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Arkansas Plant Board
Plant Industries Division
P.O. Box 1069
Little Rock, Arkansas 72203

Re: Comments on Proposed Plant Board Rule for Dicamba Use in Arkansas

Ladies and Gentlemen:

On March 3, 2021, at a regular meeting of the Arkansas Plant Board, the Board voted to initiate rulemaking proceedings for eliminating existing restrictions in Arkansas on application of dicamba, and implementing only the EPA-approved label restrictions. This firm represents a group of farmers, landowners, individuals and organizations interested in protecting their crops, their other property, and the environment of Arkansas against the consequences of such use[1]. On behalf of my clients and myself, I herewith submit comments on the proposed modifications to the Rules of the Arkansas Plant Board on the use of dicamba herbicides in Arkansas.

This rulemaking was initiated solely upon the Petition of Huntington Tyler Hydrick dated January 31, 2021, entitled "Petition for Rulemaking and Amendment to Current Rules." Mr. Hydrick holds a Masters Degree in weed science, is a licensed Arkansas crop consultant, and is the owner of or

[1] The names of this Firm's clients in this matter are not being disclosed in these Comments due to the volatile nature of the subject and the potential for retaliation or harassment. The clients will be identified on a confidential basis upon request by the Board.

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consultant to crop consulting businesses that purport to operate in northeastern Arkansas, and parts of Missouri and Tennessee. His clients appear to be farmers and applicators. Mr. Hydrick advocates the use of dicamba-based herbicides and advises his clients to utilize dicamba-based herbicides. He believes that "Xtend/XtendFlex technologies should lead the state in planted acres." He is, in essence, an advocate rather than an objective expert.

There are a considerable number of misstatements and unsupported hyperbole in Mr. Hydrick's Petition, as well as an obvious bias against persons who do not share his views. These misstatements and hyperbole cast doubt upon his objectivity and the accuracy of facts alleged in the Petition. Some of those defects are discussed in the section of these comments entitled "Response to Petition for Rulemaking."

Our comments on the proposed rulemaking are set forth in the following pages. In addition, we adopt and incorporate by reference the separate comments of Freedom To Farm, Inc., and Audubon Arkansas filed in these proceedings.

COMMENTS

1. *The State Plant Board Failed to Give Adequate Notice of the Proposed Rule Change*

These proceedings are governed by Ark. Code Ann. §25-15-204, which is the section of the Arkansas Administrative Procedure Act relative to the procedures that an agency of the State must follow to adopt, modify, amend or revoke regulations. In relevant part, subsection (a) of that section provides:

> Prior to the adoption, amendment, or repeal of a rule, the agency shall:

(1)(A)(i) Give at least thirty (30 days' *notice* of its intended action;

(B) The notice shall include:

(i) A statement of the terms or substance of the intended action or a description of the subjects and issues involved;

In this case, the Notice of Rulemaking issued by the Plant Board consisted of the following:

(i) Publication of a Legal Notice in the *Arkansas Democrat-Gazette* dated March 24, 2021, stating:

> The Arkansas State Plant Board is proposing changes to the Arkansas Rules on Pesticide Use and Classification. *The proposed changes will be to consider changes* for the use of dicamba in the State of Arkansas. **(Exhibit No. 1A)**

(ii) A statement on the Arkansas Department of Agriculture's Plant Industries website **(Exhibit No. 1B)** stating the same content as in (i), above:

(iii) The hyperlink takes the reader to the Arkansas Rules on Pesticide Use consisting of 21 pages **(Exhibit No. 1C)**. There is no explanation given to the reader regarding any portion of those Rules that are to be added, amended or repealed. On page 16, the wording "All pesticide products containing dicamba shall be used in compliance with their respective federal labels" is underlined. Thereafter, on pages 16 through 19, there is text through

> which lines are drawn. No other comments or explanation are provided regarding the proposed rule change or the effects of any proposed rule change.

This "Notice" does not meet the requirements of Ark. Code Ann. §25-15-204(a)(1)(B). Not only is it different from the resolution that was voted on and approved at the Board meeting on March 3, 2021 (see following section for elaboration on this issue), but there is no "statement of the terms or substance of the intended action or a description of the subjects and issues involved. It is difficult for interested parties to determine what is being proposed so that they can formulate and present rational responses to the proposal. Persons not familiar with legislation and regulation promulgation will not be familiar with the underlying and strike-through editing used in the Arkansas Rules on Pesticide Use and Classification

Numerous judicial authorities holds that the Administrative Procedure Act used in Arkansas, other states, and the Federal APA obligate the agency contemplating a change in the rules to inform the public of the "substance" of the proposed changes and to afford all interested persons opportunity to submit data, views or arguments, orally or in writing. The "substance" of a proposed rule means not merely the subject of it, but an intelligible abstract or synopsis of its material and substantial elements. This means that the Board has to do more than simply offer a mark-up of the proposed Rule.

To complicate matters further, the Notice on the Department of Agriculture's website states that "*The proposed changes will be to consider changes* for the use of dicamba in the State of Arkansas." This is highly misleading, in that it appears to say that the rule is being changed so that the Board can thereafter consider other changes for the use of dicamba – not that the proposed changes in the rule will actually make changes for the use of dicamba.

2. ***The Board Has Violated the AAPA By Submitting a Proposed Rule That Is Significantly Different from That Approved By The Board at Its March 3, 2021 Meeting***

The Petition for Rulemaking and Amendment to Current Rules submitted by Mr. Hydrick concluded with a section III entitled "Action Requested of the Arkansas State Plant Board." That section provides:

a. I request the following as part of the rule-making process:

i. The implementation of a full, federally-approved label for all reduced volatility dicamba formulation in the state of Arkansas without additional restrictions.

[there is no other subsection]

In other words, Mr. Hydrick, in essence, requested <u>only</u> that the restrictions added by the State Plant Board to the EPA-approved label be removed. In its meeting on March 3, 2021, the Board voted on the Petition, the following Motion was made by Board Member Stuckey and seconded by Board Member Walls that the Board:

Accept the Hydrick Petition for full federal label for dicamba use over the top of dicamba tolerant crops.

The motion was repeated by Chairman Fuller, and then voted on and approved without change. Therefore, the resolution was, as stated in Mr. Hydrick's Petition, only that the restrictions added by the State Plant Board to the EPA-approved label be removed.

However, the proposed rule that the Plant Board submitted to Governor Hutchinson, as required by the AAPA, was that "*All pesticides containing dicamba* shall be used in compliance with their respective labels." (Italics added) This is a significantly different proposal than that contained

in the Hydrick Petition. It is also a violation of the AAPA. The proposed rule should be substantially the same from the commencement of the rulemaking process, beginning with the initial proposal and public notice, through the process prescribed by the AAPA, to the final approval.

3. *The State Plant Board Has Not Provided A Reasoned Explanation For The Change In The Existing Rule Adopted in 2018*

The Petition for Rulemaking proposes to change an existing rule imposing restrictions on the use of dicamba that have been in effect since 2018. Since that time, the Board has rejected proposals to remove those restrictions as late as December 2020 – only four months before the filing of the Petition for Rulemaking.

The existence of the restrictions since 2018, with the December 2020 confirmation of those restrictions raise the question: What has changed in the science of weed control and use of dicamba herbicides since December 2020 to justify the granting of the Petition? Mr. Hydrick's Petition for Rulemaking contains no information whatsoever that presents any new science or other information about how the dangers of dicamba that led to restrictions in 2018 have changed so that such restrictions are no longer reasonable or required.

An administrative agency cannot initiate or change an existing rule without providing a reasoned explanation for the proposed rule or change, and, under the Arkansas Administrative Procedure Act (AAPA), Ark. Code Ann. 25-15-201 *et seq*, the public be given an opportunity to comment upon the proposal. The public is not being given an opportunity to comment on the Board's reason for the change, because nowhere in the proposed rule or background information is there a reasoned explanation for the proposed rule. This is a fatal flaw in these proceedings.

4. *The Board Did Not Review the Best Reasonably Obtainable Scientific, Technical, Economic Evidence And Information Available Showing A Need For, Consequences Of, And Alternatives To The Existing Rule*

As noted above, the AAPA applies to this rulemaking. One section of that Act, A.C.A. § 25-15-204(a)(3)(b)(1), provides:

> An agency *shall not* adopt, *amend*, or repeal a rule unless the rule is based on the best reasonably obtainable scientific, technical, economic, or other evidence and information available concerning the need for, consequences of, and alternatives to the rule. (Italics added)

It should be noted that the statute uses the word "shall." Arkansas courts have long interpreted that word in a statute to be mandatory. In other words, in the context of this matter, the Plant Board cannot adopt the proposed rulemaking without first having reviewed, considered, relied upon and adopted the "best reasonably obtainable scientific, technical, economic, or other evidence and information available concerning the <u>need for</u>, <u>consequences of</u>, and <u>alternatives to</u> the rule."

There is absolutely nothing in the administrative record of this matter that indicates that the Board based its decision on the factors required by A.C.A. § 25-15-204(a)(3)(b)(1). Furthermore, as will be discussed herein, there is no credible evidence supporting the proposition that dicamba herbicides can, as a practical matter, be used in Arkansas without unacceptable damage to non-dicamba resistant crops, ornamentals, fruits and vegetables, and native plants and trees.

The General Assembly intended to not only permit pesticides to be used, but to protect other parts of the environment from the potential impacts of those pesticides. That is clear from Ark. Code Ann. §20-20-202(b) (Legislative Intent) stating:

> Pesticides perform a valuable role in protecting man and the environment including agricultural production from insects, rodents, weeds, and other forms of life which may be pests; but it is essential to the public health and welfare that they be used properly to prevent unreasonable adverse effects on man and the environment.
> (Underlining added)

To emphasize protection of the environment as a factor to be considered by the Board, and to give the Board guidance on what type of environmental impacts should be considered, Ark. Code Ann. § 20-20-206, regarding the powers and duties of the Plant Board, provides in relevant part:

> (a)(1) The State Plant Board … may restrict or prohibit use of pesticides in designated areas during specified periods of time *to prevent unreasonable adverse effects by drift or misapplication to*:
>
> (A) Plants, *including forage plants, or adjacent or nearby lands;*
>
> (B) Wildlife *in the adjoining or nearby areas;*
>
> (C) Fish and other aquatic life *in waters in reasonable proximity to the area to be treated*; and
>
> (D) Humans, animals, or beneficial insects.
>
> (Emphasis added)

This statute is a key component of the Plant Board's power and authority. Again, it is clearly the intent of the Arkansas General Assembly that the Board must consider a pesticide's potential to drift, volatilize or otherwise be misapplied to other areas, including natural areas and waters.

As will be discussed herein, the overwhelming evidence regarding dicamba is that, in the relatively short time it has been authorized for use, it has had a devastating impact on wide areas of east Arkansas (including within communities and towns), not just the areas in the immediate vicinity of the fields to which it was applied.

Based on the evidence discussed herein, it is the best current scientific opinion and evidence that dicamba-based herbicides cannot be used in Arkansas without unacceptable damage to non-dicamba resistant crops, ornamentals, fruits and vegetables, and native plants and trees. Even the restrictions that the Board has applied for the past two years on dicamba herbicides are not sufficient to prevent widespread damage to unintended targets, and those restrictions, as ineffective as they are, should not be removed.

5. ***The Best Reasonably Obtainable Scientific, Technical, Economic, Or Other Evidence Available Requires Keeping The Current Rule Rather Than Adopting The Proposed Change.***

Ark. Code Ann. § 20-20-206(a)(2) provides that "In issuing rules, *the board* <u>*shall*</u> *give consideration to pertinent research findings* and recommendations of *other agencies of this state*, the United States Government, or other reliable sources. … ." (Emphasis added)

In furtherance of that statute, Regulation No. 7 of the Plant Board promulgated pursuant to the Arkansas Pesticide Control Act, Ark. Code Ann. §2-16-402, provides that the Board <u>will</u>[2] give special consideration to the *unique environment* of Arkansas, and the *source of opinions* about that environment, stating:

> The Board considers the environment in Arkansas to be unique; therefore, *there will be a higher consideration given to research that*

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[2] The word "will" in this context has the same meaning as "shall."

> *is specific to Arkansas.* Research conducted by *scientists from universities within the state will be the primary source of expertise* to allow the Board to determine if the data is scientifically sound and relevant to growing and cropping conditions in the state of Arkansas. …

Reputable weed scientists in academia and professional consulting services, within and outside the State of Arkansas, are virtually unanimous in their opinion that dicamba herbicides are extremely difficult, if not impossible, for applicators to control, and that through drift, volatilization and other migration off-target, they are causing and will continue to cause widespread damage. The opinions of a few of those scientists will be summarized.

Jason K. Norsworthy, Ph.D.

Arkansas is fortunate to be home to several of the leading weed scientists in the United States. Jason K. Norsworthy, Ph.D., is one of them. As a member of the University of Arkansas Agricultural Service, Dr. Norsworthy is considered to be an expert on the subject of the characteristics of dicamba herbicides, and their effect, not only on crops but also "non-target" plants to which the herbicides migrate through drift, volatility, and other means. He is a fellow of the Weed Science Society of America (WSSA) since 2018. Dr. Norsworthy's Curriculum Vitae is attached to these comments as **Exhibit No. 2**.

In addition, as a Distinguished Professor of the University faculty, Regulation 7, cited above, requires that *a higher consideration* be given by the Board to his opinions on this subject.

Dr. Norsworthy has been very candid on the characteristics of dicamba to drift, volatilize and otherwise migrate from a targeted field to other, non-target areas, the difficulty in controlling the movement of dicamba, and its devastating impacts on native plants, trees, bushes and other vegetation that is not genetically-engineered to resist the chemical.

On December 3, 2019, Dr. Norsworthy made a presentation to the Plant Board, a copy of which is attached to these comments as **Exhibit No. 3**. That presentation gave the Board the results of extensive research that he had performed to determine the characteristics of dicamba and its potential for volatilization, drift and other means of migration from a target field. One section of that report compared the results of Norsworthy's research to that of a researcher from Legacy Monsanto (Mr. Tom Orr) to establish the "No Effect" concentration for dicamba. Dr. Norsworthy's report states:

> There were stark differences between the results from [Norsworthy's] Arkansas field trials and those reported for Orr's humidome research. … [B]ased on results from this research, it appears that a very low air concentration of volatile dicamba is needed to elicit symptomology on soybean, and the concentration needed to cause injury to soybean is much lower than previously reported from the humidome research.

Dr. Norsworthy concluded, among other things, that "secondary movement" is considered by academics across multiple states to be "a major concern with off-target movement of dicamba, *and is not manageable by the applicator.*" In other words, he is of the opinion that dicamba herbicides cannot be controlled. For his opinions, Dr. Norsworthy was highly criticized in an unsuccessful effort by Monsanto to discredit him.

Ford Baldwin, Ph.D.

Arkansas also is home to another highly-recognized weed scientist, Ford Baldwin, Ph.D. Dr. Baldwin was the University of Arkansas Extension Weed Scientist for 28 years. Since 2001 he has worked as a private agricultural consultant with Practical Weed Consultants, LLC, a professional agricultural crop consulting business. He has been an invited speaker and hosted numerous groups of agricultural consultants, growers,

and scientists around the world. He has been a Fellow of the Weed Science Society of America since 1996. Regulation 7 also requires that *a higher consideration* be given by the Board to his opinions on this subject.

Dr. Baldwin is also candid about his views on dicamba herbicides. On July 18, 2019, he issued an "Open Letter to the WSSA Board of Directors and Other Interested Parties" in which he stated:

> From the beginning, there has been plenty of published science and plenty of experience among our members to know dicamba could not be sprayed on large acreages in summer temperatures without a train wreck… .
>
> [A]s weed scientists, we have an environmental responsibility to be good stewards. Once again in 2018, large acreages of non-dicamba-tolerant soybeans in eastern Arkansas are affected by the herbicide as well as many vegetables. In addition, most trees in the countryside and towns are cupping and even dying following multiple years of exposure. Gardens are being destroyed and commercial vegetable producers are fearful that the crop may be condemned because of no tolerances for dicamba residue. Reports from bordering states are similar to those in Arkansas.
>
> …
>
> I have simply known from the beginning that a volatile auxin could not be kept on target. … Dicamba has a chemistry problem that likely cannot be fixed, or at least no evidence has been provided that it can be successfully applied. … No other trait or technology for soybean can be grown in areas where dicamba is extensively used, preventing diversity in week control options. … Dicamba floating in the air is inflicting sub-lethal damage to all sorts of dicot plants in agricultural ecosystems, natural ecosystems, parks, gardens, wildlife refuges, timber stands, home sites, and etc. … In short, ignoring the significant scientific data regarding the off target movement

> of dicamba will be the biggest environmental disaster agriculture has ever seen, and much of that responsibility is square on the backs of agriculture … .

Dr. Baldwin's entire letter is attached to these comments as **Exhibit No. 4**.

Two other papers have been submitted by Dr. Baldwin to the Arkansas Plant Board regarding dicamba. One, dated July 25, 2016, is attached hereto as **Exhibit No. 5**, and another dated December 29, 2017, is attached as **Exhibit No. 6**. Both papers clearly describe the off-target characteristics of dicamba herbicides, the wide-spread damage they cause, and the folly in continuing to use them in their current state.

Trey Koger, Ph.D.

Dr. Koger is a Research Agronomist with and owner of Delta Crop and Research, Inc. in Indianola, Mississippi, and also farms. In 2018, he was commissioned by the Arkansas Plant Board to conduct an independent investigation regarding the impacts of dicamba herbicides on non-crop species in Arkansas.

Dr. Koger issued two reports of his investigation. The first was dated August 21, 2018, in which he stated that on August 3, 2018, he investigated an area of east Arkansas beginning in West Memphis, to Forrest City, and then south to Marianna, Marvell, Poplar Grove and Helena-West Helena.

Dr. Koger' report continues with:

> *Dicamba-like symptomology was prevalent in every city, town and community I visited.* It is important to note that the damage tended to be worst on the outskirts of each city and along roadsides that were on the edges of each city. The further away from the city/community outskirts and the closer to inner

> parts of each city/community the damage tended to lessen. This is not to say that damage could not be seen on the inner parts of each city/community that I toured, its just that the damage tended to be less severe than on the outer parts of the city/community. (Italics added)

Dr. Koger noted that some tree species are more sensitive to dicamba than other species. Those most sensitive, according to Dr. Koger, include Bradford pear, cherry, sycamore, maple, cypress and white oak.

Dr. Koger's report of August 21, 2018 is attached to these comments as **Exhibit No. 7**.

On October 28, 2018, Dr. Koger wrote a more extensive report following an extended tour of east Arkansas with Plant Board inspectors between July 23–27, August 1-3, and August 22-24, 2018. Dr. Koger commented on the widespread damage that he observed throughout east Arkansas:

> The extensive injury in this [Phillips] county, in particular the Poplar Grove community, made it obvious that the injury was caused by more than a single drift event. Significant injury was documented to the following tree species: cherry, white oak, sycamore, maple, cypress, Bradford pear. *Injury was also documented on virtually every broadleaf vegetable species, including: tomato, squash, okra, cucumbers, watermelons, and cantaloupe.*
>
> ...
>
> Extensive time was spent investigating follow-up cases in Crittenden, Poinsett, Mississippi, Craighead and Clay Counties. The amount of dicamba injury observed in those areas was extensive and severe in some cases. ... In multiple locations, it was obvious based on injury to sensitive plants that dicamba was applied well after the cutoff date. ... In summary, *dicamba injury was prevalent to sensitive trees, roadside plants, and non-*

dicamba crops throughout many of the areas in eastern AR in which made [sic] evaluations.
(Emphasis added)

A copy of Dr. Koger's complete report of October 28, 2018 is attached to these comments as **Exhibit No. 8**.

Kevin W. Bradley, Ph.D.

Dr. Kevin W. Bradley is a Professor of Plant Sciences at the University of Missouri, and holds a PhD in Plant Pathology, Physiology, and Weed Science from Virginia Tech University. He is also a Fellow in WSSA, and is highly-regarded in his profession.

To avoid being unduly repetitious, Dr. Bradley's views on the propensities of dicamba herbicides to be transmitted to off-target vegetation, and its effect on non-dicamba tolerant broadleaf vegetation are very similar to those of Dr. Norsworthy, Dr. Baldwin and the other scientists discussed herein.

Dr. Bradley has authored a number of articles on the characteristics of dicamba herbicides, and their impact on off-target vegetation. Among them are the following:

- *Identification of environmental factors that influence the likelihood of off-target movement of dicamba,* Pest Management Science (2020) **(Exhibit No. 9)**

- *Off-target pesticide movement: a review of our current understanding of drift due to inversions and secondary movement,* Weed Technology (2021) **(Exhibit No. 10)**

- *Inversion Climatology in High-Production Agricultural Regions of Missouri and Implications for Pesticide*

Applications, American Meterological Society (2019)
(Exhibit No. 11)

Thomas C. Mueller, Ph.D. and Lawrence E. Steckel, Ph.D.

Dr. Thomas C. Mueller and Dr. Lawrence E. Steckel are both Professors of Plant Sciences at the University of Tennessee, and frequently collaborate on research and writing of articles regarding that research. They are likewise highly-regarded in their professions. Much of their research has been on the subject of the characteristics of dicamba herbicides and its impact on off-target vegetation.

Their views on the propensities of dicamba herbicides to be transmitted to off-target vegetation, and its effect on non-dicamba tolerant broadleaf vegetation is very similar to those of Dr. Norsworthy, Dr. Baldwin, Dr. Bradley, and the other scientists discussed herein. They have authored a number of articles on the characteristics of dicamba herbicides, and their impact on off-target vegetation. One of those articles entitled *I Can't Keep Dicamba In the Field*, U.T. Crops, 2017), is attached to these comments as **Exhibit No. 12**.

In summary, the greater weight of scientific opinion on dicamba herbicides is that, while it is effect in killing weeds such as Palmer amaranth (pigweed), it is virtually uncontrollable in application, and cannot be prevented from migrating to and having a devastating impact on crops that have not been genetically-engineered to resist dicamba, and on any other broadleaf plant. These herbicides are proven to be causing an environmental disaster in east Arkansas.

4. *Palmer amaranth Is Developing Resistance to Dicamba*

Scientists at the University of Tennessee conducted greenhouse trials and replicated field trials on Palmer amaranth populations collected from

fields in several Tennessee counties, and University of Tennessee Extension weed scientist Larry Steckel (see bio above) also confirmed that the results showed that pigweed was developing resistance to dicamba, and some preliminary results suggest tolerance to 2,4-D was present as well.

Given this development, the useful life of dicamba herbicides in accordance with the EPA label is probably limited. In the meantime, continued use of the dicamba herbicides can cause an immense amount of damage to other plant life in east Arkansas.

5. *The Plant Board Did Not Consider Alternatives To Use of Dicamba Herbicides as Required by ACA §25-15-204(a)(3)(b)(i)*

As noticed in earlier comments, the Board is required to consider, among other factors, alternatives to the proposed rule. That would include consideration of whether herbicides other than dicamba products are available and feasible for use.

Alternatives to dicamba exist for control of Palmer amaranth that have considerably less risk for off-target movement. See *Comparison of weed control technologies for protoporphyrinogen oxidase-resistant Palmer amaranth,* Crop Forage & Turfgrass Management, by the Department of Crop Soil and Environmental Sciences, University of Arkansas (2020). The "core ideas" of that paper were that: (i) Pre-emergent pyroxasulfone + metribuzin controlled multiresistant Palmer amaranth; (ii) Roundup Ready 2 Xtend, LibertyLink and Enlist are effective postemergent options; and (iii) season-long multiresistant Palmer amaranth control is feasible with RoundupReady 2 Xtend, LibertyLink and Enlist.

The article cited above is attached to these comments as **Exhibit No. 13**.

6. *EPA's Approval Of The Current Dicamba Label In 2020 Is Being Challenged And May Be Held To Be Invalid.*

EPA's approval of the re-registration of the dicamba herbicides may be void. The re-registration was challenged almost immediately in Federal court by several organizations who had been the plaintiffs in the case of *National Family Farm Coalition, et al v. U.S. Environmental Protection Agency, et al*, 960 F.3d 1120 (9th Cir. 2020), which cancelled the 2018 certification of the dicamba herbicides. That case is now winding its way through the Federal courts. Due, in part, to irregularities in the procedures followed by EPA in its hurried re-approval process and lack of scientific information upon which to base the re-approval, the new registration is likely to be voided again, thereby rendering the use of the dicamba herbicides currently being used to be illegal until the registration process is repeated.

Again, in the meantime, the use of the herbicides can cause an immense amount of damage to other plant life in east Arkansas.

7. *Response to the Petition for Rulemaking*

This rulemaking was initiated solely upon the Petition of Huntington Tyler Hydrick dated January 31, 2021, entitled "Petition for Rulemaking and Amendment to Current Rules." Mr. Hydrick holds a Masters Degree in weed science, is a licensed Arkansas crop consultant, and is the owner of or consultant to crop consulting businesses that purport to operate in northeastern Arkansas, and parts of Missouri and Tennessee. His clients appear to be farmers and applicators who are interested in the use of dicamba-based herbicides. Mr. Hydrick advocates the use of dicamba-based herbicides to support his customers' desires. He is, in essence, an advocate rather than an objective expert, stating:

> [T]he best path for financial and stewardship success is through the Xtend [dicamba] system. I recommend that most of my

growers plant Xtend/XtendFlex cotton and soybean due to its higher yield and excellent weed control.

With all due respect to Mr. Hydrick, there are a considerable number of misstatements and unsupported hyperbole in his Petition, as well as an obvious bias against persons who do not share his views. These misstatements and hyperbole cast doubt upon his objectivity and the accuracy of facts alleged in the Petition.

- Mr. Hydrick touts the virtues of dicamba in killing palmer amaranth and other weeds, but completely ignores the documented scientific opinions of other experts in the weed science field – including a substantial number of such scientists who, unlike Mr. Hydrick have doctorate degrees and longer years of experience – regarding the many disadvantages of using dicamba, and who are not concerned about selling a product.

- He brushes aside without rebuttal the observations of many scientists and laypeople regarding the unintended but widespread dicamba damage to non-dicamba tolerant crops, ornamentals, natural areas, trees, birds and insects throughout eastern Arkansas, claiming that he has "never seen a tree, bird or bee colony killed by dicamba." Those comments are completely contrary to the views of numerous highly-qualified academic experts, including those discussed above, that state that dicamba damage to much of the broad-leaf plant life in eastern Arkansas and other states has been hard-hit by dicamba.

- He states that "farmers never intend to harm their own, neighbors' or homeowners' property EVER", and that dicamba damage "in most cases is nothing more than superficial." However, "intent" is not an issue in these proceedings. A farmer may have the best of intentions in applying dicamba,

but its properties and characteristics make the potential for harm to other crops and plant life in the general vicinity significant. Regarding the extent of dicamba damage "in most cases," Mr. Hydrick's statement that the damage is nothing more than superficial is also contrary to the evidence and opinions of virtually all other credible observers.

- He completely discounts the views of anyone "outside of the Agricultural community," making the baseless and shameful claim that "they are only here to see the destruction of Arkansas agriculture and those who take pride in their work in the field."

  Not all persons in the "Agricultural community" agree with the position taken by Mr. Hydrick, and being opposed to his views does not mean that one is "anti-agriculture." This is obviously a blatant attempt to create bias on the Board against the views of people who have an interest in agriculture and the environment, but are not farmers. The issues in this matter involve all Arkansans.

- Mr. Hydrick states that "All states, other than Arkansas, have adhered to the federal label with no need for additional restrictions to the federally accepted labels. This is false, and demonstrates a lack of research on the part of Mr. Hydrick. The states of Illinois, Indiana, Minnesota, North Dakota and South Dakota have imposed restrictions on the use of dicamba in addition to those contained on the EPA label.

  The evidence is also to the effect that other states are moving toward more - not less - restrictions on dicamba. For example, the Indiana State Chemist and Seed Commissioner (Robert Waltz, Ph.D., affiliated with Perdue University) who has studied dicamba herbicide and its characteristic for off-target movement for over ten years, has officially determined that

"dicamba-containing herbicides intended for post emergence application are not adequately labeled to sufficiently prevent unreasonable adverse effects from occurring to non-target crops and plants." In making that general determination, he found specifically:

- Since the introduction of post emergence use of dicamba on soybeans, the annual average number of dicamba complaints have risen by triple digits in 2019.

- Mandatory annual application and handling training and other product stewardship activities regarding the dicamba products conducted from 2016 to 2019 have not been successful in significantly reducing the incidents of off-target movement of dicamba.

- The exhaustive detailed restrictions on the EPA label for the dicamba herbicides have not been successful in reducing off-target incidents to a reasonable level comparable with other herbicides. Further, some of the restrictions are not technically feasible or practical for many dicamba applicators, regardless of their level of training and competency.

- University research on dicamba herbicide products demonstrates or suggests that (i) some label-permitted tank mixes may increase volatility of applications; (ii) application of the products to low pH soils may increase the likelihood of post application volatility and off-target movement; (iii) field level temperature inversions are more common than previously realized and are difficult to measure; and (iv) some glyphosate resistant week species are developing resistance to dicamba. (See comment No. 4 herein for further elaboration on (iv) relative to Arkansas).

- Several glyphosate resistant week control options and technologies other than dicamba are currently available in the marketplace, and rotating herbicide chemistries is currently recommended on most dicamba and herbicide labels.

A copy of an Analysis by the Indiana State Chemist and Seed Commissioner dated October 30, 2019, entitled "Analysis of Off-Target Movement of Dicamba Herbicides in Indiana" is attached to these comments as **Exhibit No. 14**.

▶ Mr. Hydrick states that dicamba is not the only herbicide to volatilize/drift. While that is undoubtedly true to some extent, it does not mean that it is therefore permissible for dicamba, or any other herbicide, to volatilize and drift. It oversimplifies the problem in that dicamba appears to be far more subject to volatilize, drift or otherwise migrate to other properties, and to do so to a greater degree than any of the other generally accepted and commonly used herbicides on the market. This is apparent from the dramatic increase in dicamba complaints filed with the Arkansas Plant Board and with the counterpart agencies, boards and commissions in other agricultural states in which dicamba has been used since it was approved for use in Arkansas. As noted above, after commencing the use of dicamba herbicides, the number of such complaints in Arkansas and other states exploded. That was not a coincidence.

▶ Mr. Hydrick claims that "It is only fair that Arkansas growers paying a premium for the seed technology receive a premium herbicide to control the State's most troublesome pest." However, the "fairness" argument is a double-edged sword. What is fair about using an herbicide that destroys other people's crops and vegetation, without compensation for such destruction?

As the Ninth Circuit Court of Appeals found in its Opinion revoking the registration of dicamba herbicides, the herbicides have had a heavy social cost on farming communities:

> The record contains extensive evidence that OTT application of dicamba herbicides has torn apart the social fabric of many farming communities. Major, the Kentucky grain producer, wrote in his August 2018 email to Keigwin [an EPA employee]: "This used to be a pretty close area, with neighbors helping neighbors. This chemical has changed this for quite a few growers. The applicators of dicamba are damaging their neighbor's crops, and when they are asked about it the normal answer is: 'You can't prove it,' or 'I didn't do it.'"
> 960 F.3d at page 1143.

