray (Bish et al. 2020, Willett et al. 2019). Unlike primary movement or physical drift, *secondary movement cannot be controlled by the applicator*.

    - The history of problems with secondary movement of auxin herbicides in Arkansas and other states, including issues with dicamba volatilization, which are noted throughout the published literature, partly drove the request for research from the Plant Board (Behrens and Leuschen 1979; Bish et al. 2020).

    - Subsequent evaluations were also an early indication that secondary movement, most likely volatilization, would be a problem with commercial use of the herbicide during summer months if measures were not taken to correct the problem. Research on Xtendimax with VaporGrip was not allowed by Monsanto before commercial launch.

    - Over the past 4 years, there has been a plethora of research and reports by university weed scientists from multiple states who walked fields of soybean exhibiting dicamba injury symptoms showing unequivocally that dicamba volatilization was responsible for the landscape damage observed across much of the U.S. soybean production region.

3. ***Our understanding of dicamba volatilization and the factors contributing to the causes of dicamba detection in air has increased immensely over the past four years.***

    - Glyphosate addition to dicamba increases volatilization, even though mixing the newly registered dicamba products with glyphosate is permitted on the Xtendimax, Engenia, and Tavium labels (Bish et al. 2019; Bradley 2019; Carbonari et al. 2020; Mueller and Steckel 2019b; Zaccaro et al. 2021a, c).

    - Mixing glufosinate with dicamba increases dicamba volatilization, but this mixture is not permitted by any dicamba labels registered for use in XtendFlex crops (Zaccaro et al. 2021b).

    - The presence of dew and rewetting of leaf surfaces increases dicamba volatilization (Bradley 2019; Dr. Bryan Young, non-published data). This may partly explain the greater volatilization in the Midsouth relative to other arid climates like Arizona, Texas, and Australia where volatilization research has been conducted by a dicamba registrant.

- The concentration of dicamba in the air needed to induce symptomology on soybean is approximately 55 times less than from physical drift (Norsworthy, 2019 Plant Board meeting). Soybean typically shows dicamba symptomology any time dicamba acid is detected with air samplers, even at concentrations below 1 ng/m^3/day (Brabham et al. 2019). Dicamba is frequently detected in air and rainfall samples at levels sufficient to cause soybean injury when applied to vast acres (Norsworthy, 2020 Plant Board meeting; Oseland et al. 2021).

- As the pH of soil decreases, the risk for volatilization of dicamba applied to the soil increases (Bradley 2019).

- The time of day of dicamba application influences when and to what extent it is detected in the air (Bish et al. 2019; Mueller et al. 2013). An evening dicamba application in stable air leads to greater detection than daytime application in unstable air during the first 8 hours after application. However, beyond the first 8 hours after application, dicamba detection is greater for the daytime application. In Missouri, total detection of dicamba over 72 hours under stable and nonstable air was similar (Bish et al. 2019).

- In the absence of rainfall, dicamba volatilization can occur for up to 21 days from dry soil (Long 2017).

- Lowering application spray volume and decreasing droplet size increases dicamba volatilization (Long 2017).

4. ***Research and field evidence indicates that it is volatilization, rather than physical drift, of dicamba, that is a major cause of the issues observed with off-target movement of the herbicide over the past 4 years.***

   - Physical drift leaves a pattern of injury most severe closest to the spray source. For this reason, physical drift can often be traced to a source. However, of the 1,642 dicamba complaints that have occurred since 2017, *only 15% were traceable*. Hence, volatilization or atmospheric loading appears to be the main culprit leading to these complaints.

   - Academic research in recent years, both within and outside of Arkansas, has shown volatilization of new dicamba formulations to be a principal contributor of injury to hyper-sensitive plants (Bish et al. 2019; Soltani et al. 2020; Norsworthy, 2018 Plant Board Presentation).

   - Physical drift occurs directly downwind, whereas dicamba volatilization of the new formulations can move across the landscape in multiple directions and is known to occur even at 4 days after application in the absence of rainfall (Bish et al. 2019; Norsworthy 2018 & 2019 Plant Board Presentations).

- Over the past 4 years, Dr. Kevin Bradley studied the impact of dicamba on a wide assortment of fruit, vegetable, and tree species; conducted research to understand the extent of dicamba volatilization and its causes; and has examined associations between dicamba use and landscape injury (Knezevic et al 2018; Bish et al. 2019; Ward 2019; Dintelman et al. 2020; Oseland et al. 2020; Oseland et al. 2021).