As demonstrated above, the same impact on the social fabric from the use of dicamba herbicides is occurring in east Arkansas. "Fairness" has got to be a two-way street.

There are other misstatements contained in Mr. Hydrick's Petition, and they are addressed in the legally- and scientifically-based comments contained above.

Conclusion

One thing is clear from the science: Dicamba herbicides cannot be realistically controlled and prevented from causing widespread and severe damage to other crops, plant, trees and other vegetation, with collateral damage to foraging insects and other creatures.

Based upon the lack of scientific support for the Petition, and the overwhelming weight of scientific support for retaining the restrictions in the existing Rule, the Petition should be denied.

Respectfully submitted,

RICHARD MAYS LAW FIRM PLLC

Richard H. Mays

RHM/nj
Attachments
cc: Client group

EXHIBIT NO. 1A

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

on

Legal Notices 1201

Legal Notice
Arkansas State Plant Board

The Arkansas State Plant Board is proposing changes to the Arkansas Rules on Pesticide Use and Classification. The proposed changes will be to consider changes for the use of dicamba in the State of Arkansas. The proposed rule change may be viewed on the webpage at www.agriculture.arkansas.gov/plant-industries/rules-and-regulations/proposed-rules.

Written comments will be accepted beginning March 24 through April 22, 2021. Comments may be submitted online at www.agriculture.arkansas.gov.

/s/Wade Hodge
Wade Hodge, Chief Council
Arkansas Department of Agriculture

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EXHIBIT NO. 1B

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

Cabinet Secretary
Wes Ward

Plant Industries

Serving the citizens of Arkansas and the agricultural and business communities by providing information and unbiased enforcement of laws and regulations set by the Arkansas State Plant Board

About Our Office

Rules and Regulations

- Proposed Rules

Proposed Rules

The Arkansas State Plant Board is proposing adoption of the following:

- The Arkansas State Plant Board is proposing changes to the Arkansas Rules on Pesticide Use and Classification. The proposed changes will be to consider changes for the use of dicamba in the State of Arkansas. The proposed rule change may be viewed **here.**

Comments will be accepted beginning March 24 through April 22, 2021. Click **here** to comment on the proposed rule.

- Arkansas State Plant Board Rules Regarding the Adoption of the National Institute of Standards and Technology (NIST) Handbooks. Ark. Code Ann. § 4-18-303 provides that NIST "shall be the primary state standard for weights and measures". The Bureau of Standards is charged with the duty to enforce weights and measures standards in the state, and this rule informs those subject to regulation what the standards are. Click **here** to view the proposed rule.

Comments may be mailed to the Arkansas Department of Agriculture, ATTN: Nikhil Soman, 1 Natural Resources Drive, Little Rock, AR 72205, or emailed to nikhil.soman@agriculture.arkanas.gov.

- Arkansas Regulations on Pesticide Use. To establish cutoff dates for late season permits for dicamba applications east of the Mississippi River levee that will comply with the Federal Insecticide, Fungicide, and Rodenticide Act. Click **here** to view the proposed rule.

Comments may be mailed to the Arkansas Department of Agriculture, ATTN: Susie Nichols, 1 Natural Resources Drive, Little Rock, AR 72205, or emailed to susie.nichols@agriculture.arkansas.gov.

- Arkansas Pesticide Use and Application Act. The Environmental Protection Agency now requires that restricted use pesticide applicators must be at least 18 years old. Click **here** to view the proposed rule.

Comments may be mailed to the Arkansas Department of Agriculture, ATTN: Susie Nichols, 1 Natural Resources Drive, Little Rock, AR 72205, or emailed to susie.nichols@agriculture.arkansas.gov.

Comments will be accepted beginning March 6, 2021, until the close of business April 4, 2021.

EXHIBIT NO. 1C

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

ARKANSAS RULES ON PESTICIDE USE

SECTION I. Title

The following rules of the Arkansas State Plant Board, written pursuant to the Arkansas Pesticide Use and Application Act, Act 389 of 1975, as amended, and the Arkansas Pesticide Control Act, Act 410 of 1975, as amended, shall be known as "The Arkansas Rules On Pesticide Use". Promulgation of these rules repeals all provisions of the Plant Board's current rules entitled "Arkansas Rules On 2,4-D, 2,4-DB, MCPA, And Other State Restricted Use Herbicides" effective December 31, 2002.

SECTION II. Purpose

Pesticides are valuable to the State's agricultural production and to the protection of man and the environment from insects, rodents, weeds and other forms of life which may be pests; but it is essential to the public health and welfare that they be regulated to prevent adverse effects on human life and the environment. However, at times certain pesticides present problems that were unanticipated by the manufacturer, the grower or the applicator. The purpose of these rules is to provide additional mechanisms, other than denying registration of a product in Arkansas, to minimize the adverse effects of certain pesticides to:

1. Plants, including forage plants, or adjacent or nearby lands;

2. Wildlife in the adjoining or nearby areas;

3. Fish and other aquatic life in waters in reasonable proximity to the area to be treated; and

4. Humans, animals, or beneficial insects

SECTION III. Definitions

A. "Buffer Zone" means the distance an applicator must maintain between the field or area of application and a protected subject inside of which the subject pesticide may not be applied.

B. "Desirable Vegetation" means any type of vegetation the pesticide label specifically identifies for protection, vegetation for which the product is not labeled, or vegetation for which the owner/manager desires protection from the deposition of pesticides.

C. "Drift" means off target movement of a pesticide onto desirable vegetation, waterways, or where human health or the environment may be adversely impacted that occurs as a result of pesticide application.

D. "Custom Applicator" means a commercial applicator that applies pesticides assigned the Class E or F designation.

SECTION IV. General

The effective date of these rules shall be January 1, 2003 and shall apply to all products registered for 2003. From that time forward, all pesticides registered for sale in the state of Arkansas shall be classified as Class A, B, C, D, E, F, G, H, or I. Such designation shall remain the same unless changed by the Arkansas State Plant Board by promulgation of a regulation so changing the designation. Whatever designation is assigned to a product by the Board, product dealers, users and applicators must comply with the restrictions for the assigned class. Such restrictions will apply to product uses allowed as a result of Section ~~(18)~~ or Section 24(c) actions under FIFRA except where the requirements on the label are clearly more restrictive than the Plant Board's requirements, in which case the more restrictive requirement must be followed.

The following designations apply to all pesticide products registered in the State of Arkansas. The use-restrictions itemized below are intended to be in addition to the product label. However, where the label is more restrictive than the applicable restrictions listed below, then the label shall be followed. Each successive Class designation below includes the restrictions defined in the designations that precede it.

SECTION V. PRODUCT CLASSIFICATION

The following represents the product classifications assigned to pesticides currently registered under Arkansas law.

Class A	All registered pesticides not otherwise assigned below
Class B	
Class C	
Class D	
Class E	
Class F	All 2,4-D and 2,4-D containing pesticides, MCPA
Class G	Glyphosate containing products packaged in containers one (1) gallon or larger, labeled for agricultural use, and used in row crop and rice production and commercial right-of-way treatment.
Class H	All pesticides containing dicamba
Class I	Quinclorac: See Attachment 1

SECTION VI. Class A

All pesticides when registered in the state of Arkansas shall be classified as Class A unless research or experience has shown that certain potential problems may be inherent with the use of the

product. Such knowledge may be as a result of but not limited to research findings, findings of other state and federal agencies or experience of the Arkansas State Plant Board. In such cases the Plant Board may, by regulation, place the product in another Class.

Products with this classification must be used in accordance with the label restrictions and other restrictions, if any, imposed by Plant Board rules other than this document. Documentation of equipment set-up must be maintained by the commercial applicator on forms provided by the Plant Board and made available to the ASPB upon request. Insecticides that are intended to be applied in low volume, LV or Ultra Low Volume, ULV, and product label guidelines require droplet sizes designated as "fine" or smaller in accordance with the August 1999 issue of the ASAE S572 report entitled Spray Nozzle Classification by Droplet Spectra, shall not be required to comply with the Plant Board's rules regarding spray droplet size. Said products must comply with the product label.

SECTION VII. Class B

Products with this designation shall be used in accordance with all other applicable federal or state laws and the rules written pursuant thereto, the label registered with the State of Arkansas, rules promulgated by the Board, the applicable restrictions identified for Class A and the following additional restrictions.

A. If enforcement action is taken against a Commercial, Non-Commercial or Private Applicator regarding drift of a product with this designation or a buffer zone violation, a part of the enforcement action will require the applicator to attend a drift control training class administered by the Plant Board or other training that is acceptable to the Plant Board.

SECTION VIII. Class C

Products with this designation shall be used in accordance with all other applicable federal or state laws and the rules written pursuant thereto, the label registered with the State of Arkansas, the applicable restrictions identified for Class A and B above and the following additional restrictions.

A. All commercial equipment used to apply pesticides with this designation must be in compliance with the application equipment set up requirements specified for herbicide applications contained in the rules written pursuant to the Pesticide Use and Application Act of 1975, as amended, (PUAA) prior to the initial application. Board to verify compliance with the set up that was originally authorized. If the application equipment is modified it must again be authorized to be in compliance with the requirements for herbicide application contained in the before referenced rules. The Plant Board will inspect all application equipment each year that is used to apply products with the Class C designation. A fee of $25 shall be charged for each Plant Board inspection.

   Applications of products with this designation with equipment that is not acceptable to or has not been inspected by the Plant Board will be a violation of these rules.

SECTION IX. Class D

Products with this designation shall be used in accordance with all other applicable federal or state laws and the rules written pursuant thereto, the label registered with the State of Arkansas, the applicable restrictions identified for Class A, B, and C above and the following additional restrictions.

A. Applications may be made only when the wind is not blowing in the direction of desirable vegetation, waterways, or where human health or the environment may be adversely impacted. Where desirable vegetation, waterways, or human health and the environment cannot be protected by ensuring they are not downwind from the application site then, unless a greater distance is required by the label or other applicable State or Federal rules, a 300 foot minimum buffer zone must be maintained between the protected entity (desirable vegetation, waterway, etc.) and the sprayed area.

SECTION X. Class E

Products with this designation shall be used in accordance with all other applicable federal or state laws and the rules written pursuant thereto, the label registered with the State of Arkansas, the applicable restrictions identified for Class A, B, C, and D above and the following additional restrictions.

A. Dealers Requirements

1. Before selling, offering for sale, or distributing pesticides with this designation in packages of more than one quart, a dealer must be a licensed Restricted Use Pesticides dealer. A dealer may sell, offer for sale, or distribute only those pesticides that are registered in the State.

2. Each branch of a license holding dealer which also sells or distributes these products must have a dealer's license. Firms or distributors who take orders for these products must secure a dealer's license, even though the order is placed with a dealer or manufacturer who holds a license, and even though no profit is made.

3. Dealers must keep a record of each sale or distribution of products with this designation to custom or private applicators or dealers in containers of more than one (1) quart on forms available from or approved by the Plant Board. Entries in the record shall be made at the time of sale or distribution and shall include the date of the purchase, the name, address and license or permit number of the purchaser and the name and address of the delivery location. The complete brand name and quantity of the product shall also be recorded. These records shall be kept by the dealer for two years from the date of sale and be made available for inspection by the Plant Board or its representative upon request.

4. The sale or distribution of products with this classification in containers of more than one (1) quart to any firm or person other than a dealer, custom or private applicator holding a current and valid license or permit is prohibited. Dealer must

have a copy of the custom applicator's license on file.

5. Non-residents of Arkansas shall designate and maintain a resident agent in this state for service of process.

B. Requirements For Custom Application

The application of products with the Class E or F designation shall be known as Custom Application. To be eligible to apply products with the Class E or Class F designation, a Commercial Application Firm must obtain a Firm's Custom Applicator Permit from the Plant Board prior to making any applications. Said permit must designate an Operator-in-Charge whose responsibility is to supervise all custom applications made by the firm. Issuance of the permit shall be conditioned on the following:

1. Commercial Aerial Application Firms must have a Firm's Commercial Applicator License issued by the Plant Board to apply pesticides in Arkansas.

   a. All pilots that apply pesticides for the Firm must have an Individual Commercial Applicator Pilot License (w/category) issued by the Plant Board.

      i. The Firm must have a copy of all Individual Commercial Applicator Pilot Licenses held by pilots employed by the Firm.

   b. Commercial Aerial Application Firms that wish to apply products with the Class E or F designation must obtain a Firm's Custom Applicator Permit from the Plant Board.

      i. The Firm's Permit must designate at least one of its Licensed Individual Commercial Applicators that has passed the Custom Applicator test as an Operator-in-Charge.

      ii. All Pilots making Custom Applications must have an Individual Commercial Applicator Pilot License with Authorization to apply Class E or F products. Said Authorization is obtained by passing a Custom Applicator written test administered by the Plant Board.

2. Commercial Ground Application Firms must have a Firm's Commercial Applicator License issued by the Plant Board.

   a. At least one person working for the Firm must have an Individual Commercial Applicator License (w/category) issued by the Plant Board.

   b. Commercial Ground Application Firms that wish to apply products with the Class E or F designation must obtain a Firm's Custom Application Permit.

      i. The Firm's Permit must designate at least one of its Licensed

Individual Commercial Applicators that has passed the Custom Applicator test as an Operator-in-Charge.

3. The application vehicle must be covered by a current certificate of inspection as required in Section VIII of these rules.

4. Licensed Commercial Application Firms that do tree injection work only, do not need a Firm's Custom Applicator Permit to apply products with the Class E or F designation. For such firms, a Tree Injector's Permit is required. However, the Firm's Tree Injector Permit must designate at least one of the Firm's Licensed Individual Commercial Applicators that has passed the Tree Injector test administered by the Plant Board as an Operator-in-Charge.

5. A deposit of $250.00 shall be made with the Plant Board by the Custom Application Firm, except that those persons doing tree injector work exclusively will deposit $10.00 per tree injector, up to a maximum of $250.00. Said deposit shall be returned at the expiration of the permit upon request unless the Custom Applicator is found in violation of the Plant Board's rules or suffers cancellation of his/her Custom Applicator's permit. In which case the deposit will be retained by the Plant Board to supplement cost recovery of inspection and administration incidental to such finding.

6. A deposit of funds as described in Section (X)(B)(5) and proof of financial responsibility, as described below is required. Non-residents of Arkansas shall designate and maintain a resident agent in this state for service of process. Custom Application Permits, Custom Application Authorizations, and Tree Injector Permits shall expire December 31st of each year.

   Financial responsibility in the minimum of $100,000 shall be maintained by the Custom Application Firm or Tree Injection Firm during the term of his/her permit, with proof of such financial responsibility submitted to the Plant Board.

   Proof of financial responsibility shall consist of one of the following:

   a. The deposit of a certificate of insurance or insurance policy not to exceed $5,000 deductible from an insurer or surplus line broker authorized to do business in Arkansas insuring the Custom Application Firm and any of its agents against liability for injury resulting from the application of products with this designation.

      If a claim is made on this type of policy, then the policy must not expire for at least six (6) months after the expiration of the permit;

   b. A letter of credit from a bank located in Arkansas guaranteeing financial responsibility;

   c. A surety bond; or

d. An escrow account with a bank located in Arkansas.

7. Application for a permit must be made on forms furnished by the Plant Board accompanied by the following fees:

   a. Aerial Custom Application Firms must pay an annual application processing fee of $150.00 plus $50.00 for each Operator-in-Charge. Pilots making Custom Applications must pay an annual application processing fee of $35.00 for Authorization to apply products in Classes E and F.

   b. Ground Custom Application Firms must pay an annual application processing fee of $150.00 plus $50.00 for each Operator-in-Charge.

   c. Applicants for a Tree Injector's Permit must pay an annual application processing fee of $50.00 plus $50.00 for each Operator-in-Charge.

   Should, at any time, a Custom Application Firm be left without an Operator-in-Charge or a pilot with an Individual Commercial Applicator Pilot License with Authorization to apply products with the Class E or F designation, either because of invalidation of the permit or for any other reason, such shall automatically invalidate the custom applicator's firm permit. It shall be a violation of these rules for an individual or firm to act as a Custom Applicator that is not licensed to do so by the Plant Board.

8. The Plant Board or its authorized representative(s) may refuse issuance, after a hearing, of a custom applicator's permit to any applicant when such applicant has been found in violation of these rules four times in a three year period. Such applicant may appeal to the Board. All requests for an appeal must be made in accordance with the Plant Board's policy on appealing a decision.

9. All equipment used for custom application of the products with this designation must have a decal provided by the Plant Board affixed to the device in a location where it can be easily seen by a Plant Board representative and protected from removal or disfigurement by work activity. This decal may only be affixed to equipment that meets the requirements set out in these rules and other applicable rules promulgated by the Plant Board. Use of equipment for custom application that does not have a current decal will be a violation of these rules. Decals are not transferable between equipment. Each decal shall be issued at a cost of $50.00 each. Subsequent to issuance of a decal, the equipment on which the decal is to be attached will be subject to inspection by the Plant Board. Equipment found not meeting the requirements set out by these rules or other applicable rules promulgated by the Plant Board will be issued a Stop Use Order that will be released by the Plant Board once the Plant Board is satisfied that the equipment meets the set up requirements of the applicable rules. The applicator will also be considered in violation of the Plant Board's rules on pesticide application and be subject to the required enforcement action. All decals and permits expire on

December 31st of each year.

Equipment used to apply pesticides with this designation shall not be used for the application of other pesticides that do not carry this designation or the Class F designation unless the following has been done:

a. The vehicle must be thoroughly decontaminated;

b. The tank must be thoroughly rinsed and the rinsate disposed of in accordance with the label. If the label does not address rinsate disposal, the rinsate should be collected and disposed of in accordance with applicable state and federal disposal laws; and

c. The entire spray or application system must be replaced or decontaminated using the best available technology such that a sample taken from the successive pesticide tank load would contain no detectable concentration of the previous product. Where research has established a concentration below which no adverse effects occur and that concentration level is not a violation of state or federal law or rules written pursuant to such laws, then that established concentration will be acceptable. Compliance with this provision in no way exempts the product user from compliance with any other responsibility imposed by state or federal law or regulation written pursuant thereto. Pesticide application equipment must have a leak free valve that is painted hunter orange from which a sample can be taken. Aircraft must have a sample valve located at the low point in the spray system. Ground application equipment must have a sample valve located in the pressure by-pass line.

10. All firms desiring to do custom application work must have a Custom Application Permit to do so. Said permit must designate an Operator-In-Charge. Eligibility as Operator-in-Charge will be conditioned on the following:

a. Achieving a score of 70% or better on an examination administered by the Plant Board;

b. Pilots must hold a valid FAA pilot's Commercial Certificate;

c. Applicant may not have more than four (4) enforcement actions indicated on the Plant Board's records in the three years prior to the date of testing; and

d. The fee for each test shall be $35.

Pilots and Operator's-In-Charge shall be responsible for notifying the Plant Board of the name and location of employment prior to starting work.

11. The Custom Application Firm must maintain records of each application of

products with this and the Class F designation. Said records must be retained at the principal Arkansas office of the Custom Application Firm as indicated on the Firm license for a period of three (3) years and be available for inspection by a Plant Board representative. The records shall include at a minimum the following information:

a. Name and address of the person(s) in control of the crops, plant, etc;

b. Location of the crop, plants, etc. treated. Location description must include county, nearest town, physical address if available, and GPS or map coordinates of the primary entrance to the field;

c. Date, start and ending time of the application;

d. Wind speed and direction at the start and ending time of the application and the type of instrument used to measure wind speed and direction. The location of instrument at time of reading (preferably "field of application") must also be recorded;

e. Complete brand name and EPA registration number of the material used;

f. Number of acres and type of crop to which the material was applied;

g. Type of equipment used and the Firm's Custom Application Equipment number assigned to it by the Plant Board;

h. Distance from and direction to any susceptible crops within a one mile radius of the treated crop; and

i. Name of the application vehicle operator.

C. Requirements For Non-Custom Application Of Products In This Class

1. Whether designated as "Restricted" by the EPA or not, products in containers of more than one (1) quart with this class designation and the Class F designation may not be purchased by or sold to persons who do not have a current Commercial, Non-Commercial, or Private Applicator's license.

2. All applications of products with this designation by Private Applicators must be in accordance with the applicable application conditions required of the custom applicator.

3. The Private Applicator must maintain records of each application of products with this and the Class F designation. Said records must be retained for a period of three (3) years and be available for inspection by a Plant Board representative. The records shall include at a minimum the following information:

a. Name and address of the person(s) in control of the crops, plant, etc;

b. Location of the crop, plants, etc. treated. Location description must include county, nearest town, physical address if available, and GPS reading or map coordinates of the primary entrance to the field;

c. Date, start and ending time of the application;

d. Wind speed and direction at the start and ending time of the application and type of instrument used to measure wind speed and direction. The location of instrument at time of reading (preferably "field of application") must also be recorded;

e. Complete brand name and EPA registration number of the material used;

f. Number of acres and type of crop to which the material was applied;

g. Type of equipment used. If the product was applied by a custom applicator, record the Firm's Custom Application Equipment number assigned to the equipment used by the Plant Board;

h. Distance from and direction to any susceptible crops within a one mile radius of the treated crop; and

i. Name of the application vehicle operator.

D. Exemptions

1. The licensing requirements of these rules do not apply to the U. S. Department of Agriculture, the Arkansas Experiment Stations and other State or Federal Agencies, to ornamental and turf weed control, or to company demonstrations with ground equipment, or to sales of fertilizer, soil conditioners or similar products containing registered products with this designation and packaged for home use. Provided that nothing in this section shall be construed as exempting custom applicators from the provisions of these rules when making applications for the agencies listed herein, or exempting any such agency acting as a dealer from the dealer requirements.

2. Products with the Class E or F designation that are not designated as restricted use products by the Environmental Protection Agency may be purchased from an Arkansas pesticide dealer for use outside the state of Arkansas without the dealer having to have a dealer's license or the purchaser having an applicator's license.

3. Commercial Applicators and Private Applicators that can provide proof of current certification and licensing from another State may purchase restricted use pesticides from a restricted use pesticide dealer licensed in Arkansas if the product is to be used outside of Arkansas.

Section XI. Class F

Products with this designation shall be used in accordance with all other applicable federal or state laws and the rules written pursuant thereto, the label registered with the State of Arkansas, the applicable requirements identified for Class A, B, C, D, and E above, and the following additional restrictions.

A. Dealers may not store or transport products with this designation in the same room or vehicle with seeds, other pesticides that do not have this designation, or fertilizers except in leak-proof containers not to be opened while in storage and must observe all other precautions necessary to prevent contamination of these products.

B. The use of esters of the products with this designation, except low-volatile esters, is prohibited.

C. No product with this designation may be applied within the 1/4 mile of susceptible crops at any time except as otherwise indicated by this regulation.

D. From April 16th through September 15th of each year, the following conditions shall apply:

1. Pesticides labeled for agricultural use that contain the active ingredient(s) assigned to this Class, may not be applied by ground or air in Clay, Greene, Craighead, Poinsett, Cross, Crittenden, St. Francis, Lee, Phillips, and Mississippi Counties.

2. Where no viable alternative is believed to exist, an annual permit may be obtained from the Plant Board to allow an exemption to these restrictions. Said permit must be obtained prior to application and will require a permit application fee in the amount of $100. The application for the permit must be on forms authorized by the Plant Board. This exemption is conditioned on the producer complying with the following requirements:

a. The permitee must have the permit in his/her possession prior to making the application and it must be made available to the Plant Board or its designee upon request.

b. For each application the following information must be recorded:

i. A physical description of the location of the field;

ii. Date of the application;

iii. Start and stop time for each load applied to the field;

iv. Wind speed (may not be less than 2 mph), wind direction, ambient temperature, and precipitation condition at ten minute intervals during the application of each load. Said measurements must be

made at the field of application; and

v. The producer must be present during the application and sign the document containing the information.

c. The above information must be filed with the Plant Board's Pesticide Division along with a GPS map of the application to the field within 10 days of the date of application.

d. Applications made within four (4) miles of susceptible crops (defined as cotton when applying 2,4-D) must be done when the wind is blowing at least two (2) mph away from the susceptible crop.

e. Rice levee spraying shall not require a permit in Cross, Poinsett, Clay, Greene, Craighead, Crittenden, St. Francis, Lee, Phillips, and Mississippi counties west of the approximate north-south center line of Crowley's Ridge. However, paragraphs b(i) through b(v) and paragraph d above must be complied with. The records for each application must be maintained by the producer for a period of three years and be made available to the Plant Board upon request by a Plant Board representative. The application device must 1) generate a spray with a droplet spectrum such that no more than 10 % of the spray droplets are smaller than 300 microns, 2) the boom width may not exceed 10 feet, 3) during application the spray nozzle height may not exceed 30 inches above the top of the levee, and 4) the spray vehicle may not exceed 8 miles per hour. No 2,4-D Esters may be used.

3. In the remainder of the State the following conditions shall apply:

a. A buffer zone between the field to be treated and susceptible crops (susceptible crops is cotton when applying 2,4-D containing products) of four (4) miles for aerial application and one (1) mile for ground application shall be maintained.

b. Applications made within four (4) miles of susceptible crops must be done when the wind is blowing at least two (2) miles per hour away from the susceptible crop.

c. Applications may be made within the applicable buffer zones if the owner or supervisor of the sprayed or treated field has obtained a waiver from the producers of all susceptible crops within the buffer zone. The waiver shall be developed by the Plant Board and provided to said producers by the owner or supervisor of the sprayed or treated field. A copy of the waiver must be provided to the applicator who sprays or treats the field. The applicator shall retain the record for a period of three (3) years. When making an application within the applicable buffer zone, at the time of application, the wind must be blowing away from susceptible crops.

4. Failure to comply with the requirements for a Class F product when using a Class F product will result in enforcement action being taken against the producer and the applicator in accordance with the Plant Board's Penalty Matrix. Any penalty mandated by the Penalty Matrix may have additional civil penalty added to it to bring the amount of the assessment up to the maximum amount allowed by law.

E. Any custom applicator who violates the buffer zones defined in Section (XI)(D) shall be subject to a civil penalty as prescribed by the penalty matrix for the violation plus $1000. However, the total civil penalty for one violation may not exceed $2000. Failure to comply with the decontamination requirements of Section (X)(B)(9) of these rules before making an application of a product with a Class A, B, C or D designation inside a designated buffer zone for Class E and F products will be considered a buffer zone violation.

F. Products with this designation shall be applied in accordance with the application equipment set up required for herbicide applications to field crops itemized in the rules written pursuant the Pesticide Use and Application Act of 1975, as amended. Except that these conditions will apply, in addition to field crops, to pastures, rights-of-way, drainage ditches, brush and forest land.

G. The wind velocity during the application shall not exceed eight (8) mph and the temperature may not exceed 90 degrees F.

H. Applications of products with this classification shall not be made unless the following condition exists:

1. For applications made before noon, the air temperature at the field of application at the beginning of the application must be a minimum of three (3) degrees Fahrenheit above the morning low measured at the applicator's air strip or mixing/loading facility. If the applicator has knowledge that the temperature measurement at his/her air strip or mixing/loading facility would not be the same as a reading taken at the same time at the field of application, then all temperature readings must be taken at the field of application.

2. For applications made after noon, the temperature at the field of application must not have decreased more than five (5) degrees Fahrenheit from the afternoon high measured at the applicator's air strip or mixing/loading facility. If the applicator has knowledge that the temperature measurement at his/her air strip or mixing/loading facility would not be the same as a reading taken at the same time at the field of application, then all temperature readings must be taken at the field of application.

All temperature measurements referenced above must be maintained by the grower as well as the applicator and be made available to the Plant Board upon request.

I. Enlist Exemption

a. Dow Agro-Sciences' products identified as Enlist One and Enlist Duo - premix of glyphosate and 2,4-D Choline may be used on Enlist Weed Control System soybeans, cotton, and corn. All Plant Board restrictions on 2,4-D containing products will apply except the following:

Section XI(C), and

Section XI(D)(1), and

Section XI(D)(2), and

Section XI(D)(3), and

Section XI(G), and

The application window in Section XI(D) shall not apply.

b. In addition to all product label requirements, the following conditions apply:

i. At the time of application, the wind must be blowing away from adjacent sensitive areas and non-target susceptible crops as identified by the product label.

ii. The wind speed during the application may not exceed 10 mph.

iii. The volume median diameter (VMD) of the spray droplets must be greater than 300 microns.

iv. Tank mixes will not be permitted unless research data, from a source acceptable to the Plant Board, is provided. This data must prove that the mix, when applied according to the product label and state restrictions, does not increase the driftable fines (those less than 200 microns) by more than 10% over that of the product alone. However, there will be a limit of no more than 10% of the total mix's droplets to be smaller than 200 Microns. This tank mix requirement may be waived in part or in whole by the Plant Board if no entity can be identified as an acceptable source for development of the data.

v. Where the product label is more restrictive than the Plant Board's restrictions, then the label must be complied with.

c. Ground applications of products with this classification shall not be made to Enlist seed technologies without Commercial, Non-Commercial, and Private Applicators first completing New Technology Certification training. New Technology Certification training must be obtained through the

Cooperative Extension Service. Upon request proof of training must be provided to the Plant Board.

SECTION XII. CLASS G

Products with this designation shall be used in accordance with all other applicable federal and state laws and rules written pursuant thereto, the label registered with the State of Arkansas, the applicable restrictions identified for Class A, B, C, and D above and the following additional restrictions. Products assigned to this class include only those products packaged in containers one (1) gallon or larger, labeled for agricultural use, and used in row crop and rice production and commercial right-of-way treatment.

A. Class G products may not be applied in winds greater than 10 miles per hour, 15 miles per hour if using a commercially available hooded sprayer. However, if the product label indicates a lesser wind speed should be used, then that wind speed must be used.

B. Civil penalties assessed for each violation of the product label, applicable State or Federal law or the rules promulgated pursuant to these laws that involve a product with this classification shall be assessed at the level indicated by the Plant Board's Enforcement Response Rules for a restricted-use product plus, where not otherwise forbidden by state or federal law, additional civil penalty may be added to bring the amount of the assessment up to the maximum amount allowed by law.

C. For purposes of civil penalty assessment, products named to this classification shall be considered the same as Federally Restricted Use products if not already designated as such.

D. Failure to comply with these requirements will be a violation of these rules.

SECTION XIII. CLASS H

Products with this designation shall be used in accordance with all other applicable federal and state laws and rules written pursuant thereto, the label registered with the State of Arkansas, the applicable restrictions identified for Class A above and the following additional restrictions. Products assigned to this class include only those products packaged in containers of more than one quart, labeled for agricultural use.

A. Dealer Requirements:

1. Before selling, offering for sale, or distributing pesticides with this designation in packages of more than one quart, a dealer must be a licensed Restricted Use Pesticides dealer. A dealer may sell, offer for sale, or distribute only those pesticides that are registered in the State.

2. Each branch of a license holding dealer which also sells or distributes these products must have a dealer's license. Firms or distributors who take orders for these products must secure a dealer's license, even though the order is placed with a dealer or manufacturer who holds a license, and even though no profit is made.

3. Dealers must keep a record of each sale or distribution of products with this designation to commercial, non-commercial, private applicators or dealers in containers of more than one (1) quart on forms available from or approved by the Plant Board. Entries in the record shall be made at the time of sale or distribution and shall include the date of the purchase, the name, address and license or permit number of the purchaser and the name and address of the delivery location. The complete brand name and quantity of the product shall also be recorded. These records shall be kept by the dealer for two years from the date of sale and be made available for inspection by the Plant Board or its representative upon request.

4. The sale or distribution of products with this classification in containers of more than one (1) quart to any firm or person other than a dealer or applicator holding a current and valid license or permit is prohibited. Dealer must have a copy of the applicator's license on file.

5. Non-residents of Arkansas shall designate and maintain a resident agent in this state for service of process.

B. Requirements For Commercial, Non-Commercial, and Private Application of Dicamba Containing Pesticides:

<u>All pesticide products containing dicamba shall be used in compliance with their respective federal labels.</u>

~~1. From May 26th through October 31st of each year, applications of products labeled for agriculture use that contain dicamba are prohibited except applications made:~~

~~a. for turf, ornamental, direct injection for forestry activities and home use are allowed year round;~~

~~b. for pasture and rangeland are allowed year round. However, such applications must maintain buffers required in Section 2; or~~

~~c. pursuant to a special permit for Arkansas land east of the Mississippi river levee may be allowed if all of the following requirements are met. In no event will a special permit be issued for applications made more than 45 days (soybeans) or 60 days (cotton) after planting.~~

~~i. The permit must be obtained prior to application and will require a permit application fee in the amount of $100. The application for the permit must be on forms authorized by the Plant Board. The permit will expire on December 31st of each year. Applications for the permit must be submitted to the Plant Board, no later than 10 business days prior to application and contain the following information.~~

~~aa. Name, farm entity, mailing address, county of each field of application, and phone number of individual applying for permit;~~

~~bb. Field name, GPS latitude and longitude coordinates at the primary entrance of each field to be sprayed provided in decimal degrees;~~

~~cc. Planting date of each field;~~

~~dd. Crop planted and acres of each field;~~

~~ee. Distance from and direction to any susceptible non dicamba tolerant crops;~~

~~ff. Number of prior in crop dicamba applications made to each field to date;~~

~~gg. Information (other than cost) sufficient detail to allow Plant Board staff to determine that alternative pesticides will not be practical at this location.~~

~~ii. During application a 1 mile buffer zone from non-dicamba tolerant crops must be maintained.~~

~~iii. Within ten days of the date of pesticide application, records required by the federal label must be submitted to the Plant Board.~~

~~2. From April 16th through May 25th all applications for in crop agricultural use:~~

~~a. Must maintain a one (1) mile buffer, in all directions, from University and USDA research stations, certified organic crops, and commercially grown specialty crops (defined as a minimum of 1,000 plants or the average annual crop sales for the previous three-years exceeding $25,000).~~

~~b. Are prohibited from using tank mixes of products containing the active ingredient Glyphosate mixed with pesticides containing the active ingredient dicamba labeled for in crop use.~~

~~c. During application a ½ mile buffer zone in all directions from non dicamba-tolerant crops must be maintained.~~

~~3. From April 16th through October 31st, applications of pesticides labeled for agricultural use that contain the active ingredient dicamba are prohibited for pre-plant (burndown) applications except for:~~

~~a. From April 16th through May 25th, pesticides labeled for in crop agricultural~~

~~use, by ground that contain the active ingredient dicamba and allow for the pre-plant (burndown) applications may be applied. However, such applications must maintain the requirements of buffers required in Section B.2.~~

~~4. Training Requirements:~~

~~a. Applications of products with this classification to dicamba-tolerant crops shall not be made without Commercial, Non-Commercial, and Private Applicator, first completing dicamba specific training provided by a registrant of a dicamba product for use on dicamba tolerant crops. Upon request proof of training must be provided to the Plant Board.~~

~~b. Applications of products with this classification to non-dicamba crops or pasture and rangeland shall not be made without Commercial, Non-Commercial, and Private Applicators first completing New Technology Certification training. New Technology Certification training must be obtained through the Cooperative Extension Service. Upon request proof of training must be provided to the Plant Board.~~

~~c. Applicators must provide the proof of training required by paragraph 4 to Pesticide Dealers prior to purchase.~~

~~5. Record Keeping Requirements:~~

~~Applicators must maintain records of each application of products with this designation. Said records must be retained for a period of three (3) years and be available for inspection by a Plant Board representative. The records shall include at a minimum the following information:~~

~~a. Name and address of the person(s) in control of the crops, plant, etc;~~

~~b. Location of the crop, plants, etc. treated. Location description must include county, nearest town, physical address if available, and GPS reading or map coordinates of the primary entrance to the field;~~

~~c. Date, start and ending time of the application;~~

~~d. Wind speed and direction at the start and ending time of the application and type of instrument used to measure wind speed and direction. The location of instrument at time of reading (preferably "field of application") must also be recorded;~~

~~e. Complete brand name and EPA registration number of the material used;~~

~~f. Number of acres and type of crop to which the material was applied;~~

~~g. Type of equipment used. If the product was applied by a commercial~~

~~applicator, record the Firm's Application Equipment number assigned to the equipment used by the Plant Board; and~~

~~h. Name of the application vehicle operator.~~

C. Exemptions:

1. The licensing requirements of these rules do not apply to the U. S. Department of Agriculture, the Arkansas Experiment Stations and other State or Federal Agencies, to ornamental and turf weed control, or to company demonstrations with ground equipment, or to sales of fertilizer, soil conditioners or similar products containing registered products with this designation and packaged for home use.

2. Products with the designation that are not designated as restricted use products by the Environmental Protection Agency may be purchased from an Arkansas pesticide dealer for use outside the state of Arkansas without the dealer having to have a dealer's license or the purchaser having an applicator's license.

3. Commercial, Non-Commercial, and Private Applicators that can provide proof of current certification and licensing from another State may purchase restricted use pesticides from a restricted use pesticide dealer licensed in Arkansas if the product is to be used outside of Arkansas.

SECTION XIV. CLASS I

Products with this designation are those for which none of the aforementioned classification or any combination thereof will resolve to an acceptable level the problems associated with the use of such product.

ATTACHMENT 1

Quinclorac Use Restrictions

1. The buffer zones in the table below shall apply to Quinclorac herbicide applications:

Herbicide Treatment Options	Application Equipment	Buffer Zones	
		When winds are blowing in the direction of incorporated towns or commercial plantings of the solanaceae family.	When winds are NOT blowing in the direction of incorporated towns or commercial plantings[1] of the solanaceae family.
a. Water diluted spray of Quinclorac herbicide tank-mixed with emulsifiable concentrate (EC) formulation herbicides such as: ·Stam M-4 EC ·Arrosolo 3+3 EC ·Propanil EC ·Ordram 8E ·Abolish 8E ·Bolero EC	Aircraft Spray Wind Speed 3 to 8 mph	4 miles	1 mile
	Ground Spray Wind Speed 3 to 8 mph	1 mile	1/2 mile
b. Water diluted spray of Quinclorac herbicide applied in water alone or tank-mixed with emulsifiable concentrate formulation free herbicides such as: ·Stam 80EDF ·Basagran ·Terra Propanil 80DF ·Blazer ·Wham EZ, Super Wham ·Storm ·Pentagon 60 WDG ·Londax	Aircraft Spray Wind Speed 3 to 8 mph	1 mile	1 mile
	Ground Spray Wind Speed 3 to 8 mph	1/2 mile	1/2 mile

1. Exemption: In areas where cities have annexed blocks of agricultural land, water diluted sprays of Quinclorac may be used within or adjacent to the city limits, provided the application site is no closer than 1/2 mile to subdivisions when using ground equipment or 1 mile to subdivisions when using aircraft and no closer than 1/4 mile to established plants of the solanaceae family or established/emerged cotton.

2. No water diluted spray of Quinclorac herbicide shall be applied closer than 1/4 mile by any means to established/emerged cotton, noncommercial plantings of the solanaceae family, or closer than 1/2 mile by aircraft if the wind is blowing in the direction of such plants.

3. No water diluted spray of Quinclorac herbicide shall be applied closer than 1 mile by aircraft or 1/2 mile by ground equipment to established, certified commercial plantings of the solanaceae family (>1,000 plants each kind) statewide.

4. In addition to the above statewide requirements, the following additional restrictions shall apply to Poinsett County.

   a. No water diluted spray of Quinclorac herbicide shall be applied in an area from one mile west of Highway #1 to one mile east of Highway #163 from the Craighead-Poinsett County line to the Cross-Poinsett County line.
   b. Water diluted spray of Quinclorac herbicide shall be applied only by ground equipment in the area of Poinsett County from one mile west of Highway #1 to two miles west of Highway #1 and only by ground equipment in the area of Poinsett County from

one mile east of Highway #163 to Ditch #10, from the Craighead-Poinsett County line to the Cross-Poinsett County line.

c. No water diluted spray of Quinclorac herbicide shall be applied within 1/2 mile with ground equipment or 1 mile by aircraft of commercial plantings of the solanaceae family and towns. This buffer is extended to one mile for ground application and two miles for aerial application when Quinclorac herbicide is mixed with emulsifiable concentrate formulation herbicides.

5. The buffer zones defined in paragraph one (1) (b) shall apply to tank mixes of water diluted sprays of Quinclorac and EC products for which the EC manufacturer has provided the Plant Board with atomization study data from a research entity acceptable to the Plant Board that shows that the product does not produce more "fines" (percent of total spray volume in droplets <105μm) than water.

6. All applications of Quinclorac shall be made in accordance with the applicable drift minimization recommendations of the Spray Drift Task Force.

7. Both air and ground application equipment shall be set up for application of Quinclorac in such a way that generation of spray droplets less than 105 microns in size is less than 5% of the total volume. The spray nozzle size classification must be designated as "coarse" by the British Crop Protection Council.

8. Quinclorac may not be sold to persons that do not possess a current Private, Commercial or Non-Commercial Applicator's License.

EXHIBIT NO. 2

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

Jason K. Norsworthy
Distinguished Professor
University of Arkansas, Fayetteville

Current Appointment:

75% Research, 15% Teaching, 10% Service

Education:

Ph.D.	2000	University of Arkansas
M.S.	1997	University of Arkansas
B.S.	1995	Louisiana Tech University

Professional Experience:

Distinguished Professor	University of Arkansas	July 2019 – present
Professor	University of Arkansas	July 2012 – June 2019
Elms Farming Chair of Weed Science	University of Arkansas	July 2013 – present
Associate Professor	University of Arkansas	July 2008 – June 2012
Assistant Professor	University of Arkansas	July 2006 – June 2008
Adjunct Associate Professor	Clemson University	Sept. 2006 – present
Associate Professor with Tenure	Clemson University	July 2005 – June 2006
Assistant Professor	Clemson University	May 2000 – June 2005

Publications:

	Total
Refereed Manuscripts:	298
Abstracts/Proceedings:	>800
Research Series/Service:	102

Overall Research Objectives:

- Understand the risks of off-target movement of herbicides and the benefits of new transgenic traits in Arkansas cropping system;
- Use models and develop software to understand weed population dynamics with emphasis on the soil seedbank and risk of herbicide resistance evolving;
- Develop innovative strategies that allow for increased sustainability of current weed control systems in the Midsouth.
- Evaluate short- and long-term impact of production practices on weed species shifts, profitability, and likelihood for development of herbicide resistance.

Extramural Research Funding: *Total* >$16,500,000

Regional/National Grants:
USDA-National Research Initiative (3)
USDA-Methyl Bromide Alternatives (2)
Southern Region Integrated Pest Management (2)
Sustainable Research and Education (2)
United Soybean Board (3)

Teaching and Advising:

- Principles of Weed Control (CSES 4143): Spring 2008-2021
- Advanced Crop Science (CSES 4013): Fall 2013, Spring 2018, 2020 (Team taught)
- Summer Internship (CSES 463V): Summer 2012-2020 (Team taught)
- Integrated Pest Management (CSES 2013): Spring 2012-2014, 2021 (Team taught)
- Weed Science Practicum (CSES 5001): Summer 2007-2011, 2013-2019 (Team taught)
- Colloquium (CSES 3023): Fall 2008 (Team taught)
- Pesticide Use in Agriculture (ENTO 5113): Spring 2007(Team taught)
- Introductory Weed Science (CSENV 407/607): Spring 2002-2005
- Weed Morphology and Ecology (CSENV 417/617): Fall 2003, 2005
- Integrated Pest Management (IPM 401): Spring 2004, 2005 (Team taught)
- Weed Science Practicum (CSENV 806): Summer 2004, 2005
- Successfully advised 31 M.S. students and 6 Ph.D. students.

Notable Outreach and Educational Activities from My Research:

- Invited presentations of research findings on glyphosate-resistant Palmer amaranth and mitigation strategies for developing resistance have been given in Mexico, Canada, France, Australia, and Argentina as well as more than 25 states.
- Led a global team of scientists in writing the Best Management Practices for Herbicide Resistance Management that was published in *Weed Science.*
- Helped organize an EPA tour in 2011, which focused on herbicide resistance issues in Arkansas, Missouri, and Illinois. Led an EPA tour of dicamba issues in Arkansas and Tennessee in 2018.
- A herbicide resistance screening program is annually conducted for the growers and consultants of Arkansas where samples are tested and resistance management plans are developed.

Selected Research Honors and Awards:

- Recipient of the Spitze Award, the highest faculty honor in the Bumpers College, 2020
- Co-recipient of the John W. White Team Award for Dicamba Research & Educational Efforts, 2019
- Fellow of the Weed Science Society of America, 2018
- Recipient of the Outstanding Researcher Award from the Weed Science Society of America, 2018
- Co-recipient of the Outstanding Paper in Weed Technology presented by the Weed Science Society of America, 2018
- Recipient of the John W. White Outstanding Research Award for the Division of Agriculture University of Arkansas System, 2017
- Co-recipient of the Extension Excellence State Team Award for Dicamba Research & Educational Efforts, 2017
- Recipient of the Outstanding Educator Award from the Southern Weed Science Society, 2017
- International Herbicide Resistance Challenge (invited address), 2017
- Recipient of the Outstanding Research Award from the Arkansas Chapter of Gamma Sigma Delta, 2015
- Recipient of the Australian Orator Award for the Herbicide Resistance Challenge, 2013
- Co-recipient of the John W. White U of A Division of Agriculture Team Award, 2011
- Recipient of Researcher of the Year Award presented by the Arkansas Association of Cooperative Extension Specialists, 2011

EXHIBIT NO. 3

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

Summary of presentation given to the Arkansas State Plant Board on December 3, 2019 by Dr. Jason K. Norsworthy.

1. Weed Control

    - Dicamba continues to provide effective control of Palmer amaranth in trials conducted at various locations across Arkansas, including a site in northeast Arkansas where Palmer amaranth has been documented to have resistance to five herbicide sites of action.

    - Weed control programs in other existing soybean technologies, such as LibertyLink, LLGT27, and Enlist systems, also continue to provide effective control of Palmer amaranth similar to the level provided in the Xtend system.

    - Both a broadcast and roller carpet (similar to ropewick) application of XtendiMax plus Roundup PowerMax provided better than 85% control of Palmer amaranth. However, the ropewick application of XtendiMax plus Roundup PowerMax volatilized at greater levels than the spray application.

2. Large-Scale Experiments

    - Large-scale research plots that were planned for Keiser were compromised in 2019 because of persistent dicamba injury symptoms on non-Xtend soybean cultivars for weeks following the dicamba application cutoff date. See later comments under "Spray Tank Contamination".

    - Engenia and Engenia Pro (premix of Engenia + Zidua) in the absence of glyphosate was evaluated for secondary losses (movement 30 minutes or more after application) following simultaneous application of both products to 2-acre blocks in a 40-acre field of LibertyLink soybean in Prairie Grove (Northwest Arkansas).
        - Dicamba movement as evident by injury to soybean was predominately in the north and northeast directions, which was the wind direction during and following application for the first day of the trial.
        - Slight differences in injury were observed between covered and non-covered (during spraying) soybean plants for both Engenia and Engenia Pro.
        - Injury to soybean that were covered by buckets during spraying and for 30 minutes following spray application was most likely caused by volatility during the first 10 hours after application. However, subsequent wind shifts did not induce soybean injury in directions other than the N and NE directions.

    - Off-target movement of GF-3736 (dicamba choline plus glyphosate) was evaluated following an application of the product to 7.5 acres of Xtend soybean in the center of a 120-acre field of LibertyLink soybean.

- Physical drift appeared to be the major cause of off-target movement because there was substantially more injury to non-covered plants compared to those covered by buckets during and after application for 30 minutes. Volatility and movement of dicamba in water are believed to be minor contributors to the observed injury.
- Abnormally cooler than normal temperatures occurred on July 23, the day of treatment, as well as subsequent days. Future efforts need to focus on evaluating volatility of the herbicide under higher temperatures and comparison needs to be made to a commercially available dicamba formulation for Xtend crops.

3. Low Tunnel Trials

- Engenia and Engenia Pro evaluation with and without Roundup PowerMax (glyphosate)
  - The concentration of dicamba measured in air samplers following applications of Engenia and Engenia Pro were statistically similar and the addition of glyphosate to Engenia and Engenia Pro led to increased detection of dicamba in air samples.
  - Soybean injury from Engenia and Engenia Pro treatments were statistically comparable.
  - Based on the low tunnel trial conducted on Engenia Pro as well as the large-scale trial, Engenia Pro behaves similar to Engenia.

- Dicamba detection in air samples and injury to soybean was greatest when XtendiMax was applied with a full rate of ammonium sulfate (AMS). Residues of AMS in the spray tank (1/500X rate of AMS) did not further increase volatility of XtendiMax over the XtendiMax applied alone based on dicamba detection and injury to soybean. Based on these results, typical residue levels of AMS in a spray tank would not contribute to increased volatilization of XtendiMax.

- Potassium borate has 3X the scavenging potential of H+ ions than potassium acetate (VaporGrip) on a mole per mole basis. The addition of potassium borate to DGA dicamba resulted in lower volatility than DGA dicamba alone or DGA dicamba with VaporGrip (XtendiMax) when all treatments were mixed with Roundup PowerMax. These findings over two experimental runs indicated that potassium borate is superior to potassium acetate (VaporGrip) in reducing dicamba volatility. In addition to greater H+ scavenging potential, the reduced volatility with potassium borate is attributed to its better buffering capacity. Additionally, XtendiMax or Engenia mixed with potassium borate supplied a comparable level of Palmer amaranth control similar to XtendiMax or Engenia alone.

4. Spray Solution pH

- In a document entitled, "Understanding Spray Solution pH with XtendiMax with VaporGrip Technology" Dr. Ty Witten of Legacy Monsanto discussed the impact of glyphosate addition

to pH of spray solutions containing dicamba. Drs. Mueller and Steckel from the University of Tennessee conducted research examining Roundup PowerMax addition to a spray solution of Engenia and Xtendix averaged across 12 water sources. Drs. Mueller and Steckel concluded that they were unable to replicate the results reported by Dr. Witten, specifically his claim that the addition of Roundup PowerMax only reduces spray solution pH by 0.2 to 0.3 units (Mueller and Steckel 2019b). Instead they found that the pH is reduced by 1.0 to 2.1 units with the addition of Roundup PowerMax.

- pH of water sources for spraying in Arkansas ranged from 5.9 to 8.8 across 40 samples. Most of the water samples had a pH of approximately 7.

- The addition of potassium borate to spray solutions containing a 0.25 and 0.5X rate of Engenia or XtendiMax increased the pH to more than 9.0 when the initial pH of the water source was 7.31.

5. Spray Tank Contamination

- Claims of tank contamination of spray equipment at the Northeast Research and Extension Center were addressed during the presentation. Less than 10 acres of Xtend soybean were planted for volatility research or weed control evaluations on the station in 2019. The fact that uniform dicamba damage was observed on every non-Xtend soybean on the station, regardless of growth stage (V2 to R4), was a good indication that tank contamination did not occur. With there being more than 400 acres of soybean on the station and based on the size of the spray tank on the commercial sprayer, more than 14 full loads of spray, with each being equally contaminated, would be needed to induce uniform symptoms over the entire station. Furthermore, portions of research station where non-Xtend soybean were grown was never sprayed with the commercial sprayer, yet symptomology was observed on these soybean plants. Additionally, photos of oak trees and a sycamore exhibiting dicamba-like symptoms was further evidence that tank contamination was not the cause of landscape damage on and around the station. Based on station records and conversations with the station director and farm manager, the Board can be assured that no dicamba was placed in the commercial sprayer in 2019. The last time dicamba was applied at the station by station personnel was 2018 when a large-scale, off-target dicamba movement trial was conducted.

- A photo showing a typical tank contamination with dicamba and the absence of symptomology in areas of a field not sprayed was shown. Rarely is every soybean plant in a field injured when tank contamination is the cause of the problem. The sprayer often misses plants on a field edge or near obstructions such as irrigation risers or light poles.

- The absence of noticeable dicamba symptomology on redvine in ditches at the station on July 26 was addressed. A photo showing redvine in a dicamba-treated field a few miles from the station with minor symptoms following treatment was presented along with spurred anoda and prickly sida adjacent to the treated field. Prickly sida exhibited no symptoms whereas spurred anoda showed strong signs of leaf cupping. It was noted that 2 lb/A

dicamba has been the historical, labeled rate for redvine control following soybean maturity, and this rate is 4 times the current rate labeled in Xtend crops.

- The following quote from Dr. Aaron Hager, University of Illinois Extension Weed Scientist, was shared concerning his thoughts on tank contamination being the cause of landscape damage. *"Yes, tank contamination occurs, and I have seen instances of cupping where contaminated application equipment clearly was responsible. This avenue of exposure was somewhat common in 2017, but less common in 2018 and appears to be even less common in 2019 as applicators gained an enhanced appreciation for sprayer hygiene. .....before applying dicamba in 2019, approximately 3,000 licensed Illinois operators completed the process to become licensed applicators thanks to the new label mandate instituted by EPA for the revised label. It's logical to conclude that each of these 3,000 applicators operates a spray rig, so is industry suggesting that hundreds of agrichemical facilities and thousands of tender trucks and application equipment in Illinois are contaminated? Does anyone have physical evidence of this, or is it just more speculation? If contamination is the cause of even half the instances of soybean leaf cupping, commercial applicators might question the prudence and legal ramifications of applying a product that seemingly cannot be removed from their chemical formulation, transportation and application equipment."*

6. Dicamba Symptomology on Palmer Amaranth and Residues in Tissue

- A photo from Dr. Bob Hartzler of Iowa State University was shown where soybean was cupped yet Palmer amaranth and waterhemp plants in the photo exhibited no dicamba symptomology. It was noted that Palmer amaranth is orders of magnitude more tolerant to dicamba than soybean.

- Research relating dicamba concentration in Palmer amaranth plants over time (days after application) as a function of exposure rate revealed that the herbicide is quickly broken down over time. Palmer amaranth size at exposure or application did not interact with the rate applied, meaning a similar dicamba concentration (ppb) was expected regardless of weed size at exposure. A 1/1000X drift rate of dicamba was not detectable in Palmer amaranth tissue by 7 days after treatment, and a 1/100X drift rate of the herbicide was not detectable by 10 days after treatment. Furthermore, photos of Palmer amaranth plants treated with dicamba at 1/100 and 1/1000X rates did not show dicamba-like symptoms at 10 and 25 days after exposure. Only plants treated with a 1X rate showed strong symptoms or plant death, depending on size of the plant treated. Based on these findings, it does not appear possible for drift rates or typical tank-contamination rates of dicamba to cause symptomology on Palmer amaranth. Attention should be given to date of sample collection along with concentration in the Palmer amaranth when making a decision if an application was illegally made beyond a cutoff date.

- Photos of fields illegally sprayed with dicamba were shown with this conclusion drawn based on the date photos were taken and symptomology on Palmer amaranth. Not only was the point made that Palmer amaranth was being sprayed beyond the cutoff but also

applications were being made to plants much larger than those currently listed on the XtendiMax and Engenia labels. There is a concern that resistance to dicamba could become widespread as evidenced by 1) the recent documented resistance to dicamba in Palmer amaranth by colleagues at Kansas State University, 2) the frequent occurrence of failures on Palmer amaranth in Tennessee this summer as reported by Dr. Steckel, and 3) the 934 XtendiMax failures in 2019 reported by Legacy Monsanto (information obtained from report by Dr. Ty Witten).

7. Dicamba Vapor Concentrations that Elicit Symptomology in Soybean

- Volatilization of XtendiMax occurred over a 96-hour period (the duration of measurement) with approximately 50% of the dicamba captured in the first 24 hours. Substantial reductions in dicamba volatilization beyond 24 hours after application was often associated with rainfall events. Even so, on average across eight trials, more than 10% of the dicamba that volatilized did so from 72 to 96 hours after application. Bio-indicator soybean plants placed in the field from 72 to 96 hours after application routinely showed symptoms consistent with exposure to dicamba after 21 days.

- In a document entitled "Examining Dicamba Vapor Concentrations and Plant Response", Mr. Tom Orr of Legacy Monsanto discussed the research conducted to establish the 'No Effect Concentration' for dicamba using soybean as a bio-indicator. Mr. Orr states "the ability to correlate laboratory plant effects when exposed to a known air concentration within a closed system over time could be used to establish maximum potential for plant exposure in "real world" field environments." Data presented by Mr. Orr are solely from a humidome trial where he reported on the response of soybean (injury) plants placed in humidome to various concentrations of dicamba over a 24-hour period. Notably, soybean was injured by dicamba at all concentrations evaluated, and there was no reported evaluation of exposure for longer than 24 hours.

- Trials were conducted in northwest Arkansas in 2018 and 2019 to evaluate the response of soybean to dicamba vapors and to determine if the humidome results produced by Legacy Monsanto matched field evaluations. There were stark differences between the results from Arkansas field trials and those reported for Orr's humidome research. The slope of the line describing the relationship between cumulative dicamba concentration per day and soybean injury in the Arkansas field trials was 5.077, meaning that soybean injury increased 5.077 percentage points for every 1 ng/m^3 increase in dicamba concentration. Conversely, Mr. Orr reported there is only a 0.0914 percentage point increase in soybean injury with each ng/m^3 increase in dicamba concentration. Based on the ratio of the two slopes (5.077/0.0914), soybean plants in the field exhibited 55X more sensitivity per unit of dicamba in the air. The concentration of volatile dicamba in the air in geographies of heavy use where soybean injury from dicamba is common is unknown at this time. However, based on results from this research, it appears that a very low air concentration of volatile dicamba is needed to elicit symptomology on soybean, and the concentration needed to cause injury to soybean is much lower than previously reported from humidome research.

8. Use of a Tracer to Evaluate Suspension of Spray Particles vs. Volatility of Dicamba

   - Multiple trials were conducted using imazethapyr (labeled herbicide for soybean) as a non-volatile tracer when mixed with a commercial dicamba formulation plus glyphosate. The concentration of dicamba detected in air from 0.5 to 24 hours after application of the mixture was 24X greater than concentration of imazethapyr detected, accounting for initial differences in rates applied. Based on samples collected from petri dishes sprayed during application, the dicamba rate applied was 7X greater than the imazethapyr rate applied to the plots; hence, it is apparent that most of the dicamba detected in the first sampling period was a result of volatilization. An air sampler positioned 50 feet downwind from the application collected 1.17 ng/m^3 of dicamba whereas no imazethapyr was found in this sample. Subsequent air samples collected from inside the treated area and downwind of the treated area led to the detection of dicamba but not imazethapyr. These results suggest that spray particles are not simply suspended in the air for long periods after application.

9. Findings from Recently Published Research on Dicamba by University of Missouri Researchers (Bish et al. 2019)

   - The new low-volatile dicamba formulations Engenia and XtendiMax were detected at comparable levels in air over a 72-hour period, with detection still occurring when the experiment ended.

   - Addition of glyphosate to dicamba increased dicamba losses in air.

   - Dicamba was detected at its highest concentration from 0.5 to 8 hours after application into stable air. The cause of the high level of dicamba detected was believed to be a combination of suspended particles in the inversion and volatilization into the inversion. When dicamba was applied during unstable conditions, its detection was greater when applied during stable conditions for the sampling periods of 8 to 16, 16 to 24, and 24 to 48, and 48 to 72 hours after application. A high level of volatilization when applied during unstable conditions resulted in persistent detection of the herbicide over time.

   - In summarizing their research, the authors state *"Some of the most problematic regions for dicamba injury in 2017 and 2018 were in the Missouri bootheel, northeast Arkansas, and western Tennessee. These areas typically have much lower wind speeds relative to other areas, and this region is prone to inversions during the growing season. It is possible that the stable atmosphere in these regions would allow herbicide, including dicamba, to remain concentrated in the air and unable to disperse. These regions typically have higher rates of annual herbicide usage compared to other regions. The combinations of stable atmosphere with high use rates may explain much of the observed "landscape" effects of dicamba damage."* Furthermore, they show a map of the U.S. depicting days with wind speeds above 8.9 mph (14.4 kph). The Missouri bootheel, northeast Arkansas, and western Tennessee

region generally have fewer than 10 days in a typical growing season when wind speeds exceed 8.9 mph.

- The concentration of dicamba detected in air increased as maximum and average wind speeds decreased during the first 8 hours following an application.

10. Occurrence of Temperature Inversions in Areas where Dicamba Complaints are Common

- Weather stations were placed at Keiser, Crawfordsville, and Marianna and air temperature monitored beginning May 9 at heights of 18 and 120 inches above the soil surface. When air temperature at 120 inches was warmer than at 18 inches, a temperature inversion was deemed present.

- From May 9 to July 31, there was a temperature inversion every day at Keiser, with the exception of one day in June. Similarly, there were five or fewer days at Crawfordsville and Marianna when an inversion failed to occur. On some days, especially at Keiser, weak inversions seemed to persist throughout most of the day. At Keiser, daily inversions formed on average at 5:12 PM, 4:08 PM, and 4:39 PM for the months of May, June, and July, respectively. Based on these results and observations regarding spray applications, it appears likely that some spraying, regardless of pesticide, is occurring during times of the day when inversions are present or beginning to form.

11. Impact of Dicamba Exposure on Soybean Yield

- Dr. Dan Reynold's data shows soybean grain yield losses of 10% following exposure to a 1/1024X rate of dicamba. Based on his findings, a single dicamba exposure at 1/1024X rate to soybean could result in a yield loss of 8 bu/acre if the yield potential was 80 bu/acre. Using the current cash price of $8.84/bu for January soybean, this one time exposure would cost a grower $70.72/acre in lost yield alone.

- Multistate research evaluating the impact of multiple dicamba exposure to soybean revealed a yield loss of approximately 33% following three exposures of dicamba at 1/200X rate.

12. Alleged Dicamba Complaints and Comparison to Herbicides

- In 1998, there were 103 alleged quinclorac (Facet) complaints within the state. Subsequently, the Plant Board placed a sizeable buffer on quinclorac applications relative to commercial tomato production and the herbicide was banned in portions of Poinsett County. In 2006, there were 118 complaints against 2,4-D. The Plant Board followed this unusually high number of complaints with a ban of the herbicide in northeast Arkansas where there was a high concentration of cotton grown and restricted applications in the remainder of the state using a buffer to cotton fields. These buffers far exceeded any documented movement in research plots, yet they were established with the intent of

protecting those that could not protect themselves from potential harm from these herbicides.