5. ***There has been no large-plot, field-scale testing of VaporGrip Xtra or Sentris in Arkansas, so it is uncertain whether new volatility reducing agents that are required with the recent registration will circumvent the widespread damage caused by dicamba in our unique environment and landscape.***

- There has been no testing of the new volatility reducing agents in Arkansas other than a single evaluation of each product in a low-tunnel trial.
- There is no known published research that examines the relationship between dicamba volatilization and temperature when mixed with the new volatility reducing agents.
- It is well established that volatilization and risk for off-target movement of dicamba differ greatly among geographies across North American soybean-producing regions (Soltani et al. 2020). Conditions unique to eastern Arkansas partly contribute to potentially enhanced dicamba movement, and it is unknown whether the new volatility reducing agents will alleviate this problem.
- Dicamba damage across the Iowa landscape in 2020 was the greatest that had been observed since the introduction of dicamba in the 1960s. The environment in 2020, particularly with temperatures above 85°F during periods that dicamba was sprayed is believed to have greatly contributed to the damage (Hartzler 2020).

6. ***Defensive planting of Xtend and XtendFlex soybean is not the solution to this problem*.**

- The adoption of dicamba-resistant soybean in geographies of heavy dicamba use during the summer months does not ensure that other issues associated with dicamba volatilization will be mitigated.
- Even with defensive plantings of dicamba-resistant crop varieties by growers, there are still trees, gardens, and other sensitive species within these geographies for which there are no protective trait options.
- Weed scientist, Dr. Trey Koger, in 2018, noted landscape damage to trees, ornamentals, and vegetables in Arkansas counties where dicamba use is widely supported. Tree species that frequently displayed dicamba symptoms within and in the outskirts of these communities in eastern Arkansas included Bradford pear, red oak, sycamore, peach, and maple (Dr. Trey Koger's 2018 report to the Plant Board).

- There is no residue tolerance for dicamba on vegetable and fruit crops (EPA 2014), meaning that *fruit from any plant that exhibits symptoms for which dicamba residues are found could result in total crop destruction*.

- The linkage between the extent of dicamba use in the summer months and landscape symptomology has been established (Oseland et al. 2021).

7. The impact of sublethal, chronic exposure of trees and other perennial plants to low doses of dicamba leads to greater long-term physiological stress and susceptibility to pests.

- Sublethal rates of dicamba have a serious effect on the growth and physiology of trees. High concentrations of dicamba can inhibit cell division and growth. Sublethal doses result in curling and twisting of the stem, defoliation, and abortion of flowers and fruit. Wells et al. (2019) found that pecan trees were damaged by sublethal doses as low as 0.01%. Damage was greater later in the season than earlier.

- Dintlemann et al. (2019) found that apple, crabapple, dogwood, elderberry, elm, grape, hydrangea, maple, oak, peach, pecan, redbud, rose, red raspberry, strawberry, sweetgum, blueberry, and walnut exhibited dicamba injury symptoms at 1/200 of an application rate.

- The amount of herbicide affecting the plant is the sum of the amount of herbicide of each application less the amount of detoxification.

- Tree exposures within a short time are more damaging than exposures with a longer period between applications. Tree death is generally a long process since sapwood and roots store a considerable amount of carbohydrates.

- Campbell and Valentine (1972) found that healthy trees can die if defoliated for two or three seasons in a row. If the tree does not die from defoliation, crown and branch dieback can occur and tree vigor declines. As the tree is defoliated, carbohydrate reserves are depleted, and feeder roots often die. Water and nutrient uptake are reduced further stressing the tree.

- Chronic exposure of trees to dicamba lead to the attraction of insects or trees succumb to diseases that lead to death. Often, trees are diagnosed with one form of malady or the other, but the defoliation was the base cause of tree death (Franklin et al. 1987; Das et al. 2016).

- Repeated exposure to sublethal doses of dicamba has a cumulative effect. Loss of photosynthesis and carbohydrate reserves due to defoliation will lead to tree death and this process may take years. Increasing exposure events will increase the chances of death and death is often a result of a secondary pest being able to overcome the weakened tree defenses (Franklin et al. 1987; Das et al. 2016).

- Dicamba has been proven not to have any direct effects on adults, pupae, or larvae of bee species and monarch butterflies (Oregon State University 2021; Stevenson 1978).
- Several studies have demonstrated that dicamba movement affected the food and habitat of pollinators (Olszyk et al. 2015; Hatterman-Valenti 2004). Bohenbust et al (2020) demonstrated the indirect effects of dicamba on butterflies including monarch butterflies through food source reduction.
- Low doses of dicamba reduce the number of flowers and the size of flowers (Bohenblust et al. 2015). This reduction led to a reduced number of feeding sites and less visitation of pollinators to the plants.