- There were a total of 210 alleged complaints against dicamba in Arkansas in 2019, with a cutoff date of May 25th. Conversely, there were 1014 alleged dicamba complaints in 2017 in the absence of a cutoff until well after the spraying season was completed. In 2018, an April 15th cutoff resulted in 200 alleged dicamba complaints.

- Assuming that complaints would likely occur 14 to 21 days after application, approximately 90% of the total complaints in 2019 occurred following the May 25th cutoff. I attribute extensive spraying beyond the cutoff to 1) dicamba being the only means for postemergence control of Palmer amaranth in some fields where the Xtend technology was planted, 2) late planting of the crop beyond the cutoff because of frequent rainfall through much of the spring, and 3) the fact that some individuals were spraying with no apparent consequences.

13. Impact of Air Temperature on Dicamba Volatilization

- The relationship between air temperature and dicamba volatilization has been presented to the Board on numerous occasions using peer-reviewed findings from published literature. In 2019, Drs. Mueller and Steckel (2019a) published a paper further examining dicamba volatility as affected by temperature and herbicide treatment. From this research, they concluded that dicamba volatilization begins at approximately 59°F. Addition of glyphosate to XtendiMax increased dicamba volatilization. Detectable dicamba in air increased 2.9 to 9.3 times across evaluated temperatures when glyphosate was added to XtendiMax.

- Based on weather data for Keiser, AR available from NOAA, the average high from April 16 to April 30 was 73°F, with the daily high temperature exceeding 80°F on several days. From May 1 to May 15, the average daily high was 75°F, but from May 16 to May 31, the daily high averaged 90°F, with temperatures in mid-90s common during this period. Based on volatility research published by Drs. Mueller and Steckel, the occurrence of high levels of volatilization beyond May 15th at Keiser was likely in 2019 if spraying beyond this date occurred. Daily temperatures at other locations across the state were not examined, but routinely higher daily temperatures would be expected at locations south of Keiser.

14. Environmental Stewardship

- As documented with photos of damaged trees at the Northeast Research and Extension Center, the damage from dicamba goes beyond soybean. While it is true that soybean plants exposed in early spring during vegetative growth have the greatest potential for recovery without yield loss, the impact of a one-time annual exposure or multiple exposure on perennial species is unknown as stated by the EPA in fall of 2018. As noted with a photo of a weeping mulberry in downtown Crawfordsville, AR, some tree and ornamental species are highly sensitive to dicamba. A strong appearance of dicamba damage on this weeping

mulberry in 2017 was followed by reoccurrence of the same symptomology in 2018. Was the damage in 2018 carryover from the persistence of dicamba within the tree or was it a result of repeat exposure again in 2018? What ultimately led to the demise of this tree in 2019? Did it die from a third year of exposure to dicamba? Did dicamba weaken the tree, leading to increased susceptibility to a disease or other stressors for which the tree would normally survive? Did someone within the small town remove the tree because the sign of dicamba was a daily reminder of an issue that has torn at the fabrics of agriculture, especially in this region of Arkansas? I doubt we will ever know the answer to these questions.

15. Overall Conclusions

- Academics across multiple states continue to conclude that secondary movement is a major concern with off-target movement of dicamba and is not manageable by the applicator.

- Defensive planting is not possible for all crops. Individuals growing ornamentals, peaches, vegetables, etc. do not have the option of integrating a dicamba trait into their production system.

- With multiple effective weed control technologies available today, it is imperative that cropping systems coexist.

- Dicamba was successfully used in Arkansas prior to the launch of the Xtend technology and it can continue to be used with an appropriate cutoff and strong proactive enforcement.

- Beyond dicamba, there is strong need to strengthen methodology and testing protocols to ensure that new herbicide technologies are brought forth in a manner where adequate evaluation and understanding of environmental risks and impacts occur prior to launch.

Literature Cited

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Mueller TC, Steckel LC (2019a) Dicamba volatility in humidomes as affected by temperature and herbicide treatment. Weed Technology 33:541-546.

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EXHIBIT NO. 4

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

PRACTICAL WEED CONSULTANTS, LLC.

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Open Letter to the WSSA Board of Directors and Other Interested Parties

R.E. Auxin Herbicides

As a WSSA Fellow, I must ask my Society "where are we going, and what are we thinking?" Are we truly a body of scientists that make ourselves available and contribute science in decision making processes; or are we the Herbicide Science Society of America, the Chemical Company Society of America; or are we trying to be a lobby group? From the beginning, there has been plenty of published science and plenty of experience among our members to know dicamba could not be sprayed on large acreages in summer temperatures without a train wreck. However, science aside, we have gone down the road of vigorously supporting the dicamba-tolerant technology and even lobbying for the technology. Quite frankly I am embarrassed.

I am an applied weed scientist in the heart of Palmer amaranth country and fully understand the need for new herbicides and technologies. I am also fully aware that dicamba will kill a pigweed that is resistant to other herbicides. However, as weed scientists we have an environmental responsibility to be good stewards. Once again in 2018, large acreages of non-dicamba-tolerant soybeans in eastern Arkansas are affected by this herbicide as well as many vegetables. In addition, most trees in the countryside and towns are cupping and even dying following multiple years of exposure. Gardens are being destroyed and commercial vegetable producers are fearful that their crop may be condemned because of no tolerances for dicamba residues. Reports from bordering states are similar to those in Arkansas. In all likelihood, this widespread damage will move north as the season progresses. All the while there are those acting like everything is fine and in some cases attempting to shield people of influence from coming to see things for themselves. I am appalled when key influencers who view from afar make flippant statements such as "the benefits of this technology clearly outweigh the risks" with no environmental impact data to back up the statements. Those are similar to farmer's statements like "we have to kill our weeds and whatever happens as a result just happens."

As a Board of Directors, I challenge you to tour the areas and people most impacted by this technology. Visit a farmer who would like to grow an alternative soybean technology for diversity or a price premium. Visit a peach grower who has gone from 900 acres to 500 acres because half the trees have been killed over the past 4 seasons and is on the verge of being out of business. Visit a person whose stand of 200-year old oak trees has been affected. Visit an elderly lady who is crying because her garden in the middle of town has been destroyed. Visit a truck crop grower who has been put out of business or an organic farmer who cannot sell his crop. Visit a large- scale bee farmer and honey producer whose production in high dicamba use areas is half what it is in other areas. Are we environmental stewards or is it all about weed control regardless of the costs and environmental impact? Protective buffers are an ineffective tool as vegetation is often damaged a mile or more from the nearest sprayed field. Some will say this cannot be right as the number of complaints do not reflect it. Most by nature do not complain. A vegetable producer won't complain because the crop will be condemned and can't be sold. An organic farmer who complains could lose their certification. Soybean growers have grown weary of complaining as nothing ever seems to come from it. If anything it will be a token fine. In many cases, the state regulatory agencies can't work complaints in a timely manner due to the sheer number of fields with damage. Likewise, reports are often not finished until a year later. Most home owners do not even know who to complain to.

I began my weed science career as a graduate student in 1969. I have been in some way a part of every major herbicide development since that time and even those developed earlier were in major use during my career. Every game changing herbicide or technology sold itself. While the dicamba-tolerant crops have been touted by some as the next revolutionary technology, the current use of dicamba has been the most divisive issue in my career- both within and outside of agriculture. It has taken extensive lobbying and in some cases even lawsuits to get it registered and available for use. Weed scientists in some states have been muzzled by their administrators or have had their jobs threatened just for standing on sound science or trying to report the true situations in their states. Others are fearful of losing grant funds needed to support their programs. The price for that is we are losing our integrity and our industry. How as a Society can we possibly condone the use of a herbicide that cannot be kept on target and can be so damaging when it moves off target. This will absolutely destroy the credibility of agriculture in the eyes of the public and it has tarnished the integrity of WSSA as a science-based society because of a lack of vocal leadership. In fact, the damage done to the credibility of an entire agricultural industry could exceed the real monetary damages.

I have no monetary reason to question the use of this technology. I have simply known from the beginning that a volatile auxin could not be kept on target. Everyone has their own opinions on the exact reasons for the huge off target issues. In the big picture it doesn't really matter what the causes are. Dicamba has a chemistry problem that likely cannot be fixed, or at least no evidence has been provided that it can be successfully applied. If it can, it will only be through advances in chemistry. As the technology currently exists, renewing the cotton and soybean registrations will leave the industry no choice but to plant 100% of the soybean acreage to this technology. This defies historical lessons and everything we stand for on resistance management. Will we have "Take Action" only within the confines of this one technology? No other trait or technology for soybean can be grown in areas where dicamba is extensively used, preventing diversity in weed control options. Furthermore, contamination of air with an auxin herbicide defies environmental stewardship responsibilities. Dicamba floating in the air is inflicting sub-lethal damage to all sorts of dicot plants in agricultural ecosystems, natural ecosystems, parks, gardens, wildlife refuges, timber stands, home sites, and etc. People outside agriculture, who are already distrustful of agricultural chemicals, can now see visual evidence to confirm this distrust. In short, ignoring the significant scientific data regarding the off target movement of dicamba will be the biggest environmental disaster agriculture has ever seen, and much of that responsibility is square on the backs of agriculture- including WSSA. This travesty will affect the development and registration of new technologies for many years to come.

As the leaders of our Society, I challenge each of you to get the Society back on the course of making sound recommendations to the EPA rather than responding to lobbyist and other monetary influences.

Respectfully Submitted

Ford Baldwin, Ph.D.
WSSA Fellow, 1996

EXHIBIT NO. 5

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

My Perspective on Dicamba Tolerant Crops: Ford Baldwin, Ph.D., Professor Emeritus- University of Arkansas and Partner- Practical Weed Consultants, LLC.

Prepared for 7/25/2016 Arkansas State Plant Board Pesticide Committee Meeting

1. The University of Arkansas has the best weed science faculty anywhere. When differences of opinion on weed science issues have arisen in my career the sound approach has been to navigate through them using the best available research. Arkansas also has excellent crop commodity specialists. You have the right people to lean on.
2. I fully support any recommendations the University of Arkansas scientists put forth and all I can add is perhaps a perspective from 42 years of experience.
3. This year's off-target issues with dicamba were very predictable when the Roundup Ready Xtend crops were allowed to be planted without the registration of improved formulations of dicamba; and without intensive training of growers and applicators. The primary response I have seen to date has been to throw the farmers that sprayed dicamba on these crops under the bus. We have known from the beginning soybean is as sensitive to dicamba as cotton is to 2,4-D, or tomato is to quinclorac. The dicamba applications to Xtend crops were off-label but the currently available dicamba formulations would have behaved the same had a label been approved. Regardless, these applications provided a real world look at what will happen if the technology goes forward as it currently exists. Compared to spring applications, the DMA and DGA salts of dicamba behave much differently applied when temperatures are higher and susceptible crops and other vegetation have emerged.
4. As a Board you now have the unenviable task of deciding a path forward. With recent EU approval, if the program for 2017 is the same as this year's, it is entirely predictable the row crop area of Arkansas could look like the MO boot heel and the technology may not survive.

5. Having weed control options tied to seed traits would not be my choice but that is what we have. The seed side has not made full eye contact with the weed science side of the genetics. Mainly from the seed side you hear yield, yield, and yield. I have sat in numerous presentations and discussions the past year hearing Xtend soybeans will out yield anything on the market- but have seen no data. They will certainly out yield any other soybeans that are injured by dicamba. The marketing model appears to be "we committed to this technology, we have all this seed, we are going to sell this seed and anything happening after that is someone else's problem." Companies simply must assume more ownership in the herbicide side of the seed. Weed control and the ability to manage the herbicide will ultimately drive choice of seed.
6. This year has shown RR/Xtend as it currently exists is an all or nothing technology meaning all of the soybean acres will have to be planted to it; or none of the acres can be planted to it without the risk of off-target injury. If the technology cannot be used, we lose a needed tool. On the other hand planting the entire soybean crop to ANY single technology is faulty science as it will prevent necessary herbicide diversity for resistance management. We cannot afford to lose another single herbicide to resistance. In the case of Xtend, the use of dicamba could prevent growing seed for other soybean technologies due to carry over of the herbicide in the seed of an affected plant into the offspring from those seed planted the following year. If having 100% of the soybean acreage planted to a single technology is the path chosen, it takes the weed scientist's ability to advise you out of the picture. Roundup Ready Xtend can be an effective tool but is not a superior weed control technology compared to other options available or becoming available- i.e. Liberty Link, Enlist, or Balance GT/Liberty Link. It is unlikely all growers would choose Xtend on its own merits. I constantly hear the flippant remark "when everybody plants Xtend soybeans the off target

problem is solved." No grower should be forced to plant anything. For the grower who chooses not to plant the technology or perhaps would like to but may not be able to obtain seed next year, is it fair to put their crop in jeopardy? That begs the questions why would any company want to go there and why would any regulatory body allow it?

7. While I have had considerable experience with dicamba throughout my career, this year has provided an excellent refresher course. We have known that dicamba is an average pigweed herbicide and that has been obvious this year. At currently labeled rates, Palmer amaranth control from dicamba alone has been disappointing in the research plots observed. In fairness, I have also observed it in some program approach plots where the weed control was very good. The off-target injury to soybeans has been widely documented. Dr Larry Steckel from TN reported to me that on a recent drive down TN Rt. 54 from Brownsville to Alamo he noted about 70% of the soybean fields were showing dicamba symptoms. He further reported that he had been on approximately 30,000 acres of injured soybeans in the past month. I have observed fields in Arkansas and in the MO boot heel. In the boot heel it would be difficult to find a non-Xtend soybean field that does not have some level of dicamba symptoms. In addition auxin herbicide symptoms can readily be observed on oak trees, sycamore, Bradford pear, sumac and other native and cultivated broadleaf vegetation throughout the area. This issue could easily get outside of agriculture and that could be a game changer.

8. I totally support and encourage any reasonable effort to make RR/Xtend a viable technology. I understand the need for new herbicide technology as I am extremely concerned that we could be without effective weed control programs for soybeans in 5 years.

9. In order to have a viable path forward, it should be proven that new lower volatility formulations of dicamba like Engenia and Vapor Grip combined with drift reducing nozzles and application techniques can allow Xtend crops to be grown in concert with non-dicamba crops and with native and cultivated vegetation. Improved formulations and application technology can offer improvement- the question is will it be enough? What cannot be changed is plant sensitivity to the herbicide. You will likely have the choice to either assume these corrections will fix the problem -or allow this to be determined in future research and on a real-world trial basis in the field. I suggest the latter. If the registration of the new formulations are delayed again next year there will be the opportunity for research and field scale testing to assess how effective they are in reducing off target movement. If they are approved there will likely be a large landscape test conducted similar to what happened in MO, AR and TN this year, and this could be a poor way to find out.
10. I struggle to see how the DMA and DGA salt formulations of dicamba can be allowed for use after soybean emergence. In fact I question why the DMA salt should be allowed to be sold- period. The current dicamba formulation being considered by the EPA is M1691 which is a DGA salt. The proposed label leaves much to be desired in terms of sound resistance management principles. If it and only it receives a label for next year I fail to see how it offers any improvement in the ability to keep dicamba on target. Obviously there are multiple options for registration that could occur at the EPA between now and next season. If new formulations prove effective, the technology must be tied to these formulations and the option to use current dicamba formulations eliminated. Otherwise, the new formulations do not have a chance nor does the technology. Both the regulatory agencies and the companies must step up to make the penalties for illegal applications of any type such that nobody will consider them.

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EXHIBIT NO. 6

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

Terry Walker: Director, Arkansas State Plant Board
Larry Jayroe: Chairman- Pesticide Committee, Arkansas State Plant Board

Re: My Thoughts- Again

As per your request, I will provide some thoughts on the proposed dicamba regulations. The first thing that must be decided is will you base your decision on the best science available; or on politics? If it is the latter there is no point in reading any further. The Xtend technology provides an excellent tool for controlling resistant weeds in soybean and cotton. That is a given but unless the off target issues with dicamba can be brought back in line with the other herbicides being used in the state, the technology has no path forward. If that is the objective of the Board, then I see no alternative to reducing the amount of dicamba being sprayed during the growing season. If the objective is to maintain or increase the acres being sprayed and at the same time reduce the extent of the off target issues, those two are not compatible.

I disagree with those saying the Board has not relied on science. First, it was learned with 2,4-D esters on cotton in the late 1940's to early 50's that you can't spray an auxin herbicide in the summer without damage from secondary movement. Secondary movement of 2,4-D was solved through the development of formulations stable enough for field volatility not to be an issue. The supporting science is well documented in the literature.
For the dicamba issue specifically- Behrens, R. and W.E. Lueschens. 1979. Dicamba Volatility. Weed Sci. 27:486-492 should be required reading for anyone participating in the dicamba discussion. In their research, results from closed chamber studies comparing dicamba formulations with varying levels of volatility, using soybean as a bioindicator, did not correlate well with results from field studies using the same formulations. The formulations with the highest potential volatility resulted in more soybean injury than those with the least degree of volatility in the closed chamber studies. However the lower volatility formulations such as a sodium salt did not result in soybean injury in the closed chamber studies but injury occurred in the field studies. They offered an explanation when they stated "under field conditions, a combination of sufficiently high temperatures to volatilize dicamba with relatively slow air movement may be necessary for the build-up and maintenance of phytotoxic concentrations of dicamba vapors over sensitive crops over a substantial period of time, perhaps several hours, required to cause dicamba vapor drift injury." This along with my personal observations in 2016 and 2017 provides the basis for my opinion that the landscape injury effect that resulted in over 900 complaints was primarily the result of dicamba vapors accumulating in night time temperature inversions.

After 2017, there is an adequate body of field research using both soybean as a bioindicator, as well as air sampling that shows the field volatility of the newer low volatility formulations of dicamba to be sufficient to cause off target plant injury. These results were not predicted by humidome studies conducted by the manufacturers, but are very similar to those of Behrens and Lueschens nearly 40 years ago. The current studies were conducted by very competent weed scientists from several major universities. Because of this, the academic community across the country believes strongly that vapor movement is playing a significant role in the off target issue. The Board has the option to either believe the academic scientists or believe the manufacturer's position that misuse is the primary cause of the off target issue. If you chose the latter, just consider adopting the Federal Label. Two questions then beg answers: why would you expect a different result in 2018; and who takes ownership of the decision?

If you chose to believe that volatility was a major contributor to the off target issue in 2017 (and there is no question regarding that in my mind) then you have all the science you need. In addition, the actual

application parameters have little to do with the volatility component of movement. If you chose to believe the current academic science then I must question why more science is being demanded from academics rather than from the manufacturers? Volatility does not have an on-off switch so science cannot be used to establish parameters such as a specific cutoff date or maximum temperature. Some factors that influence dicamba volatility include formulation, application rate, temperature along with other environmental factors, what it is being applied too, and the number of acres being sprayed in a concentrated area in a short period of time. Of these, I believe the number of acres sprayed exerts the most influence. It is this factor that elevates the magnitude of the problem from a point source where in some cases the source can be determined; to a landscape level where it is impossible to determine the specific source of any damage.
Is April 16 an arbitrary date? Sure it is. The same is true for any other date you may choose. However, based upon the behavioral science of dicamba, as you move forward from a mid April period, temperatures increase, weeds can be larger so rates or the number of applications will increase, the probability of night time temperature inversions increases, more dicamba will be contacting vegetation instead of soil, and the number of acres sprayed in a short period of time will increase. The environmental factors conducive to volatility are already in play by the time soybean, cotton and weeds have emerged. Therefore, the variable you have the most control over is acres sprayed. Unfortunately I see no way to affect acres sprayed other than a cutoff date. I will support any date chosen. However, I have supported the April date chosen through due process because I believe any meaningful date must protect emerged susceptible crops, trees, pollinator plants, gardens, etc.

As I final thought, I would simply offer this April marks my 44th year as a practicing weed scientist and nearly 50 if graduate school is included. During this time, I have been a part of essentially every game changing herbicide development since the beginning. In soybean, some of the more notable have been Treflan, Basagran, Blazer, Scepter, Roundup Ready and Liberty Link. In every case, weed scientists were eager to help get them into the marketplace and into Extension recommendations as quickly as possible. Once on the market the herbicides sold themselves and few off target issues occurred. In the cases where they did, it was the result of physical drift and these problems were easily correctable.
Now with what is being referred to by some as the next game changing technology: anger abounds, at least two farmers have been killed in alleged dicamba disputes, there is a tremendous divide among farmers that want the technology and those who do not, between academia and industry, and between agriculture and non-agriculture related entities to name a few. Insurance companies do not know how to deal with the issue nor do most applicators. Many people feel their livelihoods are being threatened with no hope of restitution. An increasing number of farmers feel compelled to have to plant the Xtend technology as the only means of defending themselves against damage. Outstanding university weed scientists are being scorned for simply doing their jobs. Some universities have chosen not to recommend dicamba in the Xtend crops because they don't know how. Record numbers of off target complaints have occurred in essentially every state where the technology was implemented. This has caused Arkansas and several other states to implement additional regulations because they feel the manufacturers and the EPA have not adequately addressed the problem. As a result they are being attacked by industry by farmers and even politicians for "being arbitrary."

Respectfully Submitted 12/29/17
Ford Baldwin

EXHIBIT NO. 7

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

Delta Crops and Research, Inc.
15 Carmons Lane, Indianola, MS 38751
Tel 662-207-2131
trey@deltacrop.com

COPY

August 21, 2018

SUSIE NICHOLS

Agriculture Division Mgr Pesticide Division
Arkansas State Plant Board

Dear Susie,

In light of the ongoing concern for off target movement and placement of dicamba as well as other auxin type herbicides in the state of Arkansas, I was asked by the Arkansas State Plant Board to conduct an independent investigation regarding the impacts of this class of herbicides on non-crop species in Arkansas. On August 3rd, 2018 I investigated non-crop areas in cities and roadside areas of eastern Arkansas. My tour started in West Memphis, TN and went westward into Forrest City and then south thru the towns of Marianna, Marvell, Poplar Grove, and Helena-West Helena, AR.

Dicamba like symptomology was prevalent in every city, town, and community I visited. It is important to note that the damage tended to be worst on the outskirts of each city and along roadsides that were on the edges of each city. The further away from the city/community outskirts and the closer to inner parts of each city/community the damage tended to lessen. This is not to say that damage could not be seen on the inner parts of each city/community that I toured, its just that the damage tended to be less severe than on the outer parts of the city/community.

It is very difficult to estimate the short and long-term impacts of the damage inspected in these areas of AR I visited, as these are non-crop bearing species in which it is difficult to estimate an economic impact. It is important to note that there is a wide range of degree of sensitivity in tree species to dicamba / auxin herbicides. Some of the more sensitive tree species include Bradford pear; cherry, sycamore, maple, cypress, and white oak. Conversely, tree species that appear to be more tolerant include pecan, red oak species, and elm. Its not to say that these species are immune to damage from auxin herbicides, but they do appear to be tolerant to injury than the aforementioned species that are extremely sensitive to auxin herbicides.

Respectfully,

Trey Koger

DELTA CROP AND RESEARCH, INC.

EXHIBIT NO. 8

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

Delta Crops and Research, Inc.
15 Carmons Lane, Indianola, MS 38751
Tel 662-207-2131
trey@deltacrop.com

OCTOBER 28, 2018

Butch Calhoun
Director,
Arkansas State Plant Board

Addendum to letter dated August 17, 2018.

To Director, members of State Plant Board, and others:

This letter is to serve as a brief summary of herbicide drift cases in which I was asked to investigate while accompanying AR State Plant Board inspectors between July 23 thru 27th, August 1st thru 3rd, and August 22nd thru 24th, respectively. These investigations I assisted on were follow up investigations for the AR State Plant Board Inspectors. I was asked to provide technical advice on what type of herbicide, and in many cases what specific herbicide, caused the injury as well as to what severity has the herbicide injured sensitive species investigated in the case. I was asked to not take pictures, but to only provide advice. I was also asked to not spend time on trying to determine where the drift came from, only to confirm what herbicide potentially caused the injury to sensitive species and to determine the severity of the injury.

This report will serve four purposes: 1) to provide a summary of the counties in which time was spent investigating cases, 2) details on plant species that were sensitive to the herbicide under investigation, 3) cases in which injury caused to sensitive plant species was thought to be dicamba only to determine it was another herbicide of the same class of chemistry as dicamba herbicide, and 4) a summary of some of the concerns as well as benefits of dicamba technology.

Extensive time was spent in Phillips county over the three week period. During this period, multiple stops were made to investigate dicamba injury to gardens, trees in yards of homes, trees in municipalities, as well as non-dicamba crop fields. The extensive injury in this county, in particular the Poplar Grove community, made it obvious that the injury was caused by more than a single drift event. Significant injury was documented to the following tree species: cherry, white oak, sycamore, maple, cypress, Bradford pear. Injury was also documented on virtually every broadleaf vegetable species including: tomato, squash, okra, cucumbers, watermelons, and cantaloupe. Interestingly; red oak, pine, and pecan appear to be fairly tolerant to dicamba, at least from a visual standpoint.

Several cases were investigated as well numerous stops were made in Lee and St. Francis counties. One particular stop was made to investigate injury to non-dicamba soybeans that were directly across the road from a rice field. Initially we thought that injury to the soybean was caused by quinclorac that may have been sprayed on the rice. However, spray records indicated that the rice field was not sprayed with quinclorac. Based on the injury to the soybean not being that typically observed with dicamba, and the injury being more severe closer to the highway, we strongly suspected the injury came from an herbicide sprayed on the roadside area. I spent some time with a beekeeper in the area and evaluated redvine in multiple places. It was suspected by the beekeeper that dicamba is having an adverse effect on redvine in areas where bee hives are located. I must say that before this time spent with the beekeeper, I have really never paid a lot of attention to redvine and the potential benefits it serves to beehives and subsequent honey production. I will say that redvine is a species that does exhibit typical dicamba symptomology, especially on younger growth. We observed extensive dicamba symptomology to redvine in roadside areas throughout the Lee county area.

Extensive time was spent investigating follow up cases in Crittenden, Poinsett, Mississippi, Craighead, and Clay Counties. The amount of dicamba injury observed in these areas was extensive and severe in some cases. To summarize, injury indicative to dicamba herbicide was commonly found within and in outskirts of communities on the following tree species: Bradford pear, red oak, sycamore, peach, and maple. Dicamba injury to non-dicamba soybean was prevalent throughout this geography. Injury ranged from severe to fairly light. In multiple locations, it was obvious based on injury to sensitive plants that dicamba was applied well after the cutoff date. It is important to note that several stops were made to investigate potential dicamba injury to non-dicamba soybean, only to determine the injury was actually caused be quinclorac or the active ingredient in Loyant herbicide. In each of these cases, rice was grown nearby and the injury was more severe closer to the rice. It is also important to note that symptomology caused by dicamba, quinclorac, and Loyant herbicide to non-dicamba soybean are all slightly different from one another. Dicamba tends to cause more leaf cupping; whereas quinclorac tends to cause leaf cupping but causes a draw string effect on the tip of the center leaflet of a trifoliate soybean leaf. Loyant typically causes more leaf elongation than cupping. This type of injury is closer to what you will see on cotton that has been sprayed with 2,4-d herbicide. I will say that differentiating these 3 herbicides based on symptomology can be difficult. Especially if the plant has begun to recover and grow new leaves.

We also investigated a case in the Arkansas county area which turned out to be quinclorac on non-dicamba soybean. During this investigation we made a stop at the Rice Research Station in Stuttgart and evaluated quinclorac injury to a soybean variety trial that neighbored a block of rice on the station as well. It was interesting to see that some varieties and/or experimental lines are more tolerant to quinclorac than others.

In summary, dicamba injury was prevalent to sensitive trees, roadside plants, and non-dicamba crops throughout many of the areas of eastern AR in which made evaluations. There are several plant species that extremely sensitive to dicamba with respect to visually injury; whereas different species adjacent to the

sensitive ones exhibit no to very little injury. The most sensitive tree species we evaluated during our investigations included: Bradford pear, cherry, sycamore, cypress, and white oak. Pecan and red oak tree species appear to be fairly tolerant. The road side and ditch bank species of redvine and giant ragweed are fairly sensitive with respect to visually symptomology.

It is important to bear in mind that it is fairly easy to mistake injury caused by herbicides in the same class of chemistry as dicamba for dicamba injury. This is especially true in rice growing areas of Arkansas. This report is not written to shed favoritism or negativity on dicamba herbicide, but to simply summarize evaluations made while doing follow up investigations on herbicide drift cases investigated by AR State Plant Board inspectors. I will say that during my 17 year career as a weed scientist, I have never observed an issue that has divided our agriculture industry so divisively. It is so very unfortunate that a technology as useful as dicamba is to our industry has far reaching issues that cannot be solved entirely, at least not entirely for the foreseeable future. I do hope we as an industry are able to find a feasible way to use this technology that can have less impact with respect to off-target deposition and injury to sensitive species.

Warm regards,

Dr. Trey Koger

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EXHIBIT NO. 9

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

Research Article

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Identification of environmental factors that influence the likelihood of off-target movement of dicamba

Eric Oseland,[a] Mandy Bish,[a] Larry Steckel[b] and Kevin Bradley[a*]

Abstract

BACKGROUND: Commercialization of dicamba-resistant soybean and cotton and subsequent post-emergence applications of dicamba contributed to at least 1.4 and 0.5 million hectares of dicamba-injured soybean in the United States in 2017 and 2018, respectively. This research was initiated to identify environmental factors that contribute to off-target dicamba movement. A survey was conducted following the 2017 growing season to collect information from dicamba applications that remained on the target field and those where dicamba moved. Weather and environmental data surrounding applications were collected and used to identify factors that reduce the likelihood of off-target movement. Soil pH was one factor identified in the model, and field experiments were conducted in 2018 and 2019 to validate the model. Three commercially-available dicamba formulations and one formulation currently in development were applied to soil at five distinct pH values. Sensitive soybean was used as a bioassay plant to detect dicamba volatilization.

RESULTS: Wind speeds the day of and following application, nearest water source to the field, soybean production acreage in the county, and soil pH were identified as factors that influence the likelihood for off-target movement. In the field study, when dicamba was applied to pH-adjusted soil and placed under low tunnels for 72 h, dicamba volatility increased when soil pH decreased as the model predicted. Dicamba choline, which is not commercially available, had reduced volatility compared to other formulations tested.

CONCLUSION: Results of this study identified specific factors that contribute to successful and unsuccessful dicamba applications and should be considered prior to applications.
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Keywords: dicamba; drift; herbicide; volatility; soil pH; synthetic auxin

1 INTRODUCTION

Herbicide resistant weeds continue to threaten production of soybean [*Glycine max* (L.) Merr.] and cotton (*Gossypium hirsutum* L.) by reducing the number of effective chemical options for weed control.[1] Dicamba (3,6-dichloro-o-anisic acid) is a herbicide that has been widely used since the early 1960s in pastures and cereal crops for successful control of broadleaf weed species with few reported cases of resistance.[1,2] Recently, soybean and cotton were engineered with resistance to dicamba (DR-soybean and DR-cotton) and released for the first time in 2016.[3,4] Many broadleaf plant species and non-DR soybean and cotton are highly sensitive to very low rates of dicamba.[5–11] Exposure at rates as low as 1/20 000th of the labeled-use rate can cause non DR-soybean to express distinct leaf cupping symptomology associated with dicamba injury.[12] Historically, the sensitivity of plants to such low rates of dicamba has been problematic because dicamba acid is prone to volatilize and move to unintended locations.[13,14]

To reduce likelihood of volatility, newer dicamba formulations have been developed and commercialized since the initial introduction of the dimethylamine salt of dicamba in 1962.[15] This has commonly been accomplished by attaching various salts to dicamba acid to increase the molecular weight.[16] Concurrent with development of DR crops, two new dicamba formulations were developed to be applied in conjunction with the seed technology. These formulations were the only dicamba products approved by the United States Environmental Protection Agency for application to DR-soybean and cotton and were released 1 year following seed approval.[17,18] The new formulations included dicamba acid bound to a tridentate salt, BAPMA (N,N-bis-(3-aminopropyl) methyl-amine), and the previously commercialized diglycolamine (DGA) formulation combined with a proprietary compound, which contains an acetic acid buffer that scavenges free H^+ protons in the spray solution.[16,19] The first studies conducted to evaluate volatility of these new dicamba products showed that volatility was reduced compared to older formulations, but still occurred.[20,21] For further protection against off-target movement, extensive label restrictions were placed on these products.[22–24] Currently, an additional proprietary dicamba formulation that combines dicamba acid with an aqueous choline hydroxide

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solution (dicamba choline) is under development but not yet approved for application in DR crops.[25]

Even with the introduction of less-volatile formulations and restrictive pesticide labels, substantial off-target dicamba movement occurred in the first year of commercial applications. In 2017, state departments of agriculture throughout the United States reported 2700 claims of plant injury suspected to have originated from off-target dicamba movement.[26,27] Off-target injury was attributed to multiple factors including: application equipment contamination; use of unapproved, more volatile dicamba products; physical drift of particles; applications during temperature inversions[28]; and volatilization of newly-approved formulations.[27,29] While most of these factors are within a pesticide applicator's control, volatility cannot be controlled by the applicator and remains a concern.[30]

Many studies have been conducted to identify factors that increase volatility potential of dicamba. For example, Egan and Mortensen[31] found that increases in temperature and decreases in relative humidity can increase dicamba volatility. Behrens and Lueschen[13] observed similar results, but also mentioned that dicamba may be more likely to volatilize from leaf surfaces of corn (*Zea mays* L.) and soybean than from leaf surfaces of certain weed species. More recent work with the newer formulations has focused on the effects of pH on dicamba volatility.[22,32] Dicamba introduced to low pH environments may lead to increased volatility due to the potential for conversion back to dicamba acid.[33] Mueller and Steckel[22] found the addition of glyphosate to either new dicamba formulation substantially decreased pH of the spray solution. Additionally, Bish *et al.*[27] observed that dicamba volatility was higher when potassium salt of glyphosate was added in the spray tank. Behrens and Lueschen[13] found a nearly 2-fold increase in volatility from a glass surface when the spray solution pH was 4.7 compared to 8.8. While spray solution pH has been intensively evaluated for its contribution to volatility, little research has been conducted to evaluate what may occur when a dicamba solution is applied to a surface with low pH. After leaving the spray nozzle, dicamba that remains in the sprayed area will contact either leaf tissue or soil. Behrens and Lueschen[13] noted more volatility from leaf surfaces compared to the soil surface, but they did not report pH of the soil used in their experiment. Oertli *et al.*[34] reported that leaf surfaces of most crop species have pH values above 7, however, dew formation on leaf surfaces has been reported to increase acidity and volatility.[35,36] For soybean production, a soil pH near 6.0 is recommended, and also to sample to a depth of 15–20 cm.[37] However, Blevins *et al.*[38] and Moschler *et al.*[39] found that pH of the soil surface is often more acidic than lower in the soil profile where sampling occurs. In an Iowa soil survey, Pagani *et al.*[40] determined soil pH ranged from 4.6 to 8.0. Agricultural inputs such as nitrogen have been found to lower the pH of soil even more, especially at the soil surface.[41,42] Avnimelech and Laher[43] also reported that soil pH was one of the most important factors when measuring volatility of ammonia from soil. More research is needed to determine the effect soil surface pH has on dicamba volatility.

To further understand off-target dicamba movement associated with volatility, an analysis of dicamba applications was conducted. Weather and environmental factors surrounding dicamba field applications with no off-target dicamba injury detected were compared to those with unexplained off-target movement, and models were generated to predict the likelihood of dicamba applications remaining on-target. Soil pH was one variable identified in the model as affecting the likelihood of successful application. Field studies were carried out to validate that finding and compare volatility of newer dicamba formulations across a range of soil pH.

2 MATERIALS AND METHODS

2.1 Dicamba application survey and data collection

In the fall of 2017, information pertaining to dicamba applications made in the summer of 2017 was requested from a network of agricultural chemical retailers, state and regional extension specialists, and state departments of agriculture. Requested information included date of application, GPS coordinates, whether off-target movement was observed, and if off-target movement was observed, what caused the movement. The requests resulted in information pertaining to 256 applications. For 135 of the applications, the application date was known. These 135 applications were treated as one data set. Of these applications, 61 were categorized as 'successful', in which all evidence indicated that dicamba remained at the point of application. The remaining 74 applications were deemed 'unsuccessful', meaning that unexplained off-target dicamba movement (OTM) occurred. Records on the 61 successful applications came from Illinois, Kansas, and Missouri. The 74 non-successful applications came from Canada, Indiana, Kansas, Missouri, and North Carolina. Of these applications, the largest number of successful and non-successful applications were sprayed in June (Fig. 1(A)). For confidentiality

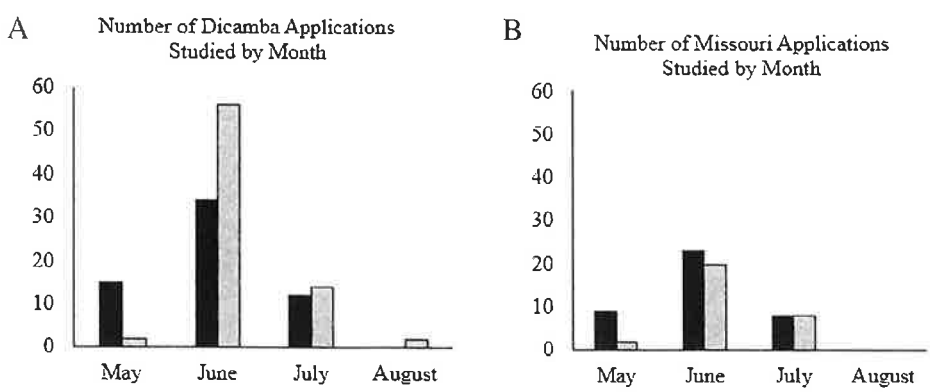

Figure 1. Total number of dicamba applications graphed by month the application was made (A), and total number of Missouri dicamba applications by month (B). Gold bars represent applications resulting in off-target dicamba movement (OTM). Black bars represent applications in which no OTM was observed. Data came from applications made in 2017 at locations in Illinois, Kansas, Missouri, and North Carolina, USA or Ontario, Canada.

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purposes, agricultural retailers were reluctant to disclose street address or GPS coordinates for 84 of the applications but shared the nearest town, which was used as a point-of-reference.

Applications disclosed by state departments of agriculture did not always have application dates identified. There were 58 off-target incidences with unknown application dates but in which GPS coordinates were known. Those applications were made in Missouri, South Dakota, and Tennessee, and were included in a second data set of 172 applications with known GPS coordinates.

Weather data were retrieved from the nearest university- or state-maintained micrometeorological station for each of the 135 applications in which application dates were known. Maximum wind speed, average air temperature, maximum air temperature, and total precipitation data were available for each site and retrieved for the day of application and day following application. The height above ground level (AGL) for air temperature probes are typically standardized and placed at 168 cm AGL. However, the height AGL for anemometers can vary, and in this study ranged from 3 to 10.7 m. The log wind profile equation was used to convert wind speed readings to 3 m AGL.[44]

$$v \approx v_{ref} \times [\ln(z/zo)/\ln(z_{ref}/zo)]$$

Variables are as follows: v = velocity to be calculated at height z; v_{ref} = known velocity at height z_{ref}; z_0 = roughness length in the current wind direction. Roughness length is determined by the type of land, and for this study, open agricultural area without fences was used, which has a roughness length of z = 1. Missouri micrometeorological stations were equipped to monitor additional weather variables including: average air temperature, minimum air temperature, maximum dew point temperature, solar radiation and vapor pressure. These variables were used to generate a model for Missouri applications with known application dates (n = 69).

For all applications, the percent acreage in soybean production per county was retrieved from the 2017 U.S. Dept. of Agriculture National Agricultural Census.[45] For those applications with known street addresses or GPS coordinates, soil pH was estimated using data from the National Resources Conservation Service (NRCS) Web Soil Survey[46] for the top 2 cm of soil. Additionally, nearest waterway classifications were collected (n = 172).[47,48] There were five waterway classifications: river, perennial stream, intermittent stream, lake (sessile water), and canal or ditch.

2.2 Model development

Analyses were conducted using SAS (Version 9.4 SAS Institute Inc.). Binary logistic regression models were generated with stepwise selection to identify variables that were indicators or predictors of a successful application. Successful application = 1 and unsuccessful application (unexplained dicamba OTM) = 0. Akaike's information criterion (AIC) was used to select the best prediction models. The *a priori* significance level chosen for variables to be included and remain in the model was α =0.157.[49] Independent variables included the weather variables, soybean acreage, soil pH, and nearest waterway, as previously described. Only 12 of the 135 applications with known dates had recordable amounts of precipitation, likely due to practical reasons, such as herbicide label language and attempts to avoid applications during rain. Therefore, precipitation was excluded from model development. Logistic regression will only allow numerical data; therefore, waterways were assigned the following numerical values: pipe (or river) = 5, perennial stream = 4, intermittent stream = 3, lake or sessile water = 2, and ditch or canal = 1. The PROC GLIMMIX procedure was used to describe means for each variable during successful and unsuccessful applications. Means were separated by Fisher's protected LSD ($P < 0.05$).

2.3 Field assessment of soil pH influence on dicamba volatility

Soil pH was identified as a variable in the model that influences likelihood of successful dicamba applications. To validate this relationship, a field experiment was conducted in 2018 and 2019. Each year the experiment was repeated in time and space for a total of four site-years with five replications each. During winter of 2018 and 2019, 2300 kg of Mexico-silt loam soil was collected from the Bradford Research Center in Columbia, MO. Only the upper 5-cm of soil were collected to simulate soil texture conditions that would be exposed during a herbicide application. Soil was passed through a 10 mm sieve to remove debris and create a uniform particle size for all treatments. Soil was added to a concrete mixer 15.8 kg at a time with one of the pH-amending treatments (Table 1). A fifth treatment of non-treated field soil served as a control. Soil was allowed to mix with the treatment for approximately 5 min, and then placed on a plastic tarp in a temperature-controlled building (20 °C) and kept moist with 22.7 L of water applied weekly to allow pH reactions to occur. Prior to initiation of field trials, soils were tested to determine final pH values. Soil pH was measured in $CaCl_2$ (0.01 M) and adjusted to soil pHw by adding 0.5 (Table 1).[37,50]

In the spring of 2018 and 2019 non-DR soybean (Pioneer P37T09L, Pioneer Hi-Bred Johnston, IA) were planted at 345800 seeds ha^{-1} in 76 cm rows in 3- by 7.6-m field plots to serve as a bio-indicator species for dicamba volatility. This method of bioassay-based volatility research has been previously conducted

Table 1. Soil amendments and resulting pH values for field experiment assessing soil pH influence on dicamba volatility in the field using low-tunnels, 2018 and 2019 in Columbia, MO

Starting soil pHs†	Soil amendment -Per 15.8 kg of soil-	Final soil $CaCl_2$ pH -	Adjusted for pH_w -
6.3	216 g $(Al_2(SO_4)_3$	3.8	4.3
	108 g $(Al_2(SO_4)_3$	5.0	5.5
	Non-Treated	6.3	6.8
	25 g $(Ca(OH)_2)$	7.2	7.7
	50 g $(Ca(OH)_2)$	7.8	8.3

†pHs is pH measured in $CaCl_2$. This value was converted to pHw or pH measured in water by adding 0.5.

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by a number of authors and is described by Mueller.[51] Approximately 7 weeks after planting and when soybean reached the four-leaf growth stage, 1.5 m wide by 6 m long low tunnels were constructed by bending eight fiberglass rods (6.5 mm × 2.4 m each) (Row Cover Supports, Seven Springs Farm, Check, VA) across two rows of soybean to span 6 m. Once rods were in place, 4-mL clear plastic sheeting (HDX Brand, Home Depot, Atlanta, GA) was draped over rods and secured using 15 cm u-shaped garden staples along each side. Ends of tunnels were secured to remain open, which prevented plastic sheeting from closing and restricting airflow through tunnels. An 8-m buffer remained lengthwise between all tunnels.

After low-tunnels were in place, 4.5 kg of pH-adjusted soil was measured and placed in a 54- by 27 cm plastic greenhouse tray (Hummert International, Earth City, MO), which had edges covered with 2.5 cm masking tape to prevent herbicide coming into direct contact with the plastic. This precaution was necessary given that Strachan *et al.*[14] found an increase in volatility when herbicides were applied to plastic. Soil was moistened to a soil water content of 8%. Soil trays were then transported to a remote location approximately 300 m from the field study location for herbicide application. Each tray received a 1 kg ae ha^{-1} application from one of four dicamba formulations: DGA (Clarity®, BASF Corporation, Raleigh, NC), DGA plus VG (XtendiMax®, Bayer CropScience, St. Louis, MO), BAPMA (Engenia®, BASF Corporation) or dicamba choline (Corteva Agriscience, Wilmington, DE). The DGA dicamba salt was included to allow comparison of a commonly-used older formulation known to volatilize. Herbicides were applied using a CO_2 pressurized backpack sprayer and a 2-m wide boom equipped with TTI11002 nozzles (TeeJet®, Spraying Systems Co. Wheaton, IL) calibrated to deliver 140 L ha^{-1} at 179 kPa. Each dicamba formulations was applied separately in time and space to avoid cross contamination. Between each application, spray equipment was rinsed with an ammonia and water solution followed by a triple rinse of water to ensure removal of the previous dicamba formulation. An appropriate drift reducing agent was used at 0.5% volume to volume to simulate real world application methods (OnTarget™, Winfield Solutions, LLC, St. Paul, MN). After herbicide applications, masking tape was removed from tray edges, and trays were transported *via* open vehicle to the field study location. A separate team of individuals waited at the field site to place two trays of treated, pH-adjusted soil in the center of each low tunnel between the two rows of soybean. Approximately 30 min elapsed from when dicamba was applied to trays and when trays were placed under tunnels. Trays were left in place for 72 h. Previous research has shown that both the BAPMA salt and DGA plus VG formulations can volatilize for at least 72 h following on-label applications.[27] At the end of the 72-h time period, low tunnels and soil trays were removed from the field location carefully to ensure no contamination of dicamba between plots. Weather data associated with each site-year of the experiment was retrieved from a University of Missouri-maintained weather station located approximately 400 m from the field site and can be found in Table 2.

Visual estimates of soybean injury were determined using a previously-established scale adopted from Behrens and Lueschen[13] to evaluate injury from dicamba. Injury intensity was most prominent nearest to where trays were placed. To be consistent in evaluations, soybean injury was observed in the center of each plot approximately 1 m in each direction from where the treated trays were placed. Visual injury estimates were assessed 14 days after tray and low tunnel removal. Data were subjected to ANOVA using the PROC GLIMMIX procedure in SAS 9.4. Repetition and replication were considered random effects in the model to allow inferences to be made over a wider range of environmental conditions.[52,53] Differences between treatment means were separated using Fisher's protected LSD ($\alpha \leq 0.05$).

3 RESULTS AND DISCUSSION

3.1 Generation of logistic regression models to predict the likelihood of successful applications

Relationships between successful dicamba applications and weather and environmental variables are illustrated in Table 3. Three models were generated based on three different types of available data sets. Maximum air temperature, average air temperature, maximum wind speed, and soybean production (% of county planted to soybean) were recorded at all locations in which application dates were known (n = 135). The best-fit model generated from this data lacked significance ($P = 0.07$) and had a concordance statistic (c value) of 0.59, suggesting only 59% accuracy in predicting which of the 135 applications were successful (Table 3).

A second stepwise regression model was generated using only application data from Missouri (n = 69) (Fig. 1(B)). Missouri micrometeorological stations are equipped to monitor minimum air temperature, soil temperature, maximum dew point temperatures, solar radiation, and vapor pressure in addition to the previously-mentioned weather variables. Minimum air temperature on the day of application and maximum wind speeds the day of and day following application were included in the best-fit model, which was significant at $P = 0.03$ and had a c value of 0.7 (Table 3).

Mean minimum air temperature for successful applications was 15.6 °C compared to a mean minimum air temperature of 17.5 °C for unsuccessful applications (Table 4). The result provides additional support for previous research findings that air temperature plays a role in unexplained off-target movement.[13,20,31] Average

Table 2. Weather data for dates when experiments were performed in Columbia, MO

Experiment #	Temperature (°C)†			Avg. relative humidity (%)	Avg. wind speed (kPH)
	Avg.	High	Low		
1- (6/27/18 - 6/30/18)	27	34	20	78	9.7
2- (8/3/18 - 8/6/18)	26	34	19	59	8.0
3- (7/5/19 - 7/8/19)	24	29	19	85	6.4
4- (7/19/19 - 7/22/19)	26	33	19	76	11.2

†Temperatures under low tunnels were increased by ~4 °C on average during daytime hours.

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Table 3. Best-fit logistic regression models to identify variables associated with successful dicamba applications in 2017†

Data set	Parameters‡	Likelihood ratio	Pr > ?²c	c value (ROC)
All applications with known dates (n = 135)	Intercept - AveAir0§	3.31	0.07	0.59
Missouri applications known dates (n = 69)	Intercept - MinAir0 + Wind0 - Wind1	8.96	0.03	0.70
All applications with known GPS coordinates (n = 172)	-Intercept + Soil pH – Water Type ¶ - Acre	49.5	<0.01	0.89

†Best-fit models were determined based on the Akaike's information criterion. Successful dicamba applications used to generate the model were those with no evidence of dicamba injury to surrounding area.
‡Variables tested in the first model included maximum and average air temperatures on the day of and day following application, maximum wind speed on the day of and day following application, and total percent of county in soybean production. Variables tested for Missouri applications include the previously mentioned and maximum dew point temperature, vapor pressure, solar radiation, soil temperature and minimum air temperature on the day of and day following application.
§AveAir0 is average air temperature on the day of application. MinAir0 and Wind0 are minimum temperature and maximum wind speed on day of application, respectively. Wind1 is maximum wind speed on the day following application.
¶Water type was the nearest water source and was classified based on U.S. Geological Survey hydrology map data.[48] Classification of water type was from pipe, or river, as the largest to canal, or ditch, as the smallest source.

and maximum air temperatures were excluded from the model, which may be the result of co-linearity with minimum air temperature that would have led to redundancy in and lowered the statistical strength of the model. Regardless, the trend in both models was that cooler average or minimum air temperatures were associated with greater likelihood of successful applications. These results provide quantitative support that although air temperature alone is insufficient to explain off-target dicamba movement, there is a role of air temperature in off-target movement.

Mean maximum wind speed on the day of application (MaxWind0) was 9.0 m s^{-1} for successful applications and 8.4 m s^{-1} for unsuccessful applications (Table 4). Although too much wind at the time of application can result in physical drift of herbicide droplets, wind is necessary to disperse droplets that are suspended or volatilize into the air. Previous research has shown higher wind speeds negatively correlate with dicamba concentrations in the air for the first 8 h following application.[27] Inclusion of maximum wind speed on the day following application (MaxWind1) as a predictor variable in the model indicates that conditions the day following application are important and provides additional support for a growing body of literature that has shown dicamba can move the day following application.[19,54] The relationship between MaxWind1 and likelihood of successful dicamba application was negative, indicating that higher wind speeds the day after application were associated with higher risk of off-target movement (Table 4). This relationship could be explained by the fact that dicamba that volatilizes into or remains suspended in a stable air mass is susceptible to movement by horizontal wind gusts, which push stable air masses. Additionally, wind is needed to disrupt stable air masses. Once disruption occurs, dicamba that has volatilized or been suspended in a stable air mass would be deposited to the surface below. Both of these mechanisms could account for greater off-target dicamba movement as a result of increased wind speeds the day following application.

A third regression model was developed with data from applications in which street addresses or GPS coordinates were known (n = 172). This allowed for mapping of nearby waterways and soil pH estimates to be included as potential predictor variables along with percent of county in soybean production. This model was the best predictor of successful applications with $P < 0.01$ and c = 0.89 (Table 3). All three variables were included in the model. As soil pH increased, likelihood of a successful application increased. The mean soil pH for successful applications was 6.5 while the mean for unsuccessful applications was 5.9 (Table 5). When applications were made near larger and more consistently-moving waterways, they were more likely to move off-target. 'Cool air drainage' is a phrase that has been associated with dicamba off-target movement.[28] If dicamba is suspended in cooler air masses, such as those resulting from temperature

Table 4. Logistic regression model associated with successful dicamba applications in Missouri (May to August 2017)†

Parameter‡	Mean (Successful)	Mean (Unsuccessful)	Estimate	WaldChi-square	Pr > ?²	Odds Ratio
Intercept	—	—	5.26	4.21	0.04	—
MinAir0§	15.6 ± 0.6	17.5 ± 0.7	−0.08	4.48	0.03	0.92
MaxWind0	9.0 ± 0.6	8.4 ± 0.4	0.08	2.50	0.11	1.08
MaxWind1	9.3 ± 0.5	10.5 ± 0.8	−0.07	3.41	0.06	0.93

†Successful dicamba applications used to generate the model were those with no evidence of dicamba injury to surrounding areas. Unsuccessful applications were those with evidence of dicamba injury to nearby sensitive plants (n = 69).
‡Variables tested were maximum, average, and minimum air temperatures; maximum wind speed; maximum dew point temperature; vapor pressure; solar radiation; soil temperature and percent of county in soybean acreage.[45] All weather variables were tested for the day of and day following application.
§MinAir0 is minimum air temperature (°C) on day of application. Wind0 and Wind1 are maximum wind speed (m s^{-1}) on day of and day following application, respectively.

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Table 5. Logistic regression model associated with successful dicamba applications when environmental factors are considered (2017)†

Parameter‡	Mean (Successful)	Mean (Unsuccessful)	Estimate	WaldChi-square	Pr > ?^{2}	Odds ratio
Intercept	—	—	−13.3	16.7	<0.01	—
Soil pH	6.52	5.92	2.79	23.0	<0.01	16.3
Water type	2.97	3.53	−1.16	11.1	<0.01	0.31
Acreage	21.4	24.0	−0.09	6.47	0.01	0.91

†Successful and non-successful applications with known street address or GPS coordinates.
‡Parameters included soil pH estimates of approximately 200 ha. Water type was the nearest water source and was classified based on U.S. Geological Survey hydrology map data.[48] Classification of water type was from pipe, or river, as the largest to canal, or ditch, as the smallest source. Acreage was percent of harvested soybean in the county of application, based on U.S. Dept. of Agriculture census data,[45] divided by the total area of the county.

inversions, it will likely move with the cool air towards the lowest area as cool air is more dense than warm air. There have been several observations of dicamba movement along major water sources, which are prone to inversion formation and 'cool air drainage'[55,56] (multiple personal communications by extension weed scientists). Lastly, the more soybean grown in the county, the higher likelihood of dicamba moving off-target. This could be due to an increase in the amount of dicamba being applied to DR soybean as well as an effect of having a higher acreage of sensitive, non-DR soybean in close proximity.

3.2 Comparison of soybean injury from dicamba applied to pH-adjusted soils

There were significant effects for soil pH ($P < 0.001$), dicamba formulation ($P = <0.001$) and the interaction of soil pH x dicamba formulation ($P = 0.003$). Non-treated plots were free of dicamba injury, which indicated that no cross-plot contamination of dicamba drift occurred. Consistent with the model (Table 5), soybean injury due to dicamba volatility was greatest when applied to the lowest soil pH (Fig. 2) across all formulations. As the model suggests, dicamba volatility decreased as soil pH increased. In the model that included soil pH, the average soil pH for an unsuccessful application of dicamba was 5.9 and for a successful application, 6.5. In the field experiment, when dicamba was applied to the three soil pH values above 5.9 (6.8, 7.7, and 8.3 respectively), there

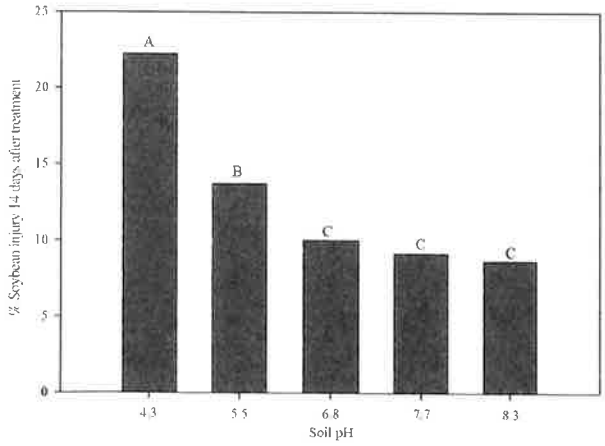

Figure 2. Influence of soil pH on percent soybean injury caused by dicamba volatility from dicamba applications to soil. †Severity of injury based on scale of 0–100% established by Behrens and Lueschen.[13]. ‡Injury means are averaged across 4 site-years, means followed by the same letter are not statistically different $P \leq 0.05$. §No injury was present in non-treated plots therefore they were not included in this analysis.

was no longer an observed increase in volatility (Fig. 2). These results validate the soil pH prediction and provide increased confidence in the model.

3.3 Comparison among dicamba formulations on volatility from pH-adjusted soils

As previously mentioned, the DGA dicamba formulation was included in this study as a comparison treatment for the newly-formulated salts. Across all soil pH values tested, dicamba formulations were ranked from greatest level of volatility to least as DGA > BAPMA>DGA plus VG > dicamba choline (Fig. 3). There was an increase in volatility from BAPMA in comparison to DGA plus VG that other researchers whom have compared these two formulations did not observe.[27] This effect could be due to the increased use rate utilized in our study in comparison to label recommendations. At the lowest soil pH of 4.3, volatility of the DGA, DGA plus VG and BAPMA formulations resulted in similar levels of soybean injury, ranging from 24 to 26%, while dicamba choline resulted in less, although still noticeable, soybean injury of 14% (Fig. 4). At a soil pH of 5.5, the DGA, DGA plus VG and BAPMA formulations resulted in similar levels of soybean injury that ranged from 15% to 17% while injury due to dicamba choline volatility was 6%. At a soil pH of 6.8, the DGA plus VG formulation exhibited a reduction in volatility compared to DGA and BAPMA formulations, based on soybean injury ratings. However, dicamba choline once again resulted in lower soybean injury. At a soil pH of 7.7, the DGA formulation resulted in the highest level of soybean injury followed by BAPMA then DGA plus VG and lastly dicamba choline. For the highest soil pH of 8.3, DGA resulted in the most soybean injury, followed by DGA plus VG and BAPMA, which were followed by dicamba choline. The DGA formulation seemed to be the least affected by pH, as a reduction in volatility was observed only between the 4.3 soil pH and the remaining soil pH values. For DGA plus VG, a reduction in volatility was observed between 4.3 and 5.5, followed by another reduction between 5.5 and the remaining soil pH values. A volatility reduction was observed for BAPMA between the 4.3 and 5.5 soil pH, followed by a reduction between the 5.5 and 7.7 soil pH. There were no differences for BAPMA when soil pH 7.7 was compared to either 6.5 or 8.3. Volatility reductions for dicamba choline were observed between soil pH 4.3 and 5.5, as well as between 5.5 and 7.7, however this formulation did not exhibit any additional differences in volatility between the other pH values. The interaction between dicamba formulations and soil pH values indicates that certain dicamba formulations are more sensitive to soil pH fluctuations.

Due to the proprietary chemical properties of dicamba choline, the basis for the observed reduction in volatility compared to

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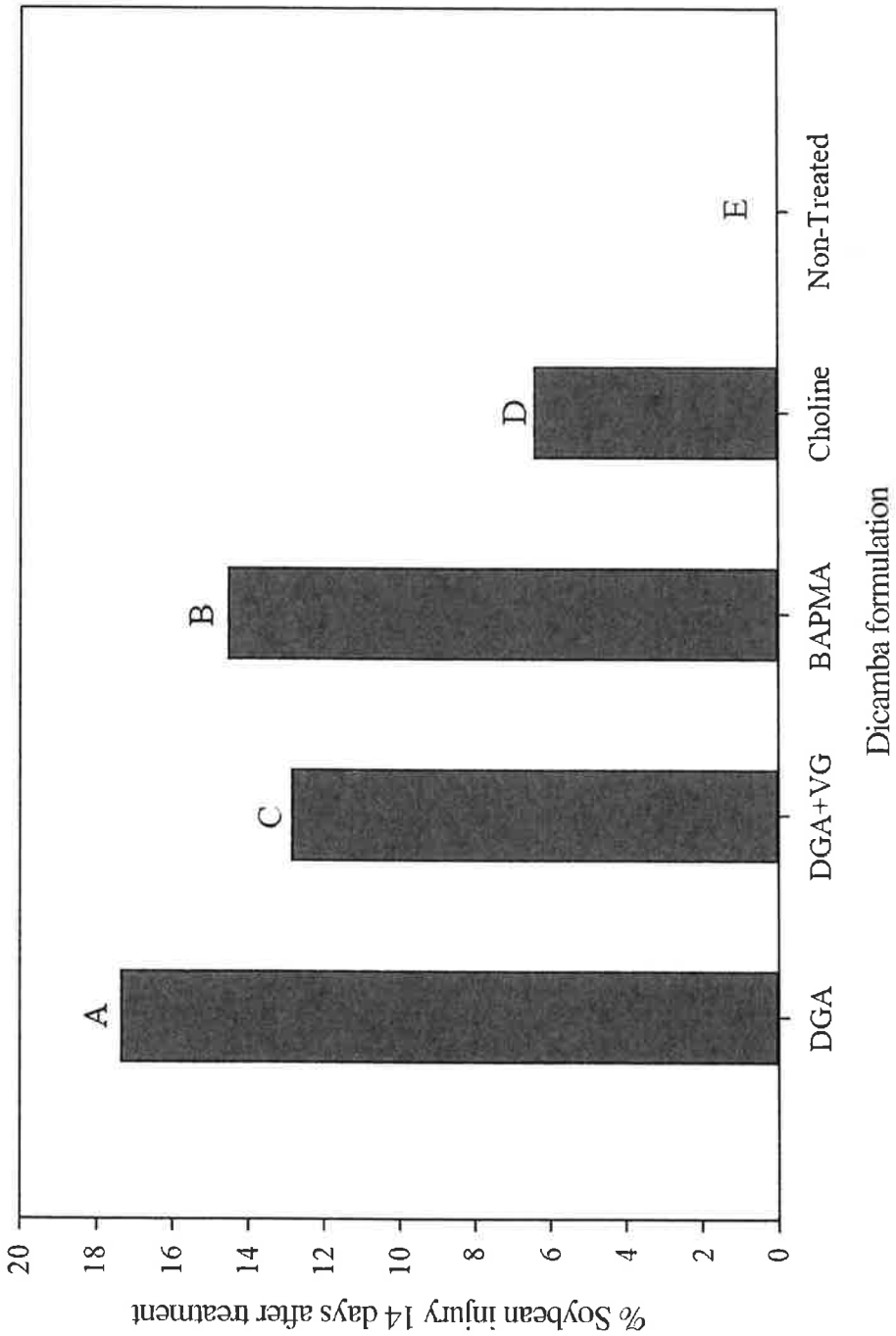

Figure 3. Influence of dicamba formulation on soybean injury caused by dicamba volatility from dicamba applications to soil. †Severity of injury based on scale of 0–100% established by Behrens and Lueschen.[13]. ‡Injury means are averaged across 4 site-years, means followed by the same letter are not statistically different $P \leq 0.05$.