8. ***Dicamba buffers established by the EPA do not protect against injury and resulting complaints to the Plant Board.***

- The EPA historically has developed spray drift buffers based on single application rate, spray drift deposition curves, and estimated distances to biomass, height, or survival endpoints. The EPA typically does not set spray drift buffers based on the occurrence of injury symptoms, unless those signs of visual injury can be linked to reductions in biomass and/or plant height (Kelly Tindall – EPA, personal communication).
- The EPA set the endangered species buffer for dicamba-based on "Off-Field Movement" field studies from small-plot research that displayed visual signs of injury sufficient to reduce plant biomass or height. In-field setbacks are intended to prevent off-field exposures that would result in 5% height reduction and 5% yield loss following a single exposure. No "Off-Field Movement" study on the new volatility reducing agents was conducted in Arkansas (Kelly Tindal – EPA, personal communication; Wagman et al. 2020).
- Dicamba symptoms on soybean are expressed at much lower concentrations of dicamba than needed to reduce soybean height or biomass, thus buffers set by the EPA are insufficient to protect highly sensitive plants like soybean (Wagman et al. 2020).
- The EPA does not model landscape damage caused by treating multiple fields over a short period within a confined geography. Because of federal label restrictions on the dicamba products, it is typical for a large number of spray applications to occur simultaneously when weather is conducive for spaying. The model used by the EPA only simulates the application of the herbicide to a single 80-acre field.

- Federal labels failure to include multiple exposures, the lack of modeling landscape-scale applications, and the use of biomass or height reductions as criteria for setting a sufficient buffer may be ineffective in preventing dicamba symptomology on surrounding plants.

9. Protection of research on stations throughout Arkansas is needed.

- The future success of weed control programs in Arkansas hinges on the ability of weed scientists to evaluate and compare technologies, leading to recommendations on how to best use available tools. The ability to conduct research is critical because most growers, either directly or indirectly, rely on Division scientists to make recommendations or train consultants that prescribe herbicides on a field-by-field basis. Research is conducted across the state of Arkansas at as many sites as possible because of differences in soil texture, soil pH, environmental conditions, and weed response to herbicides.

- The buffer size needed to protect dicamba-sensitive plants at research stations is unknown. Based on the dicamba symptoms observed at research stations from 2017-2020, three years of which a 1-mile buffer was in place, the buffer distance in the federal dicamba label is insufficient to provide adequate protection. The buffer distance in the federal labels is for endangered species, not protection against symptomology on dicamba-sensitive plants.

- While it is impossible to know whether a 1-mile buffer around research stations will provide sufficient protection, elimination of such a buffer distance increases the risk of dicamba damage to dicamba-sensitive plants at research stations.

- The frequent and sustained damage caused by dicamba at the Northeast Research and Extension Center (Keiser, AR) has made it impossible to accurately and fairly evaluate other herbicide technologies in soybean at this site.

10. Dicamba and 2,4-D, in addition to glufosinate, are effective options for controlling Palmer amaranth in most Arkansas cotton and soybean production fields, but to state "the Enlist system is no different from the Xtend system" is false for many reasons.

- The Enlist and Xtend technologies are vastly different in terms of weed control options, limitations, and risks.

- Glufosinate can be mixed with 2,4-D choline (see Enlist One label). Mixing two effective herbicide modes of action is the most effective strategy for mitigating the development of herbicide resistance (Evans et al. 2015), a tactic that can be employed in the Enlist technology but not the Xtend or XtendFlex technologies (see Engenia and Xtendimax labels).

- Glyphosate can be mixed with Enlist One for grass control without increasing volatility of the mixture (Norsworthy, unpublished data). Glyphosate can be mixed with Xtendimax/Engenia but increased volatilization results (Bish et al. 2019; Bradley 2019; Carbonari et al. 2020; Mueller and Steckel 2019b; Zaccaro et al. 2021a, c).

- Multi-year data collected by Division weed scientists clearly show that the Enlist technology is a viable and effective option for multiple-resistant Palmer amaranth in northeast Arkansas as evidenced by on-farm research at several locations in this geography (Houston et al. 2020). Furthermore, the Xtend technology is also effective if sufficient time can be found to apply the herbicide without violating label requirements and applications can be made before temperatures reach levels known to significantly increase dicamba volatilization.

11. Complaints filed alleging off-target injury caused by dicamba exceeds that of any other Plant Board regulated pesticide in Arkansas history.

- In the past 4 years, there have been 1,642 complaints filed with the AR State Plant Board alleging dicamba injury compared to 52 paraquat drift complaints, 106 glyphosate drift complaints, and 10 ALS herbicide drift complaints.

- Division weed scientists frequently visit fields to diagnose crop injury caused by off-target movement of paraquat, glyphosate, ALS-inhibiting herbicides, and other herbicides. However, injury caused by off-target movement of dicamba, as observed by Division scientists, has increased dramatically in number, scope and severity.

- Changes to the new dicamba labels over the past 4 years have not corrected the problem of secondary movement of dicamba.

- In a report to the Plant Board in 2018, Dr. Trey Koger wrote, "Dicamba-like symptomology was present in every city, town, and community I visited."

- The number of dicamba complaints over the past 3 years has remained constant to slightly increasing (Figure 2). The number of yearly complaints remains about twice that for quinclorac and 2,4-D in the years before greater regulations were placed on both of these herbicides.

- Symptoms on Arkansas crops caused by 2,4-D, clomazone, and quinclorac have previously led to strong regulations of these herbicides, regardless of the yield loss caused by the herbicides. These regulations remain in place today.

- Documenting yield loss is not required by Plant Board investigators; rather symptomology caused by chemical trespassing is documented by the Plant Board.

- The Plant Board has relied upon data from academic scientists in Arkansas and other states to make informed decisions regarding the science of dicamba and off-target movement.

- The Arkansas State Plant Board has used scientific data and expert opinion to regulate 2,4-D, quinclorac, clomazone, and other pesticides in Arkansas. Understanding the behavior of herbicides in Arkansas requires research conducted under Arkansas conditions. Research conducted in environments starkly different from the Midsouth can produce results that do not accurately reflect the situation within our state. Volatility evaluations conducted in the upper Midwest, Australia, Arizona, and Texas are examples.

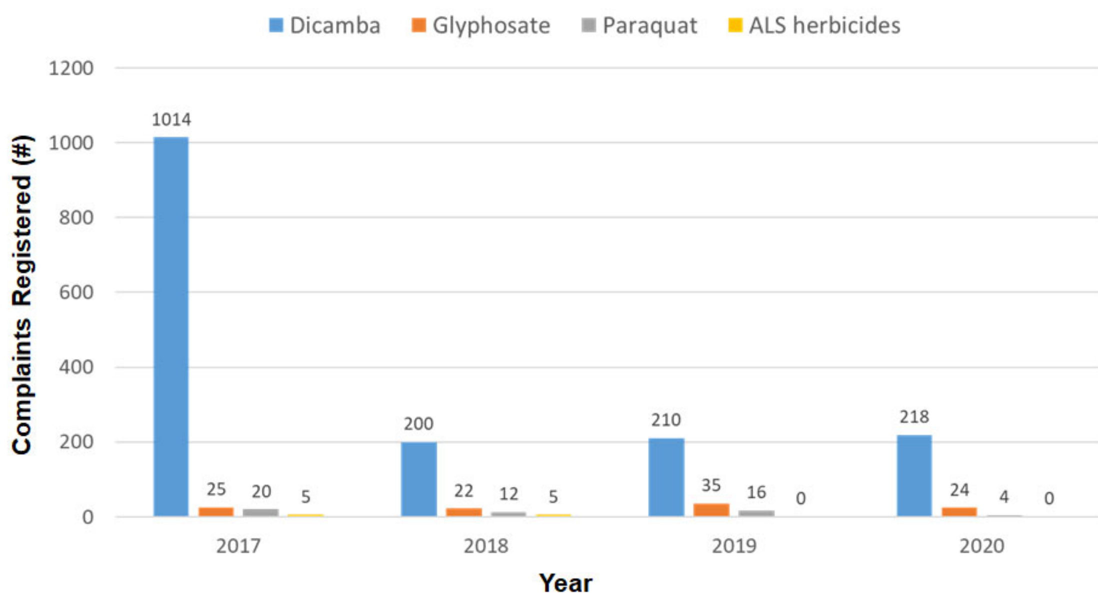

Figure 2. Complaints in Arkansas in 2017 through 2020 against dicamba, glyphosate, paraquat, and the acetolactate synthase (ALS)-inhibiting herbicides halosulfuron, penoxsulam, bispyribac, imazethapyr, and imazamox.

12. It was stated at a Plant Board meeting that consultants and farmers now know the rules, and the confusion with labels and guidelines that occurred in 2017 has not occurred since.

- Use of illegal (non-labeled) dicamba formulations has been common in U.S. cotton, according to the EPA based on findings from a 2018 survey that reported 47% of dicamba in-crop applications (at planting and after planting) were of a formulation other than Engenia, Fexapan, or M1768 (XtendiMax with VaporGrip) (Chism et al. 2020).

- Examination of the dicamba complaints and applicator violations found by the Plant Board shows that, excluding 2017, there have been 47 dicamba violations found against commercial applicators and 496 violations against private applicators over the past 3 years.