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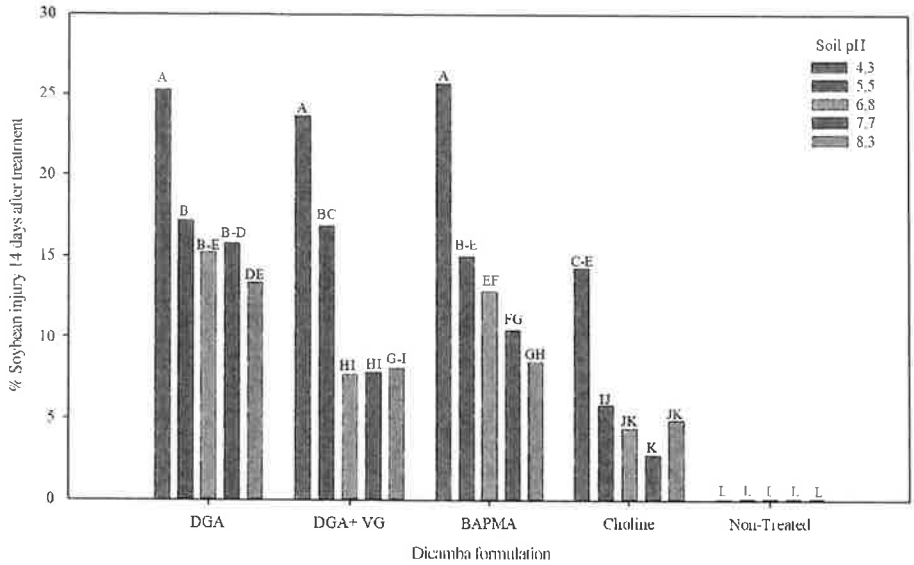

Figure 4. Influence of soil pH and dicamba formulation on percent injury to bioindicator soybean plants. †Severity of injury based on scale of 0–100% established by Behrens and Lueschen.[13]. ‡Injury means are averaged across 4 site-years, means followed by the same letter are not statistically different $P \leq 0.05$.

other formulations of dicamba tested is unclear. Regardless, this formulation shows promise for reducing volatility of dicamba compared to currently-approved formulations. When 2,4-D acid, a structurally-similar auxin herbicide, was reacted with the same choline base, it also demonstrated a reduction in volatility compared to other commercially available 2,4-D formulations.[57] The effect low soil pH has on increased dicamba volatility could be related to several factors. As pH decreases, hydrogen ions become more readily available and allow more rapid formation of dicamba acid, which is prone to volatilization.[58] Additionally, microbial biomass and activity can be decreased at low soil pH. Lower microbial abundance in the soil results in a decrease in dicamba degradation, which should result in longer persistence in the soil for potential volatilization.[59] However, it is important to note that studies measuring microbial degradation are typically conducted for longer periods of time (weeks), and it remains unknown how microbial degradation of dicamba might be affected for shorter time periods (days) in which dicamba has been shown to volatilize.

4 CONCLUSIONS

Models generated in this study provide quantification of variables that have been associated with unexplained off-target dicamba movement. Quantitatively identifying factors that contribute to successful dicamba applications is important for overall sustainability and longevity of the DR system. Results of this research identify some tangible factors that are likely to increase success of dicamba applications such as avoiding applications near low-lying river bottoms and at times when wind speeds are too low to adequately disperse the volatilized herbicide. The field study on soil pH confirms that greater dicamba volatility occurs at lower soil pH values. The effect soil pH had on dicamba volatility that was observed in this study is a result that has previously not been reported in dicamba volatility research. It is likely that, in many agricultural fields, the pH of the surface layer of soil that the dicamba solution contacts is low. Common farming practices being used today such as reduced or no-tillage systems and surface nitrogen applications increase acidity of the uppermost layer of the soil surface. Dicamba choline shows promise as a formulation due to its greater reduction in volatility compared to currently-approved formulations. However, volatility was still observed with this formulation, and it remains unknown whether reduction in volatility associated with dicamba choline would result in substantial reductions in off-target injury after application.

Rainfall was not considered in this study as applications are typically made when the soil is dry enough for a ground spray rig to drive over the field, and applicators are typically conditioned to avoid rainfall when making applications of foliar-applied post-emergence herbicides. Additionally, the new dicamba formulations had labels that prevented applications within 24-h of an expected rainfall in 2017 and 2018. However, previous research on dicamba movement through the soil suggests rainfall could likely move the herbicide further into the soil column and away from the surface, thereby reducing the amount of dicamba available for volatility.[60]

Other variables identified in this study will be more difficult to address. For example, it is not clear how applicators will be able to prepare for wind speeds or air temperatures on the days following a dicamba application, especially given that previous research has shown dicamba can volatilize for at least 72 h after application.[27,54] Therefore, development of accurate forecasting weather models will likely be essential to increase the likelihood that dicamba applications remain on target.

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Off-target pesticide movement: a review of our current understanding of drift due to inversions and secondary movement

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Review

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Abstract

Pesticide drift has been a concern since the introduction of pesticides. Historical incidences with off-target movement of 2,4-D and dichlorodiphenyltrichloroethane (DDT) have increased our understanding of pesticide fate in the atmosphere following aerial application. More recent incidences with dicamba have brought to light gaps in our current understanding of aerial pesticide movement following ground application. In this paper, we review the current understanding of inversions and other weather and environmental factors that contribute to secondary pesticide movement and raise questions that need to be addressed. Factors that influence volatility and terminology associated with the atmosphere, such as cool air drainage, temperature inversions, and radiation cooling will be discussed. We also present literature that highlights the need to consider the role(s) of wind in secondary drift in addition to the role in physical drift. With increased awareness of pesticide movement and more herbicide-resistant traits available than ever before, it has become even more essential that we understand secondary movement of pesticides, recognize our gaps in understanding, and advance from what is currently unknown.

Introduction

Pesticide movement from intended targets onto unintended targets has been a concern as long as pesticides have been applied. The first report recognizing pesticides as air pollutants occurred in 1946 (Daines 1952). In 1953, authors of a *Stanford Law Review* article summarized the conflict of pesticide drift well: "Science has created weapons which are of inestimable value to many farmers, but which threaten the economic existence of others." (Stanford Law Review 1953).

Commercial introduction of crops with dicamba-resistant traits and subsequent off-target movement of dicamba herbicide is the most recent example of large-scale pesticide movement. However, pesticides moving off target in large quantities is not a novel concern, and additional examples, including those outlined below, have advanced our understanding and guided research on aerial pesticide movement.

Introduction of 2,4-D and Crop Dusting

The U.S. agriculture industry rapidly adopted the practice of applying pesticides via crop dusting in the early 1950s. Commercial introduction of 2,4-D; the return of newly unemployed, World War II-trained military pilots; and a surplus of military planes provided the opportunities for this expansion (Stanford Law Review 1953). It was common for crop dusters to apply pesticides in the early morning or after sundown to avoid physical drift associated with higher midday wind speeds (Stanford Law Review 1953). This practice likely resulted in pesticides being applied during inversion-like conditions. The increase in crop dusting applications resulted in an increase in legal pesticide drift cases, and in 1952–1953, nine crop dusting cases reached the appellate court (Akesson and Yates 1964; Stanford Law Review 1953).

The Grape-Growing Region of the Yakima Valley

Large-scale off-target movement of 2,4-D continued to be a problem into the next decades. The wheat and grape-growing regions of Yakima Valley in Washington state occur in close proximity, and by the 1960s, herbicide damage in the grape-growing region, resulting from applications of 2,4-D to wheat, was severe and widespread. Air sampling research conducted in the Yakima Valley region in the early 1970s indicated that 2,4-D had traveled approximately 16 km from wheat fields to vineyards and in sufficient quantities to injure grapes (Reisenger and Robinson 1976). It was during these observations that the term "air mass" damage was derived (Robinson and Fox 1978). "Air mass" damage referred to large areas where consistent herbicide injury symptoms appeared on the sensitive crop without a definable gradient and was speculated

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to be the result of a large, contaminated cloud passing through the area (Robinson and Fox 1978). The state began banning highly volatile 2,4-D formulations and enforcing cutoff dates in specific counties in the early 1970s (Reisenger and Robinson 1976; Robinson and Fox 1978).

Dichlorodiphenyltrichloroethane in the Atmosphere

Off-target movement of the highly persistent insecticide organochlorine dichlorodiphenyltrichloroethane (DDT) resulted in several research studies conducted in the 1980s. Results from air sampling research conducted aboard ships in the Arabian Sea, Indian Ocean, and north Atlantic Ocean indicated that DDT was 25 to 40 times more highly concentrated over waters in proximity to regions where the chemical was still used compared with areas where the chemical had been banned (Bidleman and Leonard 1982). Findings from Bidleman and Leonard's study combined with other research reviewed by Pimentel and Levitan (1986) led to the conclusion that atmospheric pesticide levels are a function of the location where application occurred, wind direction at application, subsequent movement of air masses containing pesticides, and atmospheric transport time.

Postemergence Dicamba Applications to Soybean and Cotton

The most recent off-target dicamba injury observations (Bish et al. 2019b; Bradley 2017a, 2017b; Steckel 2017) were unique in that applications could only be made by via ground sprayers. However, reported damage was still extensive (Figure 1) (Bish et al. 2019b; Bradley 2017b; Steckel 2017). In 2017, off-target movement of dicamba resulted in 2,708 dicamba-related injury investigations by state departments of agriculture (Figure 1; Oseland et al. 2020). During this same year, state extension weed scientists estimated that approximately 1.5 million ha of soybean were reported to be injured by dicamba in the United States (Bradley 2017b). Additional reports of injury to sensitive, nontarget vegetation were extensively documented throughout 2018, 2019, and 2020, especially in areas where adoption of soybean and cotton crops with the dicamba-resistant trait was highest (Bradley 2018; Hager 2019; Hartzler 2020a; Hartzler 2020b; Johnson and Ikley 2018; Steckel 2018, 2019; Zimmer et al. 2019; Zimmer and Johnson 2020). In a recent survey of state departments of agriculture posted on the Association of American Pesticide Control Officials (AAPCO) website, 151 dicamba-related cases were reported in Illinois, 116 in Minnesota, 102 in Missouri, 73 in Indiana, and 63 in Nebraska (AAPCO 2020). At least two surveys, including the AAPCO survey, noted that underreporting of dicamba injury to state departments of agriculture is common (AAPCO 2020; Bradley 2019). Based on these numbers and observations, it seems that the extent of off-target movement of dicamba that has occurred during this time period is more substantial than any chemical movement previously experienced in U.S. agricultural history.

Once off-target movement of dicamba began to appear in areas where adoption of crops with the dicamba-resistance traits was higher (i.e., southeastern Missouri, northeastern Arkansas, and western Tennessee), one observation that became immediately apparent was the extent of injury that occurred across entire fields of dicamba-sensitive soybean (Bradley 2017a; Hager 2017; Loux and Johnson 2017; Steckel 2017). Extension weed scientists and others who became involved in visiting these injured fields commonly reported a phenomenon in which essentially no discernable differences in the severity of the dicamba injury could be observed

Figure 1. Number of dicamba-related injury claims reported by state departments of agriculture in 2017, which was the first year dicamba could legally be applied over the top of dicamba-resistant soybean and cotton.

across entire fields of dicamba-sensitive soybean, regardless of the size of the injured field or proximity to the source of the suspected off-target movement. This phenomenon came to be known as the "landscape-level effect" and can likely be attributed to a combination of factors including 1) the extreme sensitivity of non-dicamba–resistant soybean to even the most minute quantities of dicamba (Hartzler 2020b; Solomon and Bradley 2014); 2) innate sensitivity of many other broadleaf species to dicamba (summarized in Table 1); and 3) the tendency of ground-based applications of dicamba to move into and within the atmosphere through factors that influence secondary movement.

Primary and Secondary Pesticide Movement

Pesticide drift is commonly described as either primary or secondary movement. Primary movement occurs when pesticides move off target at the time of application (Carlsen et al. 2006; Jones et al. 2019). The terms primary movement, primary drift, spray drift, and direct drift are often used interchangeably (Carlsen et al. 2006). This drift is the result of an active ingredient of a pesticide being transported away from the intended area after coming through the application spray nozzle, due to air flow at the time of application (Combellack 1982). Primary drift is not affected by the formulation of a pesticide's active ingredient (Bird et al. 1996; Carlsen et al. 2006). Many factors that result in primary movement are largely within an applicator's control (Bish and Bradley 2017; Vangessel and Johnson 2005). The scope of this review does not include analysis of these factors, which include nozzle type, droplet size, adjuvants, boom height, and sprayer speed.

Secondary movement occurs after herbicide application (Jones et al. 2019; Mueller 2015). Variables that affect secondary movement are much more difficult to control than those associated with primary movement and can be more difficult to characterize. Vapor drift is one form of secondary movement and is the result of chemicals volatilizing into the atmosphere. Wind erosion is another form and occurs when the pesticide is deposited on the intended surface but is moved back into the atmosphere with the soil particulate to which it is bound (Clay et al. 2001). Application method, size and chemical makeup of soil particulate, and herbicide dissipation rates affect secondary movement by wind erosion. In a comparison of residual herbicides incorporated into the soil and herbicides applied on undisturbed soils, the amount of

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herbicide collected on wind-erodible soil sediments was approximately 8% and 65%, respectively (Clay et al. 2001). Additionally, pesticides applied during stable atmospheric conditions can remain in the atmosphere and be readily available for secondary movement (Bish et al. 2019a). Although these conditions might seem like the perfect time to spray to minimize physical drift, they can result in high levels of off-target pesticide movement (Bird et al. 1996).

This review covers our current understanding of how pesticides move into or remain in the atmosphere and become available for secondary movement. Much of the review will encompass research specific to dicamba and 2,4-D. The extreme sensitivity of nonresistant plants, distinct injury symptoms, and historical volatility issues associated with these chemicals have resulted in a vast array of studies published in the literature. However, most of the factors discussed in this review will apply to pesticide movement in general.

Factors That Promote Volatility

Volatility allows chemicals to return to the atmosphere and become available for off-target transport. Synthetic auxin herbicides such as 2,4-D and dicamba are prone to volatility due to their chemical properties. A study conducted in Canada in the late 1970s suggested that vapor drift was the major contributor to off-target 2,4-D movement with an estimated 35% of high-volatile 2,4-D formulations volatilizing off of Canadian prairie soils (Maybank et al. 1978). Later in the 1970s, Behrens and Lueschen (1979) found that dicamba applied to corn could volatilize in sufficient quantities to injure soybean for up to 3 d following application and cause symptoms to sensitive soybean plants 60 m from the treated area. They also found that of four formulations tested, the acid form of dicamba was most susceptible to volatilize in laboratory settings, and that dicamba volatilized more readily from soybean and corn leaf surfaces than from soil (Behrens and Lueschen 1979).

The vapor pressure of synthetic auxin herbicides is in general higher relative to many other common herbicides, and subtle increases in air temperature can result in more rapid transition of molecules from liquid to vapor (Spencer and Cliath 1983). New 2,4-D and dicamba formulations have since been developed to reduce volatility in large part by reducing the vapor pressure of the chemical. Two of the most recently developed formulations of dicamba salts, the diglycolamine salt of dicamba combined with an acetic acid:acetate pH modifier (DGA-VG) and the *N,N*-bis-(3-aminopropyl)methylamine salt of dicamba (BAPMA), have much lower vapor pressures than dicamba acid (Hartzler 2017; Hemminghaus et al. 2017; MacInnes 2017; Werle et al. 2018). However, both formulations were detected for 72 h after application in air sampling studies conducted 20 cm above the soybean canopy indicating that detectable amounts of these new formulations were volatilizing over time (Bish et al. 2019a). Using bioassay plants, Jones et al (2018) showed that injury associated with secondary movement, indicative of volatility of BAPMA and DGA-VG applications, could be observed at 108 m and 180 m from the sites of application, respectively (Jones et al. 2018). These results provide more research support to field observations that lower-volatile dicamba formulations can volatilize in meaningful quantities.

Research on the most recent formulation of 2,4-D known as 2,4-D choline, the choline being a quaternary ammonium salt, has shown reduced volatility when tested in Georgia using cotton as bioassay plants (Sosnoskie et al. 2015). Potted cotton plants were placed outside of treated plots approximately 1 h after applications with three formulations of 2,4-D and removed at either 24 h or 48 h following application. Injury from the 2,4-D choline application was not detected further than 1.5 m from the site of application. Older formulations of 2,4-D ester and 2,4-D amine moved 48 m and 3 m from the treated sites, respectively (Sosnoskie et al. 2015). It is important to note that a complete understanding of 2,4-D choline volatility and secondary movement may not occur until 2,4-D resistant cotton and soybean are grown on a larger scale for concurrent years.

Additional factors that can influence volatility include a plant's ability to absorb the chemical, pH of the environment, and air temperature. The rate of chemical uptake affects how long the pesticide is available on the surface for volatilization. Uptake is influenced by epicuticle thickness of the leaf on which the droplet lands (Baker and Hunt 1981) and relative humidity at the surface of the leaf, which influences stomatal conductance (Pallas 1960). Legleiter et al. (2018) found that following applications of 2,4-D plus glyphosate with various nozzles and over four weed species, 2,4-D levels on the leaf surfaces were 4% to 16.6% of the initial levels at 24 h after application. Studies in the early 1970s showed that 40% of radiolabeled dicamba applied to wheat or Tartary buckwheat leaves remained on the leaves after 24 h (Chang and Vanden Born 1971). In 1993, research showed that surface residues of 2,4-D and dicamba on wheat plants was greatly reduced 24 h after application (Cessna 1993). We have preliminary data indicating that DGA-VG can be detected on soybean leaf surfaces 48 h after an application; however, we are unaware of any peer-reviewed literature on the half-lives of new dicamba formulations on leaf surfaces.

Dicamba is most likely to convert to the highly volatile dicamba acid as pH lowers to near 5 (Abraham 2018). Sources that can influence dicamba pH include spray tank solution pH and soil pH (Mueller and Steckel 2019a; Oseland et al. 2020). Other sources such as pH of morning dew on leaf surfaces are also likely. Mueller and Steckel found that adding glyphosate to the DGA-VG or BAPMA formulations of dicamba decreased spray tank formulation to a pH of near or below 5.0 depending on the carrier volume and starting pH of the water source (Mueller and Steckel 2019a). They went on to show that addition of glyphosate to DGA-VG increased the amount of dicamba detected compared with dicamba alone (Mueller and Steckel 2019b). Those findings were similar to ours, in which addition of glyphosate to a dicamba spray solution increased the amount of dicamba detected in the air from 4.45 ng m^{-3} to 8.45 ng m^{-3} (Bish et al. 2019a). More recently, we found that soil pH can affect the likelihood of dicamba volatilization (Oseland et al. 2020). In a series of binary logistic regression models developed to identify weather and environmental factors that improve the likelihood of dicamba applications remaining on target, we found that as soil pH increased, the likelihood of a successful application increased. Model results were validated with field studies, which showed that dicamba applied to soils when the pH was <6.8 was more likely to volatilize and move onto sensitive bioassay plants (Oseland et al. 2020). The significance of the pH of the soil surface, which is often more acidic than the entire layer of topsoil, has likely been underestimated in its role in dicamba movement, especially when early POST applications are made to vegetative soybean that have not yet canopied and a significant portion of the soil surface is exposed.

Mueller and Steckel (2019b) used humidomes to study the effects of temperature on volatility of the DGA-VG and DGA formulations. As temperature increased from 20 C to >30 C dicamba concentrations in the air following applications of either formulation also increased. When applications were made at air temperatures <20 C, differences in dicamba concentrations were not

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Table 1. Select literature on sensitivity of species to dicamba and/or 2,4-D arranged by year published from oldest to newest.

Plant species	Herbicide(s)	Reference	Brief Summary
Alfalfa	Multiple including 2,4-D	Al-Khatib et al. (1992a)	2,4-D drift can result in injury following multiple alfalfa cuttings unlike other herbicides tested.
Sweet cherry	Multiple including 2,4-D and 2,4-D + glyphosate	Al-Khatib et al. (1992b)	2,4-D applied at 1/3 the labeled rate caused visible injury, restricted growth and leaf area on sweet cherry trees.
Wine grape	Multiple including 2,4-D and 2,4-D + glyphosate	Al-Khatib et al. (1993)	2,4-D applied at 1/100th the labeled rate resulted in injury to established Lemberger grape that was still visible 120 d after treatment.
Tomato	Glyphosate and dicamba	Kruger et al. (2012)	Dicamba applied at 2.3 g ae ha^{-1} to vegetative stage tomato resulted in 5% marketable fruit loss. It took 21.2 g ae ha^{-1} of glyphosate to result in a similar effect.
Soybean	Multiple including 2,4-D and dicamba	Solomon and Bradley (2014)	Low rates of synthetic auxin herbicides applied to sensitive soybean cause different levels of injury and yield loss depending on the herbicide. Dicamba applications to R2 soybean resulted in significant injury and yield loss. Similar rates of 2,4-D did not result in yield loss.
Soybean and cotton	2,4-D and dicamba	Egan et al. (2014)	Soybean is more sensitive to dicamba and relatively tolerant to 2,4-D when injured at the flowering stage. Cotton is highly sensitive to 2,4-D and more tolerant to dicamba at the vegetative stages.
Broccoli and bell pepper	2,4-D, dicamba, and 2,4-D plus glyphosate	Mohseni-Moghadam and Doohan (2015)	Total yield of broccoli and fruit maturity of bell pepper can be affected by driftable fractions of 2,4-D and dicamba.
Wine grapes	2,4-D, dicamba, glyphosate, 2,4-D + glyphosate, 2,4-D + dicamba	Mohseni-Moghadam et al. (2016)	Grape cultivars were most sensitive to 2,4-D, but also sensitive to dicamba. Glyphosate applications resulted in less than 10% visual injury across all rates tested.
Watermelon	2,4-D and dicamba	Culpepper et al. (2018)	The number of marketable watermelons was greatly reduced with treatments of dicamba or 2,4-D applied at 1/75th of the labeled rate and 20 or 40 d after planting.
Soybean	Dicamba	Kniss (2018)	A meta-analysis of 11 field studies indicated that a dicamba dose of 0.9 g ha^{-1} at the flowering stage results in 5% soybean yield loss.
Soybean	Dicamba	McCown et al. (2018)	Dicamba applications at 2.18 and 8.75 g ae ha^{-1} on V4, V6, R1, R2, and R3 sensitive soybean yielded less than soybean injured at later reproductive stages.
Ornamentals and Fruiting Trees	2,4-D and dicamba 2,4-D + glyphosate dicamba + glyphosate	Dintelmann et al. (2019)	Apple, red maple, peach, and pin oak are more sensitive to dicamba than 2,4-D. Black walnut, grapevine, and American elm are more sensitive to 2,4-D.
Common garden annuals	2,4-D and dicamba 2,4-D + glyphosate dicamba + glyphosate	Dintelmann et al. (2020)	Coleus was the most sensitive of eight species screened with driftable rates of dicamba or 2,4-D. Petunia exhibited the highest tolerance to 2,4-D or dicamba applied alone.

observed. We (Oseland et al. 2020) also found a relationship between minimum daily air temperature and the likelihood of a successful dicamba application. The lower the air temperature, the more likely the application was successful.

Although temperature is an essential component for volatilization of pesticides, other transport mechanisms must be responsible for movement of those pesticides once they are in the air. Statistics for our regression model with air temperature improved when maximum wind speed was included as a variable (Oseland et al. 2020). Additionally, a recent study by Soltani et al. (2020) showed that high temperature alone was insufficient to explain differences observed in secondary drift following dicamba DGA-VG applications made in Arkansas, Indiana, Michigan, Nebraska, Ontario, and Wisconsin.

Volatility is one mechanism that allows pesticides to move in the air. Regardless of the cause, once pesticides move into the air, they are available for transport. The following sections highlight the role of the atmosphere in transporting chemicals that have moved into the air, whether through volatility or applications made during stable conditions.

The Role of the Atmosphere in Pesticide Movement

Boundary Layer

The atmosphere has many layers, and as Fritz et al. (2008) pointed out, this is "the most uncontrollable factor requiring the applicator to make adjustments in real time". It is an important factor in distribution and deposition of pesticides (Majewski and Capel 1995). Within the atmosphere, the boundary layer is an essential component of primary and secondary pesticide transport given that pesticides are applied in this layer, and that volatilized, eroded, or suspended particles will first enter this layer (Majewski and Capel 1996). The boundary layer is within the troposphere, which is the lowest region of the atmosphere. Boundary layer depth fluctuates throughout the day and is defined as the portion of atmosphere that is directly influenced by the earth's surface (Hu 2015). Surface boundary layer depth is critical for vertical dispersion of airborne pesticides (Thistle 2004). A deeper boundary layer provides a greater opportunity for dispersion and dilution of pesticide droplets (Hu 2015). In the daytime and over land, the boundary layer can reach several kilometers above the earth's surface (Wyngaard 1990), whereas the same layer may reach only tens of meters above the earth's surface during evenings (Smith and Hunt 1978). Changes in depth of the boundary layer are largely impacted by radiative heating and the resulting turbulence or wind.

Radiative Heating and Cooling

Radiative heating and cooling are effects of solar radiation, and radiation cooling is associated with formation of temperature inversions and stable air masses. During daytime hours, radiative heating occurs as the sun emits energy that contacts the earth's surface and is either absorbed into the soil or reflected. Reflected energy heats the air nearest the surface. The warmed air becomes less dense and rises. Simultaneously, cooler air sinks to the earth's

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surface, is warmed, and begins rising. A convection cycle forms. Radiative heating is associated with the production of winds due to the warm and cool air masses mixing. This wind results in an increased depth of the surface boundary layer, which allows more efficient dispersion and dilution of pesticide droplets. Thus, radiative heating and the generated wind create amenable conditions for pesticide applications (if air temperatures and wind speeds do not exceed maximum label limits).

Radiation cooling occurs near sunset as the earth no longer emits energy and the air near the surface remains cool and dense and does not rise. A lack of mixing between warm and cool air results in a lack of thermal turbulence or vertical wind, which in turn results in a shallower surface boundary layer, which can impede pesticide droplet dispersion and dilution (Hu 2015). This process begins rapidly on clear evenings (Bish et al. 2019b). Radiation cooling can be impeded or inhibited on cloudy evenings, because clouds absorb radiation emitted from the surface and reflect it back to the surface, preventing heat waves from escaping into higher levels of the atmosphere (Thistle 2004). Radiation cooling typically results in nocturnal inversions and little to no wind on at least half of evenings during the growing season months (Hosler 1961; Bish et al. 2019b).

Wind: Turbulent Mixing Versus Horizontal Transport

We tend to group all categories of wind and causal mechanisms together and make generalized statements about monitoring wind speeds at the time of application. This allows for an easily conveyable message to applicators, who typically understand the risks of physical drift (Bish and Bradley 2017). Wind is clearly important in primary movement of pesticides; however, wind also plays a role in dispersing pesticide droplets in the atmosphere. A lack of wind can allow pesticides to remain in the air and move into atmospheric layers that are conducive for transport of the droplets (Thistle 2004; Fritz 2006). A series of publications from California in the 1960s and 1970s showed that aerially applied pesticides moved farther off target and in larger quantities when applications were made when winds were light to nonexistent compared to movement due to physical drift (Yates et al. 1966, 1967, 1976; Bird et al. 1996). Following introduction of the dicamba-resistant crop traits, dicamba injury claims were highest in regions with high concentrations of chemicals per area and geographies with lower wind speeds during the growing season (Bish et al. 2019a). These data provide support for the necessity of wind in reducing secondary movement.

Wind is the product of thermal or mechanical turbulence. Thermal turbulence occurs on most days as a result of radiative heating and effective vertical mixing of warm and cool air masses. Mechanical turbulence is caused by air and ground friction from irregular terrain and/or obstacles such as trees, buildings, terraces, etc. (Monteith and Unsworth 2013).

Increased thermal turbulence during the midday extends the depth of the surface boundary layer, increasing the likelihood of pesticide droplets to be diluted and dispersed. A 4-yr study conducted in the midwestern United States in the 1960s revealed drastic differences in wind mixing depths between midday and overnight conditions. Mixing depth typically ranged from 1,600 to 1,900 m above ground level (AGL) during afternoon hours of the growing season and typically shrunk to 300 to 500 m AGL during early morning (Holzworth 1967).

In the regression models we developed to identify predictors of successful dicamba applications, the best fit model (concordance = 0.7; $P = 0.03$) included air temperature on the day of application and maximum wind speed on the day of application and the day following application (Oseland et al. 2020). The likelihood that dicamba remained on the intended target increased with lower air temperatures and higher wind speeds (measured at 3.05 m) on the day of application. We concluded that the higher wind speeds resulted in conditions that were favorable for dispersion and dilution of droplets or fines suspended in the air at time of application. In the same study, lower wind speeds on the day following application resulted in increased likelihood that dicamba would remain on target. We speculated that increases in wind or turbulence on the day following application, which increased the likelihood of off-target observations, would result in the degradation of stable air masses or inverted conditions, and consequently allow any pesticide droplets trapped in stable air to move toward the surface and onto unintended plants (Oseland et al. 2020).

Stable Atmosphere

Applications erroneously made into stable air masses typically occur when applicators are working to avoid windy conditions, as in the crop dusting examples mentioned from the 1950s (Bish and Bradley 2017; Stanford Law Review 1953). However, previously described mechanisms such as volatility and wind erosion can also move pesticides into stable air after pesticide application (Pionke and Chesters 1973).

We recently found a relationship between atmospheric stability and the amount of dicamba in the air for the first 8 h after application (Bish et al. 2019a). We found that as air became more stable, the average amount of dicamba detected in the air increased. Air temperature (AT) was monitored at 305 cm and 46 cm AGL. The larger the temperature difference (ΔT) of AT at 305 cm minus the AT at 46 cm (AT 305 – AT 46), the more stable the air. Regression models indicated that for each 1 degree increase in ΔT, detectable dicamba in the air increased by 1.67 ng m^{-3} over the first 8 h after the application. This is similar to findings reported by Miller et al. (2000) in which higher concentrations of malathion were collected in more stable compared to unstable conditions.