13. Dicamba injury and yield loss from susceptible soybean varieties

- Factors that influence the extent of symptomology and yield loss in soybean caused by dicamba include soil moisture availability, growing conditions during and after exposure, number of times the crop is exposed to the herbicide, growth stage at exposure, number of days after exposure until maturity, and dose of the exposure (Johnson et al. 2012; Kniss 2018; McCown et al. 2018; Osipitan et al 2019; Castner et al 2021b).
- Multiple exposures of soybean to dicamba are common in geographies where dicamba use is extensive. Each dicamba exposure increases the likelihood of significant yield loss (Meyeres et al. 2021; USB funded unpublished research summarized by Dr. Dan Reynolds of Mississippi State University and presented to the Plant Board by Dr. Norsworthy).

14. Criticism of observations, methods, results, and interpretations of dicamba research.

- The statement that Division weed scientists “never have observed injury from volatility” is contrary to what has been shown at open-to-the-public field days, including consultants, and other venues in which dicamba injury to non-dicamba tolerant plants was clearly visible. If secondary movement mechanisms including volatility were not a major cause of this injury, there would be no effort to improve the formulation, and research on volatility reducing agents would not be needed. There is a plethora of data that shows dicamba, including the new formulations developed for Xtend technology, volatilize at sufficient levels to cause injury to soybean (Behrens and Leuschen 1979; Brabham et al. 2019; Egan and Mortensen 2012; Jones et al. 2019; Soltani et al. 2020).
- Many tools are used to measure injury other than a scientist’s eyes. These tools include yield, imagery analysis, biomass production, height, photosynthetic measurements, leaf area index, analytical detection of the herbicide in plant or air samples, among others. In order to publish in peer-reviewed journals, qualitative data must be accompanied by quantitative data. Graduate students and others working in weed science are taught how to rate damage using photographs of the crop and weeds. This standardization assures consistency. The Behrens and Leuschen scale (Table 1) is often used to assess dicamba injury, and it is highly unlikely for different individuals rating injury to have significantly different ratings. Relationships between qualitative data and quantitative data are used to support the conclusions. For example, damage rating and yield differences are often used.
- Small-plot research is the standard to make recommendations and educate consultants and other clientele. Herbicides are selected and rates set based on visual assessments in small-plot research. All rates recommended by consultants and others originate from

visual assessment data, as well as all recommendations generated and presented in Extension-related publications such as the *MP44 Recommended Chemicals for Weed and Brush Control*. Efficacy and tolerance of herbicides are continually evaluated after initial testing during operational application. The Division weed scientists often hear or observe problems with particular treatments and will re-evaluate the recommendation.

Table 1. Behrens and Leuschen (1979) soybean dicamba injury index.

Rating	**Description**
0	No effect, plant normal
10	Slight crinkle of leaflets of terminal leaf
20	Cupping of terminal leaflets, slight crinkle of leaflets of second leaf, growth rate normal
30	Leaflets of two terminal leaves cupped, expansion of terminal leaf suppressed slightly
40	Malformation and growth suppression of two terminal leaves, terminal leaf size less than one-half that of control
50	No expansion of terminal leaf, second leaf size one-half or less than that of control
60	Slight terminal growth, vigorous, malformed axillary shoot growth developing
70	Terminal bud dead, substantial, strongly malformed, axillary shoot growth
80	Limited axillary shoot growth, leaves present at time of treatment chlorotic with slight necrosis
90	Plant dying, leaves mostly necrotic
100	Plant dead

15. Palmer amaranth is resistant to several herbicide modes of action in Arkansas, but it is possible to successfully produce soybean and cotton without dicamba as documented on many farms throughout the state.

- Dicamba resistance is real in Palmer amaranth (Peterson et al. 2019; Steckel 2020; Unglesbee 2020; Rowsey 2021) as well as the existence of glufosinate resistance (Barber et al. 2021). Dr. Larry Steckel in Tennessee has been vocal on social media about the inability to control dicamba-resistant populations of Palmer amaranth. According to Dr. Steckel, dicamba-resistant populations in Tennessee also exhibit resistance to Group 15 herbicides like metolachlor.

- One Palmer amaranth population in Arkansas has reduced sensitivity to both dicamba and glufosinate, and there are likely more than just this population present within the state. If these herbicides are continued to be used as the only method of control, resistant populations of Palmer amaranth to both herbicides will likely develop.

16. All plants do not respond similarly to dicamba rate.

- Palmer amaranth is one of the more tolerant species to dicamba, and we have yet to observe leaf cupping or symptomology on Palmer amaranth following drift rates of the herbicide. This was clearly shown in presentations given by Dr. Norsworthy to the Plant Board in 2019 and 2020.
- Some trees, ornamentals, and horticultural crops across the landscape where the herbicide is sprayed during summer months are hyper-sensitive (Dr. Trey Koger's 2018 Plant Board report; Dintelmann et al. 2020). Unlike soybean and Palmer amaranth, trees are perennials and chronic exposure to the herbicide year after year has long-term effects as seen at times with other xenobiotics and previously discussed in Discussion Point 8. These plants are refugia for beneficial insects and provide food and habitat to pollinators.

Conclusions

There are no scientific results that show dicamba can be used throughout the year in Arkansas without substantially injuring crops. There is, however, an abundance of complaint data showing that dicamba applications made in the summer months will cause a substantial number of complaints. Complaints to the Plant Board that lead to fines originate from the occurrence of symptomology caused by chemical trespass, not the need for documented yield loss. Before commercialization and launch of the dicamba formulations labeled for 2017, the Plant Board was repeatedly told by Monsanto (now Bayer CropScience) and BASF that there would be no issues with their low volatile forms of dicamba.

We are not aware of new published or unpublished research since the last approval of the dicamba regulations on December 2, 2020 that supports or refutes the labels or would support a regulation change. The current science and limitations placed on testing new volatility-reducing agents in Arkansas lead one to question the safe use of dicamba herbicide during the summer. There has not been a volatility test conducted in Arkansas east of Crowley's Ridge over the last few years, not because of a lack of need for testing, but rather a test cannot be completed because of the extent of spraying and concentrations of dicamba in the air sufficient to cause symptomology across the landscape.

Division recommendations to Arkansas producers whether it be pest management, agronomic practices, or fertilization are based on sound repeatable science that has been replicated over space and time. The new dicamba labels are the same as the old labels in regards to the off-target movement of dicamba, except for the addition of a volatility-reducing agent. The Division has not been allowed to evaluate these volatility-reducing agents in large-scale research. For products to be recommended by Division scientists, they must be evaluated over multiple years across environments. For that reason, we are unable to determine if these volatility reducing agents are effective and therefore cannot provide an extended-use recommendation to the Plant Board beyond what is currently known or has been already provided.

Literature Cited

1. Behrens R, Leuschen WE (1979) Dicamba volatility. Weed Science 27:486-493
2. Barber T, Norsworthy J, Butts T (2021) Arkansas Palmer amaranth found resistant to field rates of glufosinate. Available on Weeds AR Wild Blog at https://www.uaex.uada.edu/farm-ranch/pest-management/weed/weed-science-highlights-blog/glufosinate-resistant-pigweed.aspx
3. Bish MD, Farrell ST, Lerch RN, Bradley KW (2019) Dicamba losses to air after application to soybean under stable and nonstable atmospheric conditions. Journal of Environmental Quality 48:1675-1682
4. Bish M, Oseland E, Bradley K (2020). Off-target pesticide movement: a review of our current understanding of drift due to inversions and secondary movement. Weed Technol. doi: 10.1017/wet.2020.138
5. Bohnenblust, E., J. F. Egan, D. A. Mortensen, J. F. Tooker. (2020). Direct and Indirect Effects of the Synthetic-Auxin Herbicide Dicamba on Two Lepidopteran Species. Environmental Entomology, (42)3: 586–594,
6. Bohnenblust, E., A.D. Vaudo, J. F. Egan, D. A. Mortensen, J. F. Tooker. (2015) Effects of the herbicide dicamba on nontarget plants and pollinator visitation. Environmental Toxicology and Chemistry, 35:144–151.
7. Brabham C, Norsworthy JK, Zaccaro M, Varanasi VK, Mueller T (2019) Use of field evaluations to better understand dicamba volatility. Weed Science Society of America Abstract:334
8. Bradley KW (2017) How to proceed in 2018: a university perspective. Proceedings of the 72nd Annual Meeting of the North Central Weed Science Society. Available at: https://ncwss.org/wp-content/uploads/2017-North-Central-Weed-Science-Society-Proceedings-w_attendees.pdf.
9. Bradley KW (2018) July 15 dicamba injury update. Different year, same questions. Available on Integrated Pest Management University of Missouri website at https://ipm.missouri.edu/ipcm/2018/7/July-15-Dicamba-injury-update-different-year-same-questions/
10. Bradley KW (2019) Five things we've learned about dicamba. Available on Integrated Pest Management University of Missouri website at https://ipm.missouri.edu/IPCM/2019/4/dicamba/
11. Carbonari CC, Costa RN, Bevilaqua NC, Pereira VGC, Giovanelli BF, Lopez Ovejero RF, Palhano M, Barbosa H, Velini ED (2020) Volatilization of standalone dicamba and dicamba plus glyphosate as function of volatility reducer and different surfaces. Agriculture 10:495 doi:10.3390/agriculture10110495
12. Castner MC, Norsworthy JK, Barber T, Gbur EE, Roberts TL (2021a) Is there a hormetic response of sensitive soybean to dicamba? Crop, Forage and Turf Management (in review)