Topography, ground cover, wind, and nearby bodies of water can all affect the stability of the air. In the studies on 2,4-D movement in the Yakima Valley, "high concentration days" were associated with stable conditions that resulted from the formation of a leeside trough, increased cloud cover, and lack of radiative turbulence. High concentration was defined as 2,4-D levels in the air being detected at ≥ 1 μg m^{-3} on a given day (Reisner and Robinson 1976).

Two more common conditions associated with the formation of a stable atmosphere and subsequent off-target pesticide movement are temperature inversions and cool air drainage.

Temperature Inversions

The temperature profile on a typical day has the warmest air temperature nearest the earth and cooler temperatures farther from the surface. This temperature profile is due to radiative heating, and typically creates an unstable atmospheric condition due to the generated wind, which can make it conducive for pesticide applications. Inversions occur when this temperature profile shifts so that cooler air temperatures are nearest the earth's surface. Dense, cooler air remains near the earth's surface, so there is no mixing of air masses and little to no vertical winds, and the result is a stable atmosphere. This condition is not conducive for pesticide applications because droplets can remain suspended in the

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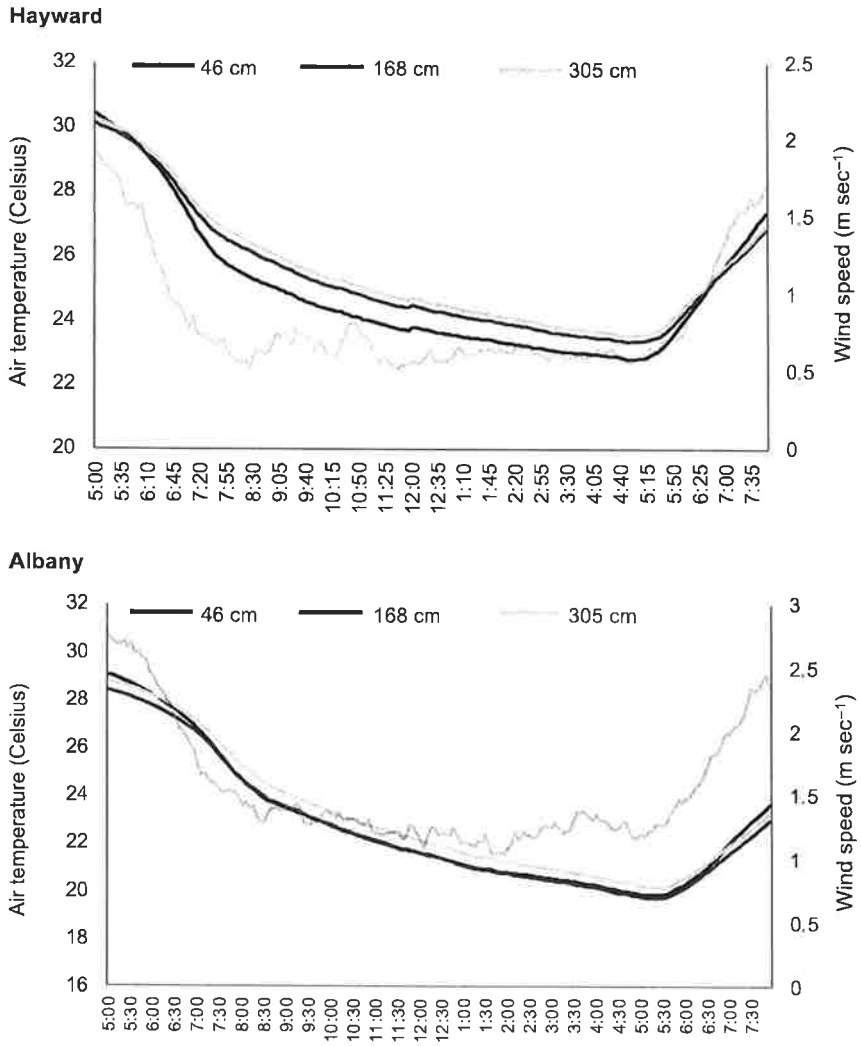

Figure 2. The 3-yr average July air temperature (primary axis) and wind speed measurements (secondary axis and light blue line) are graphed for two locations in Missouri. The air temperatures show differences in inversion depth. Inverted air temperatures at the Hayward site extended from 46 cm up to 305 cm above ground level (AGL) and likely higher. Inverted air temperatures at the Albany site extended from 168 cm AGL up to 305 cm and likely higher. Differences in the height AGL that inversions formed is likely influenced by the different topographies.

stable air mass. Additionally, inverted air temperatures and the subsequent stable air are likely involved in endo-loss and movement of volatilized droplets. Inversions can be caused by many factors including subsidence (sinking air that becomes warmer in temperature than the air below), radiative cooling, and frontal system collision (a cooler air mass that undercuts a warm air mass). Nocturnal inversions induced by radiative cooling are common in agricultural regions in the United States (Baker et al. 1969; Bish et al. 2019b; Bish and Bradley 2019b; Holzworth 1967; Holser 1961). However, inversions can occur during daytime hours as well. Fritz and colleagues (2008) used temperature probes at 0.5, 2.5, 5, 7.5, and 10 m AGL to monitor inversions at two sites in Texas: a coastal location and a land-locked location. They found daytime inversions were less persistent and had shorter durations than nocturnal inversions but did occur on >15% of days that were monitored, with 19% and 36% of days monitored having inversions between 11:00 A.M. and 4:00 P.M. (Fritz et al. 2008). Morning and midday inversions between the heights of 2.5 and 10 m AGL lasted approximately 30 min on average and were approximately half as intense as evening inversions.

Depth and strength of inversion conditions are influenced by field surroundings. Figure 2 shows a 3-yr average of evening air temperatures and wind speeds in July for two locations in Missouri. Average inversions occurred from 46 cm to 305 cm AGL at the Hayward location. (Inverted conditions may have extended beyond 305 cm AGL; however, this was the highest point of measurement.) The low point of inversions at the Albany location was commonly 168 cm AGL. Topography likely functions in the differences observed between these locations (Bish et al. 2019b). The meteorological station at Albany sits in a low-lying area adjacent to a slight upward slope. This slope may serve as an obstruction and result in mechanical turbulence as air moves over the slope. Generated wind could impede the depth of the inversions.

Degradation of the inversion system allows pesticide droplets that were suspended in the stable air mass to deposit back to the earth's surface. Typically, nocturnal inversions degrade near sunrise as radiative warming begins and thermal turbulence increases. However, topography and field obstructions that result in mechanical turbulence can also result in premature dissipation of inversions. In the 3-yr inversion analysis, we found more

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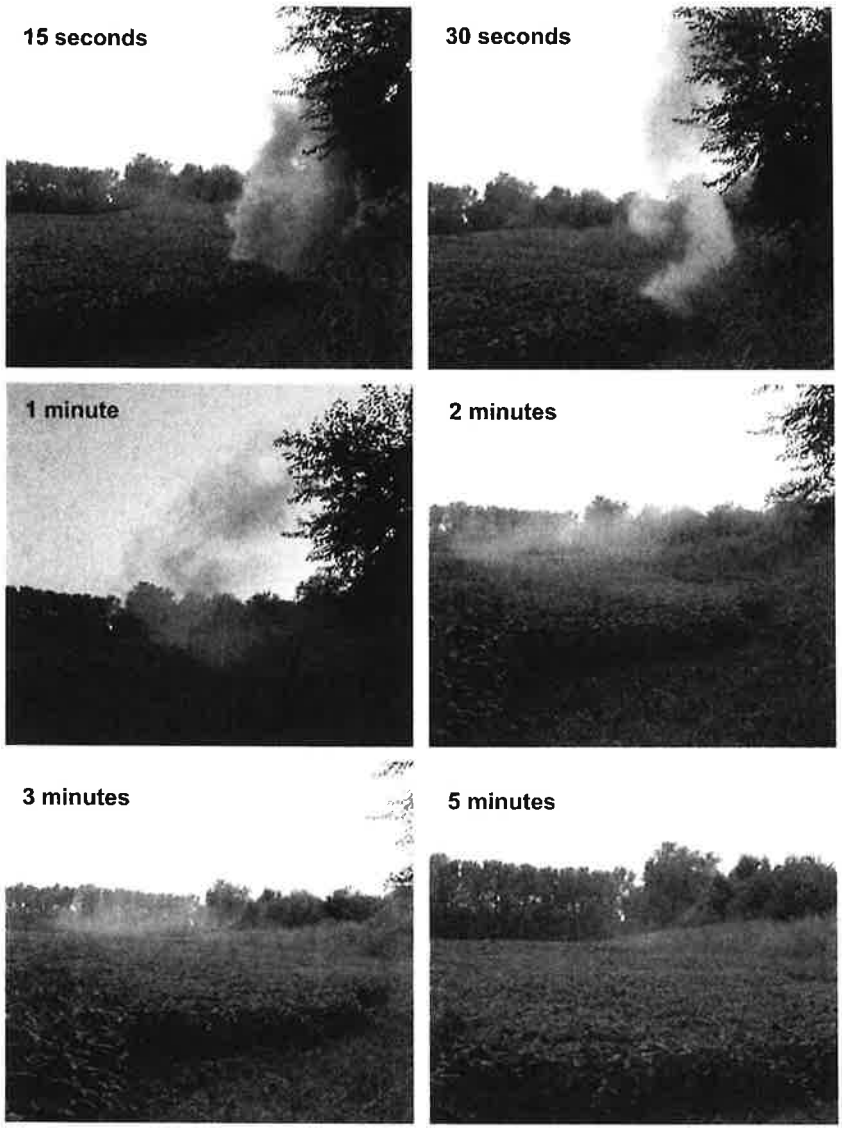

Figure 3. A time-lapse series following the release of a smoke bomb at a soybean field adjacent to a pipe river. The river is on the other side of the distal tree line. The visible plume first moved vertically. As the plume reached the height of the tree line, between 30 s and 1 min, it began sinking, which is likely the result of being incorporated into a cooler air stream. The particulate did not disperse but moved as a dust cloud to the low point in the field, where it remained visible for 3 min. (These particular smoke bombs, Enola Gaye smoke grenades, are designed to emit an observable plume for 90 s.)

variation in duration length and dissipation times of inversions at Albany compared to the other two locations (Bish et al. 2019b). Inversions at the Albany location were typically much shorter and more variable, whereas inversions at the Hayward location typically persisted through the evening, lasting on average 12 h. At the Columbia, Missouri location, inversions lasted approximately 11 h in April and became shorter as evenings grew longer, averaging approximately 7 h in length by July. Disruption of inversions occurred between 5:00 A.M. and 7:00 A.M. consistently at Hayward and Columbia, whereas this varied substantially at Albany.

Cool Air Drainage

Masses of cool air will not rise in altitude due to density; however, they can be moved by gentle horizontal winds. Sometimes this movement is associated with or labeled as cool air drainage. When moved, a dense cooler air mass sinks to the lowest area, thus it drains. Cool air drainage is most pronounced at the bases of mountains, valleys, or river bottoms. Frequently, bystanders can often feel the cooler air move through when standing in low-lying regions at or near sunset. General weather conditions favorable for drainage winds in valleys include clear skies, low humidity, light <5 m s^{-1}, and ambient winds (Barr and Orgill 1989).

Drainage also occurs in open areas with mild terrain and/or limited shelters, such as many agricultural fields (Barr and Orgill 1989). In these locations, development of the cool air mass and subsequent drainage is frequently driven by radiative cooling and inversion formation. This is one reason that a pesticide applied during inversion conditions can result in movement several miles away as suspended droplets travel in the stable air mass as part of a cool air drainage system.

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Figure 4. A few meters into the nearest tree line from where the smoke bomb was released (Figure 3), sporadic damage that resembled dicamba and glyphosate injury was observable in the trees. Red arrows point toward dicamba and glyphosate symptoms. (B) Enlarged image of injury resembling leaf cupping or leaf rolling, typical of dicamba. (C) Enlarged photograph of the generalized chlorosis and necrosis of the younger leaves associated with glyphosate injury.

Similar to inversion formation, the drainage strength, depth, and structure are influenced by many factors (Barr and Orgill 1989). Drainage flow on a downward slope is likely to be shallow in depth on much of the agricultural land in the United States given a lack of vertical elevation differences (McNider and Pielke 1984). However, even smaller disruptions to the topography, such as terraces, may restrict or influence the flow pattern of cool air drainage (Mahrt et al. 2001). In a study conducted in southern Kansas and on a terrain that varied in elevation from 450 to 475 m AGL, cool air drainage was observed during evenings. However, the flow was always weak, and the layer of cool air was typically thin (usually 3 m or less AGL). Flow was typically disrupted during the evening and would reform on some evenings, but not consistently (Mahrt et al. 2001).

Degradation of a drainage system is typically induced by radiative heating and the increased thermal turbulence needed to disrupt the stable air mass. However, mechanical turbulence can also impede drainage. Examples of vertical obstructions in open fields that may generate mechanical turbulence include tree lines and buildings. In the Kansas study, cool air drainage occurred even on evenings when the opposing wind was moderate, moving 10 m s^{-1} at 60 m above ground, which would equate to approximately 1.4 m s^{-1} at 1 m above the ground (Mahrt et al. 2001; Oseland et al. 2020). It is possible that in agricultural lands with gentle side slopes and strong stratifications of cool air formation in the evening, a shallow drainage system would persist even in moderate winds (Mahrt et al. 2001). Gentle slopes may be beneficial in that they can act as a barrier for pesticide movement from the field during drainage conditions if the depth of the cool air drainage is shallow.

Shallow drainage systems degrade rapidly and as they are disrupted, herbicide particles settle out of the atmosphere. In relatively flat areas, observations of pesticide injury may be restricted to the lowest lying areas of the field. Drainage systems along rivers tends to be more pronounced due to more pronounced

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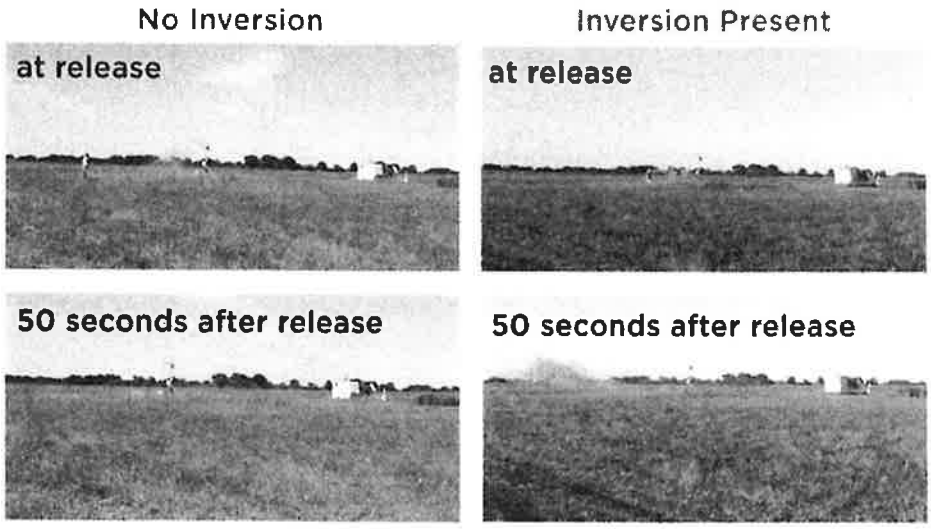

Figure 5. Smoke bombs released at the same site in Columbia, Missouri (2017), during unstable, noninversion conditions (approximately 4:00 P.M.) and inversion conditions (approximately 7:30 P.M.). The smoke plume has dissipated by 50 s following release during noninversion conditions while the plume remained intact during stable conditions.

elevation differences. The larger depth (height) of such a drainage system requires more turbulence or stronger vertical winds to disrupt. Consequently, drainage systems in fields along river bottoms can persist longer and move farther, which provides an opportunity for pesticides to be transported over long distances.

Figure 3 is a time-lapse series following the release of a smoke bomb at a soybean field adjacent to a pipe river in Missouri. The river is on the other side of the distal tree line. The smoke plume moved vertically for the first 30 s, indicating a ground level inversion had not yet formed. However, as the plume reached the height similar to the top of the tree line, between 30 s and 1 min, it did not continue to dissipate but began sinking, indicative that it was part of a cooler air stream. The particulate did not disperse but moved as a dust cloud to the low point in the field, where it was visible for 3 min before dissipating. In the study by Oseland et al. (2020), we found that applications made near large bodies of water were more likely to move off target. This may be in part due to cool air drainage.

Removal of Pesticides from the Atmosphere

Pesticides suspended in the atmosphere are removed via five mechanisms: degradation of a stable air mass or drainage system, dry deposition, wet deposition, chemical degradation, and photochemical degradation (Glotfelty and Caro 1975). Virtually all airborne particles undergo one or a combination of these factors for their removal from the atmosphere.

In the same field where a smoke bomb was released to illustrate cool air drainage, and a few meters into the nearest tree line, sporadic damage that resembled dicamba and glyphosate injury (Figure 4) was observable at heights similar to those reached by the smoke plume in Figure 3. One possible explanation for the observed injury is that the pesticides moved into the air following application and in a similar fashion to the initial vertical rising of the smoke bomb. Another possibility is that the pesticides may have volatilized into the air. Regardless of how the pesticide moved into the air, horizontal winds likely moved the chemicals into the tree line where the leaf surfaces could have served as an obstruction to the horizontal air movement, allowing dry deposition of the chemical.

Dry deposition is the settling of pesticides that have sorbed onto suspended particulate matter in the atmosphere (Majewski and Capel 1996). Wet deposition occurs when particles are scavenged by raindrops and redistributed to the earth's surface. This is a rapid and predominant pathway for removal of pesticides from the atmosphere (Glotfelty and Caro 1975; Majewski and Capel 1996). Bulk deposition samplers are a common method of collecting wet and dry deposition samples for downstream analysis (Messing et al. 2014; Waite et al. 1995, 1999). Studies using either wet deposition or bulk deposition have been used to identify potential relationships between concentrations of pesticides removed from the atmosphere and usage of those pesticides within that region (Farenhorst et al. 2015; Goolsby et al. 1997; Thurman and Cromwell 2000; Waite et al. 2002, 2004). In a study of rainfall samples collected from 81 sites in the Midwest and Northeast United States in 1990 and 1991, Goolsby et al. (1997) found that peak concentrations of atrazine and alachlor were detected in May through July and deposition was highest in the corn belt and decreased with distance removed from the corn belt. Waite et al. (2004) found a similar relationship between dicamba and bulk deposition in Canadian prairies, in which dicamba concentrations peaked in June at ranges from 0.5 ng m^{-2} d^{-1} to approximately 1.7 ng m^{-2} d^{-1} depending on location and year. However, research is still needed to determine what concentration of dicamba (or any pesticide of interest) must be deposited from the atmosphere to result in injury of sensitive species.

Pesticide degradation is another mechanism that can act to remove chemicals from the atmosphere. Glotfley (1978) concluded that compounds able to strongly absorb solar wavelengths may be more likely to rapidly decompose. Factors that control the atmospheric half-life of a pesticide are difficult to study but likely important in understanding why some pesticides are more persistent in the atmosphere while others are not.

Practical Applications

Elaborate and extensive studies have been and continue being conducted on physical drift of pesticides (Alves 2017; Carlson et al. 2006;

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Johnson et al. 2006; Vangessel 2005; Vieira et al. 2020). Producers and agricultural professionals have readily adopted the outcome(s) from many of those findings whether it be nozzle size, drift reduction agents, and so on (Bish and Bradley 2017). To achieve similar results with regards to secondary movement of pesticides, producers and agricultural professionals will need more education on secondary pesticide movement and new best management practices and tools to adopt. The concepts of cool air drainage and inversion can easily be demonstrated with smoke bombs (Figures 3 and 5) and/or liquid nitrogen, which can provide a good example of cool air sinking and moving. Applicators need to understand that topography and obstructions in fields will influence formation of stable air masses. An inversion may be occurring in one field and not yet formed in a nearby field (Bish and Bradley 2019b). Inversion forecasting tools continue to be developed. However, developing accurate tools that predict inversions near the ground, reliably and across multiple topographies is a difficult task (Bish et al. 2019b).

From a research perspective, more consideration needs to be given to all of the potential effects of wind. Measuring wind speed at boom height at the time of application seems acceptable for concerns about physical drift. However, with regard to secondary transport of pesticides, is there a height about ground level for which wind speeds can be measured and used to predict the likelihood of an application remaining on target?

The U.S. Environmental Protection Agency published a study in 2006 showing that some agricultural areas pose higher risks for off-target pesticide movement (Pfleeger 2006). The percent of land in agriculture, diversity of crops, rates of herbicide use in a given area, and frequency of high winds were all factors that affected the risks of physical drift to nearby sensitive species (Pfleeger 2006). Perhaps a similar study is warranted that considers the effects of a lack of wind on secondary pesticide movement.

With increased public awareness of pesticides, the release of multiple herbicide-resistant traits, and concerns over environmental fate, it is essential we not become complacent in our assumptions about secondary movement but advance our understanding above what is currently known.

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EXHIBIT NO. 11

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

Inversion Climatology in High-Production Agricultural Regions of Missouri and Implications for Pesticide Applications

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ABSTRACT

Most pesticides applied in the United States have labels that include language prohibiting application during temperature inversions. This restriction, which is well known and is followed by aerial pesticide applicators, has more recently become a focus for ground pesticide applicators. This is partially due to the recent introduction of genetically engineered soybean and cotton with tolerance to dicamba herbicide. Dicamba has been utilized for more than 50 years to control weeds in grain crops, such as corn. In 2017, dicamba was approved for use in dicamba-tolerant soybean and cotton. In 2017 and 2018, dicamba movement onto nontarget plants was substantial. As based on patterns of injury to nontolerant crops and time of applications, some of which occurred during the evening, inversions were likely contributors to off-target movement. Historically, most research on surface temperature inversions and pesticides focused on aerial applications. Research presented here focused on development of inversion profiles at atmospheric heights relevant to ground applications, which typically occur 46–107 cm above ground level (AGL). During the 2015–17 soybean growing seasons, data were collected at three heights AGL (46, 168, and 305 cm) in three soybean-producing regions of Missouri to characterize inversions. Over 600 inversions were characterized; all were nocturnal in nature. Inversions typically lasted overnight at two locations; duration varied at the third. The largest temperature difference recorded was 6°C. This research has resulted in real-time inversion monitoring that is available online to applicators (http://agebb.missouri.edu/weather/realTime/maps/index.php#temp_inversion), and the data generated can be utilized to improve accuracy of low-level inversion forecasting models.

1. Introduction

Most pesticides applied in the United States have labels that include language prohibiting applications during surface temperature inversions. Similar to challenges associated with pollution dispersion, valley atmosphere transport, and plumes from forest fires, inversions are likely to impact dispersion of pesticide droplets during application (Allwine et al. 1997; Ferguson et al. 2003; Finn et al. 2008; Enz et al. 2017; Janhall 2015). Much of the previous research pertaining to the influence of surface temperature inversions on agriculture crop production in the United States has been focused at heights relevant to aerial pesticide applications, which occur between 2.4 and 3.7 m above the intended targets (Bird et al. 1996; https://pesticidestewardship.org/pesticide-drift/aerial-application/). However, in the last three years, information regarding inversions relevant to ground pesticide applications, which typically occur at heights of approximately 46–107 cm above targets, has gained interest in the agriculture community of the Midwestern and midsouthern United States. This interest has been driven primarily by applications of dicamba herbicide

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and subsequent movement of the herbicide from target plants to unintended, sensitive plants.

Dicamba was first legally utilized in soybean and cotton in the United States in 2017 following the commercial introduction of soybean and cotton genetically engineered to tolerate the herbicide (Behrens et al. 2007). Labels prohibit aerial application of dicamba to these crops (EPA 2017a,b). The chemical is unique in that the dosage required to injure sensitive plants is much lower than other commonly used herbicides (Al-Khatib et al. 1993; Al-Khatib and Peterson 1999; Behrens et al. 2007; Everitt and Keeling 2009; Solomon and Bradley 2014). Thus it stands to reason that a much lower volume of dicamba herbicide suspended during an inversion could result in injury to sensitive plants when compared with the volume that would be required of other commonly used herbicides. Unfortunately, in 2017 and 2018 widespread issues of dicamba movement and injury to nontarget plants were reported in high soybean production areas of the United States. Collectively, state departments of agriculture reported over 4000 dicamba-related investigations in the two years (Bradley 2017a, 2018). In Missouri alone, the number of dicamba-related investigations conducted in 2017 by the Missouri Department of Agriculture (MDA) was an increase of over 700% relative to the usual total number of chemical complaints filed with MDA annually (MDA staff 2017, personal communication). Similar situations occurred in Arkansas, Indiana, Illinois, and Tennessee during the 2017 and 2018 growing seasons.

Many factors were thought to contribute to off-target dicamba movement. From patterns of injury to nontolerant crops, a subset of the injury resembled physical drift, in which injury symptoms were more severe on one side of the field nearest dicamba application and lessened across the field as one moves farther from the source (Akesson and Yates 1964; Jones et al. 2019). Physical drift has been well characterized (Yates et al. 1967; Alves et al. 2017; Thistle et al. 2017), and both aerial and ground pesticide applicators have familiarity with causes of physical drift such as applications made during windy conditions, use of the wrong types of spray nozzles, and omission of a drift-reduction agent (VanGessel and Johnson 2005; Pfleeger et al. 2006; Creech et al. 2015; Bish and Bradley 2017). However, in some dicamba-injured fields, the pattern of injury was inconsistent with physical drift. Fields that were not sprayed with dicamba had consistent dicamba-injury symptoms across the entire area. Investigations into the timing of dicamba applications suggested that many applications were conducted in evening hours, when wind speeds were reduced and less problematic for physical drift concerns. Spraying dicamba at night to avoid high wind speeds, a general lack of understanding about temperature inversions or conditions associated with inversions, and dicamba-injury patterns in some fields suggest that spraying dicamba during inversion conditions was likely one contributor to off-target movement (Bish and Bradley 2017; Bradley 2017b).

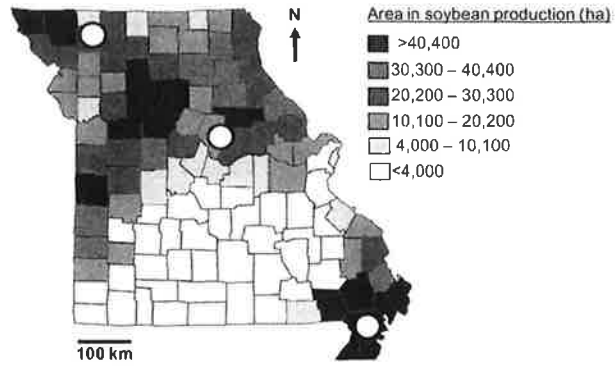

FIG. 1. Missouri soybean production by county: map of harvested soybean area from Missouri Agriculture Statistics Service data. The white circles indicate sites that were utilized for inversion monitoring over the 3-yr study.

Much research has been conducted to understand nocturnal inversions in the continental, United States. Some of the initial studies carried out to characterize frequencies and duration of inversions in the Midwestern United States utilized historical radiosonde data or real-time air temperature data to determine frequencies and durations of inversions (Hosler 1961; Baker et al. 1969; Holzworth 1967). Results from both of these studies indicated that nocturnal inversions were common in the Midwestern United States and the findings from Baker et al. (1969) revealed the number of inversions was dependent on what height above ground level (AGL) the air temperatures were being recorded (Baker et al. 1969). More recent inversion studies have focused on characterizing conditions associated with formation and dissipation of the nocturnal boundary layer (NBL; Stull 1988). Locations and dates utilized for these types of studies were selected to maximize the number of intensive observation periods (IOPs) for data collection, analysis, and NBL characterization. The CASES-99 study was conducted in southeastern Kansas in October of 1999 and included instrumentation or expertise from 31 laboratories, which resulted in substantial amounts of data that have continued to be mined (Poulos et al. 2002; Sun et al. 2012; Van de Wiel et al. 2017). One preliminary finding from CASES-99 was the observation that temperature fluctuations in short vertical distances occur frequently in the NBL. This observation on temperature fluctuations, combined with Baker et al.'s early observation of variation in inversion frequency depending on height AGL,

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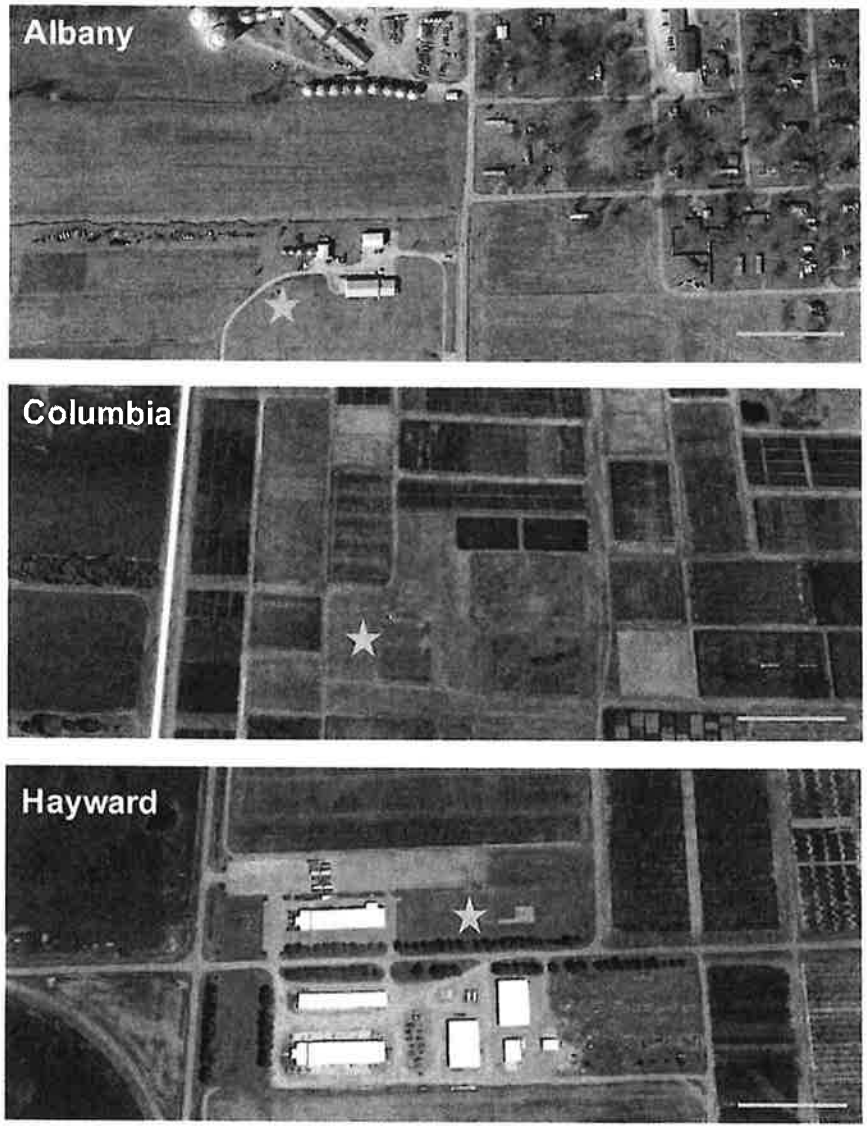

FIG. 2. Topography and points of possible obstruction at each location. The gold bar in the bottom-right corners represents 100 m. The gold star marks the location of the weather station. (The maps were generated using Google Earth.)

provides support for the need to investigate inversions at heights that would be relevant to ground pesticide applications (Baker et al. 1969).