13. Castner MC, Norsworthy JK, Barber T, Robert TL, Gbur EE (2021b) Interaction of contact herbicides and timing of dicamba exposure on soybean. Weed Technology (accepted pending revisions)
14. Chism B et al. (2020) Dicamba use on Genetically Modified Dicamba-Tolerant (DT) Cotton and Soybean: Incidents and Impacts to Users and Non-Users from Proposed Registrations (PC# 100094, 128931). EPA Memorandum, October 26, 2020, 63 pgs.
15. Das, A.J., N.L. Stephenson, and K. P. Davis (2016). Why do trees die? Characterizing the drivers of background tree mortality. Ecology 97(10): 2016:2027.
16. Dintelmann BR, Warmund MR, Bish BD, Bradley KW (2020) Investigations of the sensitivity of ornamental, fruit, and nut plant species to driftable rates of 2,4-D and dicamba. Weed Technology 34:331-341
17. Egan JF, Mortensen DA (2012) Quantifying vapor drift of dicamba herbicides applied to soybean. Environ Toxicology and Chemistry 31:1023–1031
18. Evans JA, Tranel PJ, Hager AG, Schutte B, Wu C, Chatham LA, Davis (2015) Managing the evolution of herbicide resistance. Pest Management Science 72:74-80
19. [EPA] Environmental Protection Agency (2014) Part 180 – Tolerances and exemptions for pesticide chemical residues in food. Available at https://www.govinfo.gov/content/pkg/CFR-2014-title40-vol24/xml/CFR-2014-title40-vol24-part180.xml
20. Franklin, J.F., H. H. Shugart and M. E. Harmon. (1987). Tree Death as an Ecological Process. BioScience 37(8): 550-556.
21. Hager A (2017) Observations of Midwest weed extension scientist. Proceedings of the 72nd Annual Meeting of the North Central Weed Science Society. Available at: https://ncwss.org/wp-content/uploads/2017-North-Central-Weed-ScienceSociety-Proceedings-w_attendees.pdf.
22. Hager A (2021) Make Sure You Know ALL the Changes for 2021 Dicamba Applications in Soybean. Department of Crop Sciences, University of Illinois, January 14, 2021. Available at: https://farmdoc.illinois.edu/field-crop-production/weeds/make-sure-you-know-all-the-changes-for-2021-dicamba-applications-in-soybean.html
23. Hartzler R (2017) Dicamba: Past, Present, and Future. Available on Iowa State University Extension and Outreach Blog Post at https://crops.extension.iastate.edu/blog/bob-hartzler/dicamba-past-present-and-future
24. Hartzler R (2020) Dicamba 2020: What went wrong in Iowa? Available on Iowa State University Extension and Outreach Blog Post at https://crops.extension.iastate.edu/blog/bob-hartzler-prashant-jha/dicamba-2020-what-went-wrong-iowa
25. Hatterman-Valenti, H. (2004). Annual flower response to simulated 2,4-D and dicamba spray drift. HortScience 39(4): 844D-844.
26. Houston MM, Barber LT, Norsworthy JK, Roberts TL (2020) Comparison of weed control technologies for protoporphyrinogen oxidase-resistant Palmer amaranth. Crop, Forage and Turfgrass Management https://doi.org/10.1002/cft2.20024

27. Johnson VA, Fisher LR, Jordan DL, Edmisten KE, Stewart AM, York AC (2012) Cotton, peanut, and soybean response to sublethal rates of dicamba, glufosinate, and 2,4-D. Weed Technology 26:195–206
28. Jones GT, Norsworthy JK, Barber T (2019) Response of soybean offspring to a dicamba drift event the previous year. Weed Technology 33:41-50
29. Jones GT, Norsworthy JK, Barber T (2019) Off-target movement of diglycolamine dicamba to non-dicamba soybean using practices to minimize primary drift. Weed Technology 33:24-40
30. Jones GT, Norsworthy, Barber T, Gbur E, Kruger GR (2019) Off-target movement of DGA and BAPMA dicamba on sensitive soybean. Weed Technology 33:51-65
31. Jones GT, Norsworthy JK, Barber T, Gbur E, Kruger GR (2019) Effect of low doses of dicamba alone and I combination with glyphosate on parent soybean and offspring. Weed Technology 33:17-23
32. Kniss AR (2018) Soybean response to dicamba: A meta-analysis. Weed Technology 32:507-512
33. Long JI (2017) Influence of application factors on dicamba volatility. Purdue University Thesis
34. McCown S, Barber T, Norsworthy JK (2018) Response of non-dicamba-resistant soybean to dicamba as influenced by growth stage and herbicide rate. Weed Technology 32:513-519
35. Knezevic SZ, Osipitan OA, Scott JE (2018) Sensitivity of grape and tomato to micro-rates of dicamba-based herbicides. Journal of Horticulture 5:229 doi:10.4172/2376-0354.1000229
36. Lingenfelter D (2021) Comparing Xtend and Enlist E3 soybean systems. Penn State Extension available at https://extension.psu.edu/comparing-xtend-and-enlist-e3-soybean-systems
37. Meyeres TP et al. (2021) Non-dicamba-resistant soybean (*Glycine max* (L.) Merr.) response to multiple dicamba applications. Weed Technology (in review; *used with author permission*)
38. Mueller TC and Steckel LE (2021) Dicamba emissions under field conditions. Weed Technology 35:188-195
39. Mueller TC, Steckel LE (2019b) Spray mixture pH as affected by dicamba, glyphosate, and spray additives. Weed Technology 33:547-554
40. Mueller TC, Steckel LE (2019a) Dicamba volatility in humidomes as affected by temperature and herbicide treatment. Weed Technology 3:541–546
41. Mueller TC, Wright DR, Remund KM (2013) Effect of formulation and application time of day on detecting dicamba in the air under field conditions. Weed Science 61:586–593
42. Oregon State University. 2021. Dicamba Fact Sheet – National Pesticide Information Center. http://npic.orst.edu/factsheets/archive/dicamba_tech.html

43. Oseland E, Bish M, Steckel L, Bradley K (2020) Identification of environmental factors that influence the likelihood of off-target movement of dicamba. Pest Management Science 76:3282–3291
44. Oseland, EG, MD Bish, KW Bradley (2021) Influence of environment and soybean trait adoption on dicamba concentrations in rainwater and air deposits in Missouri. Weed Science Society of America Abstract:138
45. Osipitan OW, Scott JE, Knezevic SZ (2019) Glyphosate-resistant soybean response to micro-rates of three dicamba-based herbicides. Agrosystems, Geosciences & Environment 2:180052 doi:10.2134/age2018.10.00052
46. Peterson D, Jugulam M, Shyam C, Borgota E (2019) Palmer amaranth resistance to 2,4-D and dicamba confirmed in Kansas. Available on K-State Agronomy eUpdates at https://webapp.agron.ksu.edu/agr_social/eu_article.throck?article_id=2110
47. Rowsey G (2021) Metabolic resistance: searching for solutions. Delta Farm Press, April 2, 2021
48. Soltani N, Oliveira MC, Alves GS, Werle R, Norsworthy JK, Sprague CL, Young BG, Reynolds DB, Brown A, Sikkema PH (2020) Off-target movement assessment of dicamba in North America. Weed Technology 34:318-330
49. Steckel L (2020) Dicamba-resistant Palmer amaranth in Tennessee: Stewardship Even More Important. Available on UTcrops News Blog at https://news.utcrops.com/2020/07/dicamba-resistant-palmer-amaranth-in-tennessee-stewardship-even-more-important/
50. Stevenson, J H (1978). The acute toxicity of unformulated pesticides to worker honey bees (Apis mellifera L.). Plant Pathology, 27 (1):38-40.
51. Ungleesbee E (2020) Dicamba-resistant pigweed. Dicamba-resistant Palmer amaranth confirmed in Tennessee. Available in Progressive Farmer at https://www.dtnpf.com/agriculture/web/ag/crops/article/2020/07/27/dicamba-resistant-palmer-amaranth
52. Wagman M, Farruggia FT, Odenkirchen E, Connolly J (2020) 2020 Ecological Assessment of Dicamba Use on Dicamba-Tolerant (DT) Cotton and Soybean Including Effects Determinations for Federally Listed Threatened and Endangered Species. October 26, 2020, 346 pages.
53. Ward M (2019) 10 things university research teaches us about dicamba. Available in FarmProgress at https://www.farmprogress.com/crops/10-things-university-research-teaches-us-about-dicamba
54. Wells, M L, E P Prostko, and OW Carter. (2018). Simulated single drift events of 2,4-D and dicamba on pecan trees. HortTechnology 29:360-366.
55. Willett CD, Grantz EM, Lee JA, Thompson MN, Norsworthy JK (2019) Soybean response to dicamba in irrigation water under controlled environmental conditions. Weed Science 67:354-360

56. Zaccaro ML, Norsworthy JK, Priess GL, Castner MC, Mueller TC (2021a) Large-Scale Field Evaluation of Dicamba Volatilization When Mixed with Glyphosate. 2021 WSSA 61st Meeting, February 15-19, 2021.
57. Zaccaro ML, Norsworthy JK, Piveta LB, Houston MM (2021b) Impact of Spray Target Surface and Glufosinate on Dicamba Volatility. 2021 WSSA 61st Meeting, February 15-19, 2021.
58. Zaccaro ML, Norsworthy JK, Piveta L (2021c) Does the presence of AMS residue and the addition of potassium salt of glyphosate impact dicamba volatility? Proceeding of the Southern Weed Science Society (in press)