Variations in microclimates should also be considered when studying inversions and ground pesticide applications. Many of the cropping areas in the Midwestern and midsouthern United States have been established in large and mostly open regions (USDA 1981). However, there are differences in topography, physical wind barriers, and elevation that may vary from region to region and influence formation of the NBL. The extensive Oklahoma Mesonet system has been able to capture one example of this by recording inversions at atmospheric heights of 1.5 and 9 m at 100 locations within the state (Hunt et al. 2007; McPherson et al. 2007). The El Reno Oklahoma Mesonet site (ELRE) has flat and open ground and minimal obstructions, and as a result of that topography it has unexpectedly registered some of the strongest inversions in the network. Further investigation led to the discovery that more rapid in situ cooling of the 1.5-m air temperature than the 9-m air temperature was the difference when compared with other stations (Hunt et al. 2007).

The objective of this work is to build upon the previous research pertaining to temperature inversions in the Midwest cropping region by characterizing inversions at heights relevant to ground pesticide applicators within soybean-growing geographies. The study was

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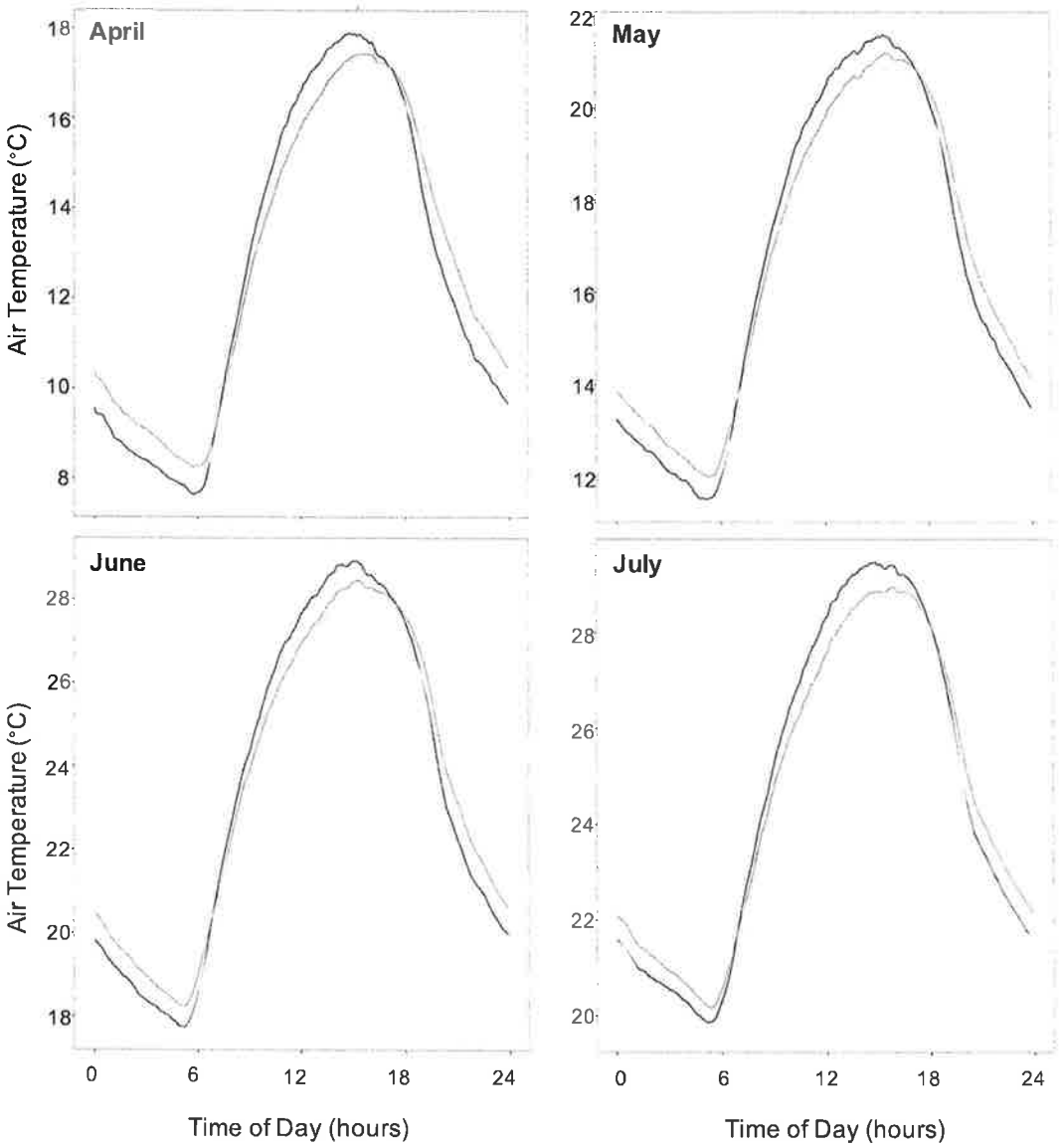

FIG. 3. Daily air temperature trends in Albany from 2015 to 2017 show that inverted temperatures are typical during the evenings in the growing season. Black, gold, and gray lines indicate the temperature at 46, 168, and 305 cm, respectively.

conducted in three distinct soybean-growing geographies in Missouri (Fig. 1), utilized real-time data measurements, and was conducted over the common soybean growing season months of April, May, June, and July from 2015 to 2017. Preliminary data generated from this research have been utilized by state governments in Missouri and Tennessee to restrict application timing for dicamba applications, have been incorporated into mandated training for dicamba applications, and have led to the establishment of a "Temperature Inversion Potential" (TIPs) website (http://agebb.missouri.edu/weather/realTime/maps/index.php#temp_inversion) for pesticide applicators to access real-time inversion potentials across Missouri. Long-term forecasting information would be most useful to agricultural producers for planning purposes, and low-level inversion forecasting "apps" have been difficult to develop given the interference of objects that can obstruct wind flow such as farm buildings, tree lines, and adjacent crops (Hall et al. 2015). The data from this study can be utilized to validate inversion forecasting apps that seek to assist U.S. crop producers with numerous agriculture-related challenges including pesticide applications, frost warnings for fruit trees, and gas emissions from livestock (Ribeiro et al. 2006; Stieger et al. 2015; Battany 2012).

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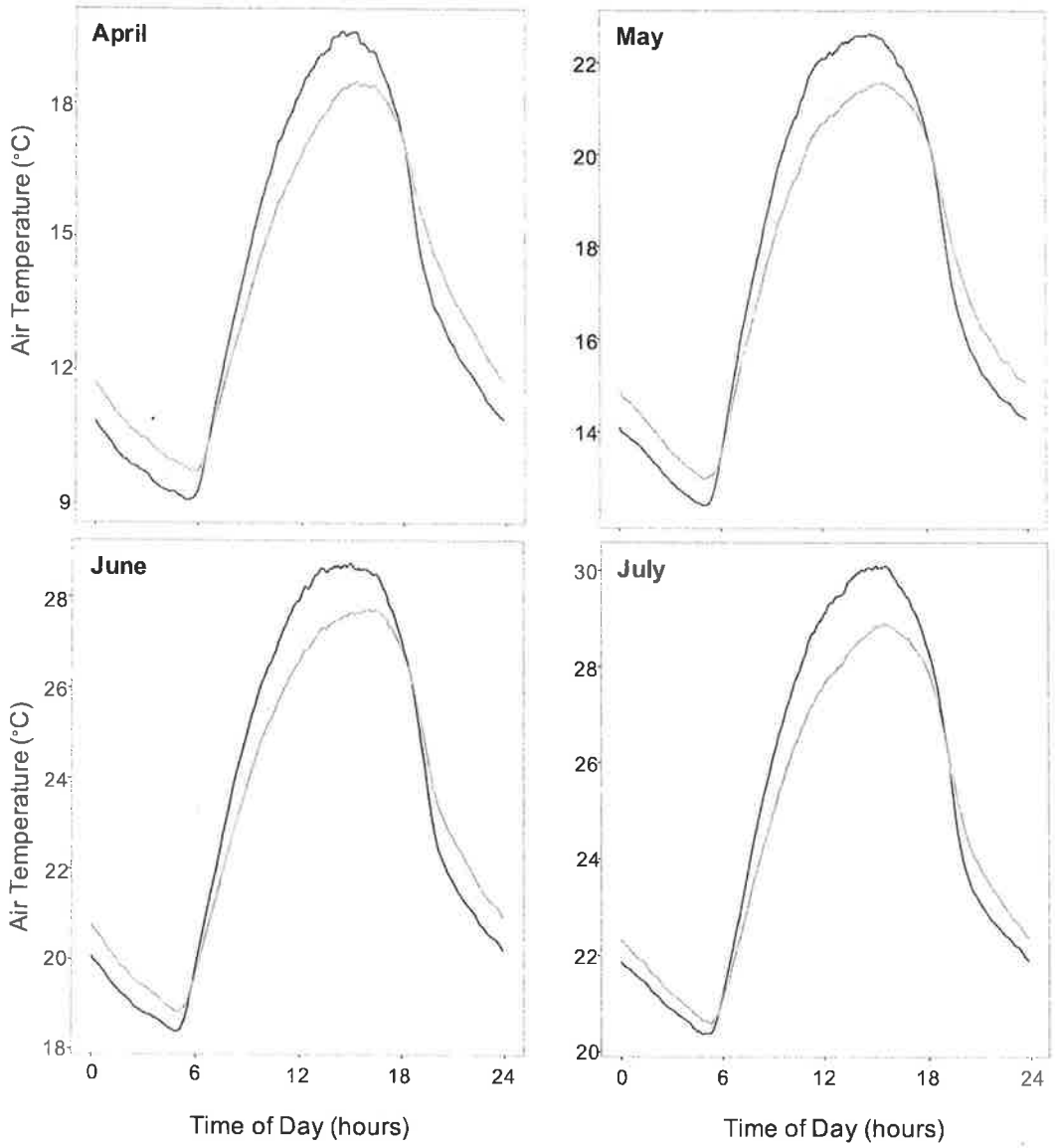

FIG. 4. As in Fig. 3, but in Columbia.

2. Data and methods

a. Site descriptions and equipping weather stations

Three currently existing research micrometeorological stations were utilized for this study. Of the 34 stations operated and maintained by the University of Missouri's Missouri Climate Center, three were selected given their locations in areas of high soybean production (Fig. 1) (USDA 2012). The Hundley Whaley Research Center (Fig. 2a), located in the northwestern portion of the state in Albany, Missouri, is within the northern plains region that covers approximately 32.3% of Missouri (Thom and Wilson 1983). The research center and weather station sit within a low-lying area at the bottom of a downward slope to the west of town, making the site subject to cold-air drainage. Prevailing winds at 305 cm AGL are from the south-southeast to south, and the nearest obstruction to wind from that direction was a building located 243 m due south (Massey and Guinan 2011; University of Missouri Commercial Agriculture 2019). This station was inactive because of a storm from 28 to 29 June 2017; therefore, no data are presented for those 24 h. The site is at an elevation of approximately 80 m. Bradford Research Center (Fig. 2b) is located centrally within the state near Columbia, Missouri, a region where the northern plains intersect the Ozark highlands (13.2% of the state) (Thom and Wilson 1983) with an elevation of approximately 270 m. Prevailing winds at 305 cm AGL were from the south, and the nearest obstruction to wind from that direction was a field plot that was left fallow or

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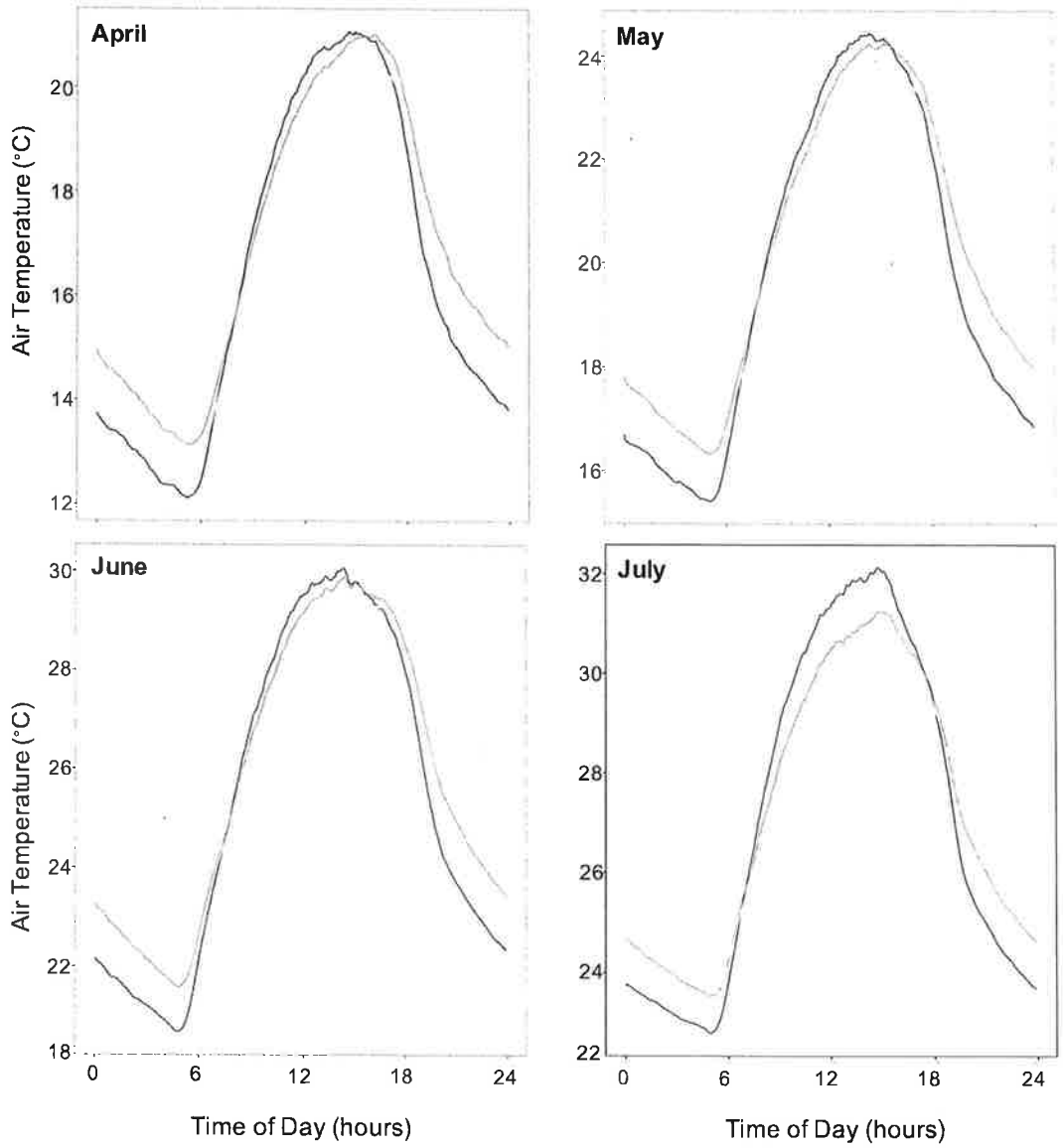

FIG. 5. As in Fig. 3, but in Hayward.

planted to corn, soybean, or wheat, depending on the year and was 194 m south-southeast (Massey and Guinan 2011; University of Missouri Commercial Agriculture 2019). The Lee Farm (Fig. 2c) is located near Hayward, Missouri, in the southeastern "bootheel" region of the state in the floodplains between the Mississippi and Saint Francis Rivers, and the land is distinctly flat with an elevation of 84 m. Prevailing winds at 305 cm AGL were from the south, and the nearest obstruction to wind from that direction was a tree line 76 m due south (Massey and Guinan 2011; University of Missouri Commercial Agriculture 2019). Although the bootheel region represents approximately 5.2% of the state's geography, this area of Missouri is a highly productive agricultural area, in terms of percent of land in crop production, according to the 2012 National Agricultural Census Data (Thom and Wilson 1983; USDA 2012).

All three stations are situated in grass alleys on the respective farms. The grass directly underneath the stations is controlled by mechanical and/or chemical removal. The soil at both Albany and Columbia sites is silt loam. Soil at the Hayward site is a mix of silt loam (78%), clay (16%), and sandy loam (6%) (USDA 2017). The Köppen climate classification zone for Albany and Columbia is Dfa (humid continental climate), and Hayward is classified as Cfa (humid subtropical climate) (Beck et al. 2018).

Each weather station was equipped with Vaisala/Campbell Scientific temperature/relative humidity probes (model HMP60-L1-PT) to monitor air and dewpoint

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TABLE 1. The number of evenings per growing season in which inversions formed and the average daily solar radiation during the same time period. The archived historical average hourly solar radiation data were utilized.

Site	Year	No. of evenings with inversions	Avg solar radiation ($W\,m^{-2}$)
Albany	2015	44	204
	2016	65	226
	2017	71	235
Columbia	2015	53	217[a]
	2016	69	231
	2017	76	236
Hayward	2015	60	211
	2016	74	225
	2017	64[b]	227

[a] Solar radiation data for April 2015 in Columbia were unavailable and were not included.

[b] Inversion data for June 2017 were omitted because of interference with the 46-cm air temperature sensor.

temperatures and relative humidity at 46, 168, and 305 cm above Earth's surface. Naturally aspirated, 12-plate Gill radiation shields (Campbell Scientific, Inc., model 41002) were installed to minimize the artificial heating effect during bright-sunlight, low-wind conditions. Cup anemometers were utilized to record wind speeds and directions at 305 cm above ground level. Stations were physically inspected each month and following storm events to ensure no obstructions by either interference or shading of the temperature probes and to confirm all instruments were in working order. Weather data were monitored routinely by studying air temperature, dewpoint, and wind charts on a weekly to semiweekly basis to identify anomalies that would suggest station error and need for maintenance. Obstructed data were removed from the analysis.

b. *Basic characterization of temperature inversions*

Real-time weather data were utilized for this study. The sampling rate for the probes was every three seconds. Three-second samples were combined into 5-min averages, and the 5-min averages were utilized for analysis. For this climatology, inversion events were classified as occurring if 1) the air temperatures at 305 cm > air temperatures at 46 cm and air temperatures at 168 cm > air temperatures at 46 cm, 2) temperatures remained inverted for ≥1 h in duration, and 3) the air temperature difference between 46 and 305 cm exceeded 1.3°C at some point during the event. The 1.3°C temperature difference ΔT spans the accuracy limitations of the temperature probes, which have a range of ±0.6°C. An event was counted as an inversion if ΔT exceeded 1.3°C temperature difference criteria at some point during the event, which is a similar approach to the one employed by Hosler (1961) in tallying inversion events. Lifted inversions (305 > 46 and 168 < 46 cm) were not considered in this analysis for practical reasons. Most ground pesticide applications occur between 46 and 168 cm. However, not all will occur at those heights, and the range of 46–305 cm should encompass all ground pesticide applications. The 5-min weather data corresponding to inversions were output into a Microsoft, Inc., Excel worksheet that could be utilized for further analysis in the software programs SAS, version 9.4, and R, version 3.5, "Joy in Playing," which was used to generate graphs and boxplots.

c. *Data analysis*

Data were analyzed utilizing difference procedures in SAS 9.4, including PROC MEANS and PROC CORR. The MEANS procedure allowed calculation of descriptive statistics and estimation of quantiles to describe inversions. Mean, mode, median, and quartiles were calculated for each month by site. The three years were combined for each month by site. SAS 9.4 analysis of time requires time to be in seconds. Before running the MEANS procedure data were converted using a modular arithmetic approach in which noon represented time 0 and midnight represented 43 200 s. After analysis, the data were then converted back to hour: minute format. The CORR procedure was used to produce Pearson and Spearman correlation coefficients and determine the strength of linear and monotonic relationships between the measured weather variables described in section 2a during inversion and noninversion conditions.

3. Results

a. *Basic characterization of low-level inversions*

April, May, June, and July are the predominant months in Missouri in which pesticide applications occur in soybean production. The mean air temperature for each height AGL was graphed for April, May, June, and July using the 5-min temperature averages over the course of 2015–17. The plotted averages revealed that generally, air temperatures at 46 cm were cooler than the 305-cm air temperature during evenings at each location (Figs. 3–5). The standard deviation for each air temperature is graphed for the same time periods (appendix A) and suggests that the probes at each height behaved similarly over the course of the study. Wind speeds also showed an expected trend of peaking at midday and decreasing near dusk, which would coincide with nocturnal inversions. The 2015–17 five-minute wind

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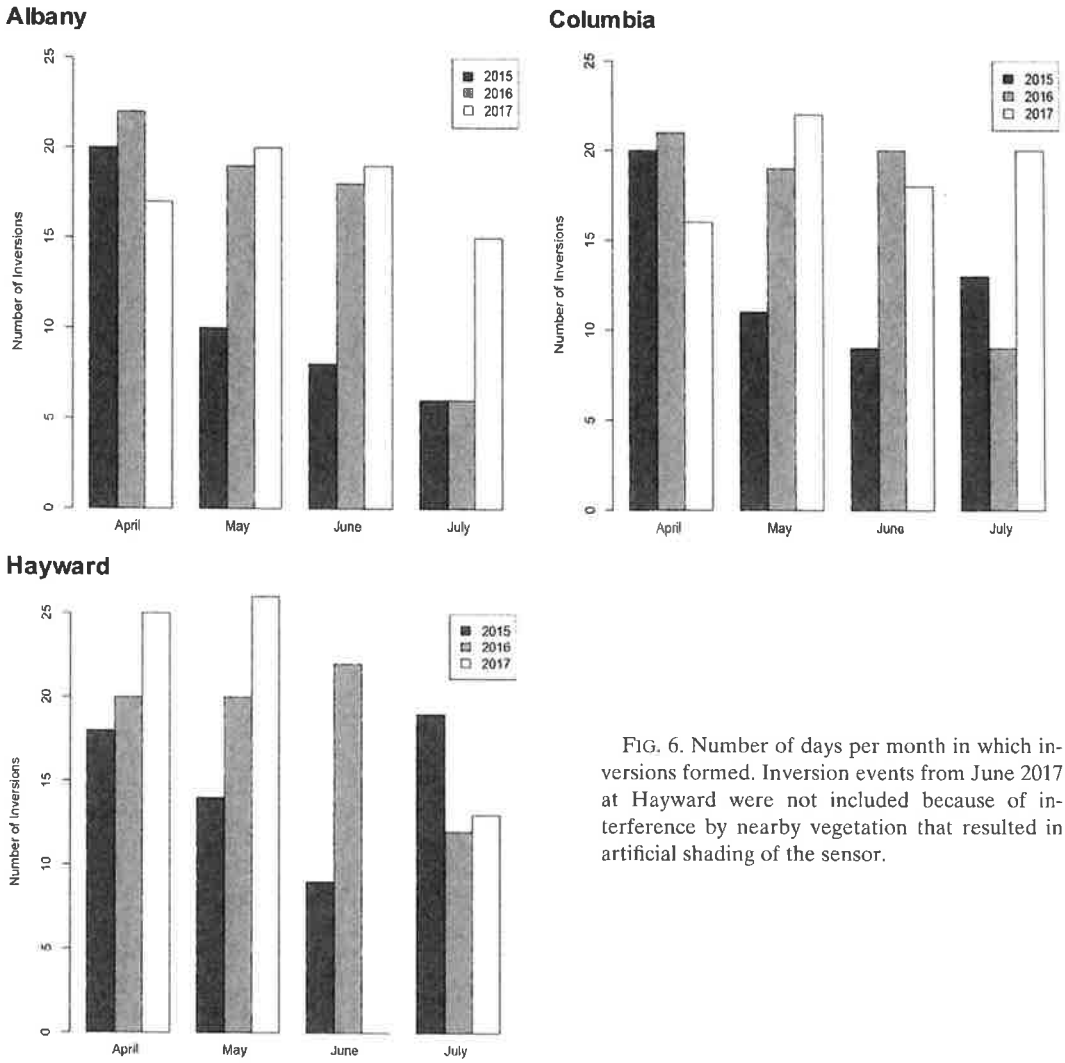

FIG. 6. Number of days per month in which inversions formed. Inversion events from June 2017 at Hayward were not included because of interference by nearby vegetation that resulted in artificial shading of the sensor.

speed averages were similar to the 10-yr, hourly, historical averages for each site (appendix A).

The air temperature trends at the Albany location differed from those at Columbia and Hayward for the months of June and July in that temperature at the 168-cm height was similar to the 46-cm air temperature during the overnight hours (Fig. 3). At Columbia and Hayward, the 46-cm air temperature trended lower than the 168-cm air temperature during the evenings across all months. One possible explanation for the differences observed at Albany is topography. The trend suggests that the cool stable airmass depth that forms as a result of inverted temperatures is greater at the Albany site when compared with the other two locations. The Albany station, unlike the other two, is in a low-lying area adjacent to an upward slope to the east and is subject to cool air drainage, which could account for a deeper pool of cool, stable air. During daytime hours, the air temperature at 168 cm was similar to 305 cm at both Albany and Hayward locations. The difference observed at Albany and Hayward relative to Columbia, in which day time air temperatures were coolest at 305 cm and warmest at 46 cm, could be due to topography or possibly that Albany and Hayward have more objects nearby that could obstruct or alter wind patterns and influence air temperatures (Fig. 2).

1) FREQUENCY OF INVERSION OCCURRENCES

Inversions were identified for each location, month, and year studied. However, data for June 2017 at Hayward were omitted from the study because of artificial shading of the 46-cm sensor by a nearby pollinator planting. All inversions detected during this study were nocturnal in nature. Collectively, fewer inversions occurred over the 2015 growing season relative to 2016 and 2017 at all sites (Table 1). One possible contributor to the differences observed

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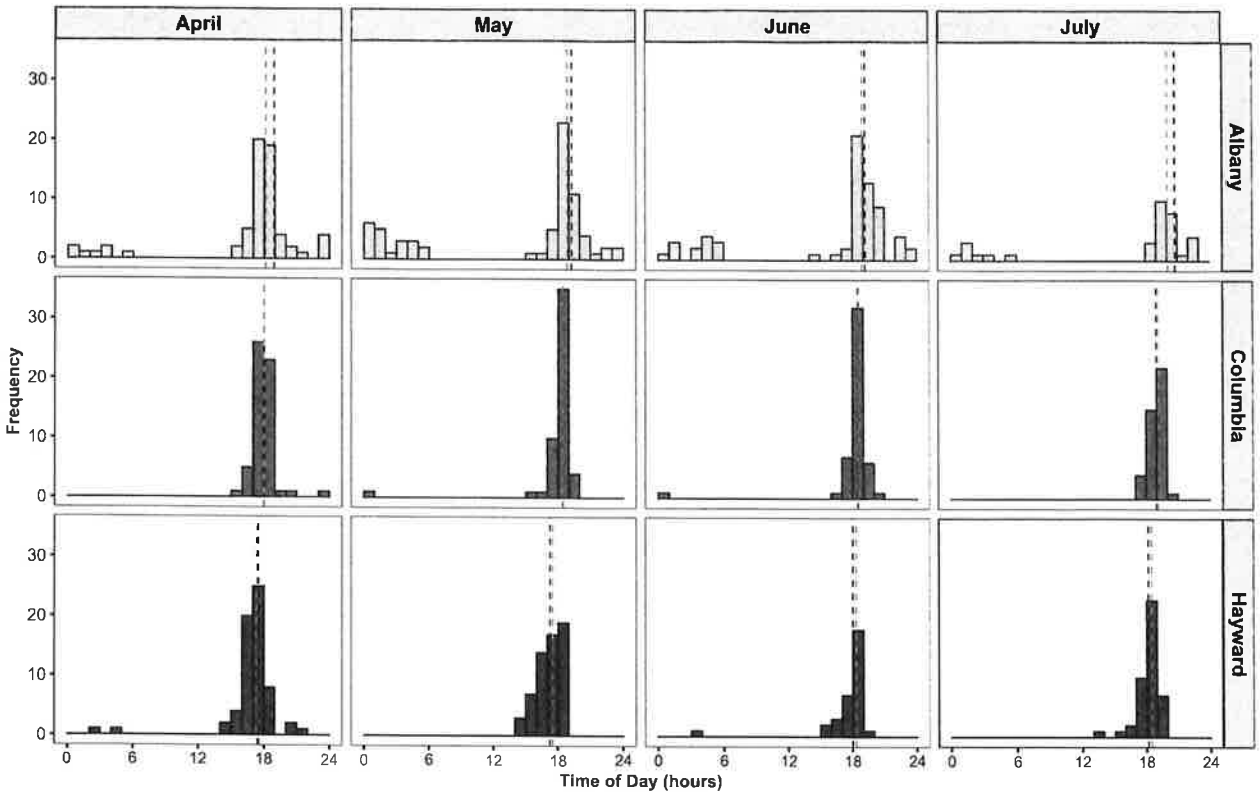

FIG. 7. The frequency of inversions that formed during each 15-min time interval throughout the day. Each month and site are graphed across all years studied (2015–17). Mean and median start times for each month and site are represented by the black and gray dashed lines, respectively.

between 2015 and the other two years 2016 and 2017 is that all sites received, on average, less solar radiation per day in 2015 than in the other two years (Table 1). Record rainfalls were observed in 2015 along with higher-than-normal cloud coverage, which likely contributed to the lower solar radiation (Guinan 2015a,b). Less solar radiation indicates an increased presence of low-level or midlevel layered clouds in 2015; such an increased cloud presence could reduce average solar radiation and interfere with inversion formation by trapping radiation in the atmosphere (Matuszko 2012; Monahan et al. 2015). For the Albany location, July of 2015 and 2016 had the least number of evenings in which inversions formed with six nights out of each month (Fig. 6a) whereas inversions formed on 15 evenings in July of 2017. April of 2016 had the most evenings in which inversions were observed with 22 (Fig. 6a). At the Columbia site, June of 2015 and July of 2016 had the least number of evenings in which inversions formed with 9 each (Fig. 6b). The maximum number of evenings per month in which inversions were observed was 22 evenings in May 2017. At the Hayward location, June of 2015 had the least number of evenings in which inversions formed with 9 (Fig. 6c). May of 2017 had 26 evenings in which inversions formed; this was the most observed of any months across sites and years.

2) FORMATION TIMES FOR INVERSION EVENTS

The times at which inversions began forming are graphed in the histogram in Fig. 7, which shows the distribution of start times by location and month. Start time was considered as the initial time point in which the air at 46 cm had cooled and reached a lower temperature than both the 168- and 305-cm air temperatures. Albany had the most variation with regard to start time as shown in Fig. 7 (see also the basic summary statistics in appendix B). Inversions typically began forming between 1800 and 1900 local time (LT) at Albany; however, there were multiple evenings in which inversions began forming between midnight and 0600 LT, which influenced the mean start time and deviation from the mean. The Columbia and Hayward locations were more consistent with regard to start times. The mean, median, and mode start times at Columbia ranged from 1800 to 1915 LT across all months. Hayward, which is south and notably east of the other two sites, had slightly earlier start times

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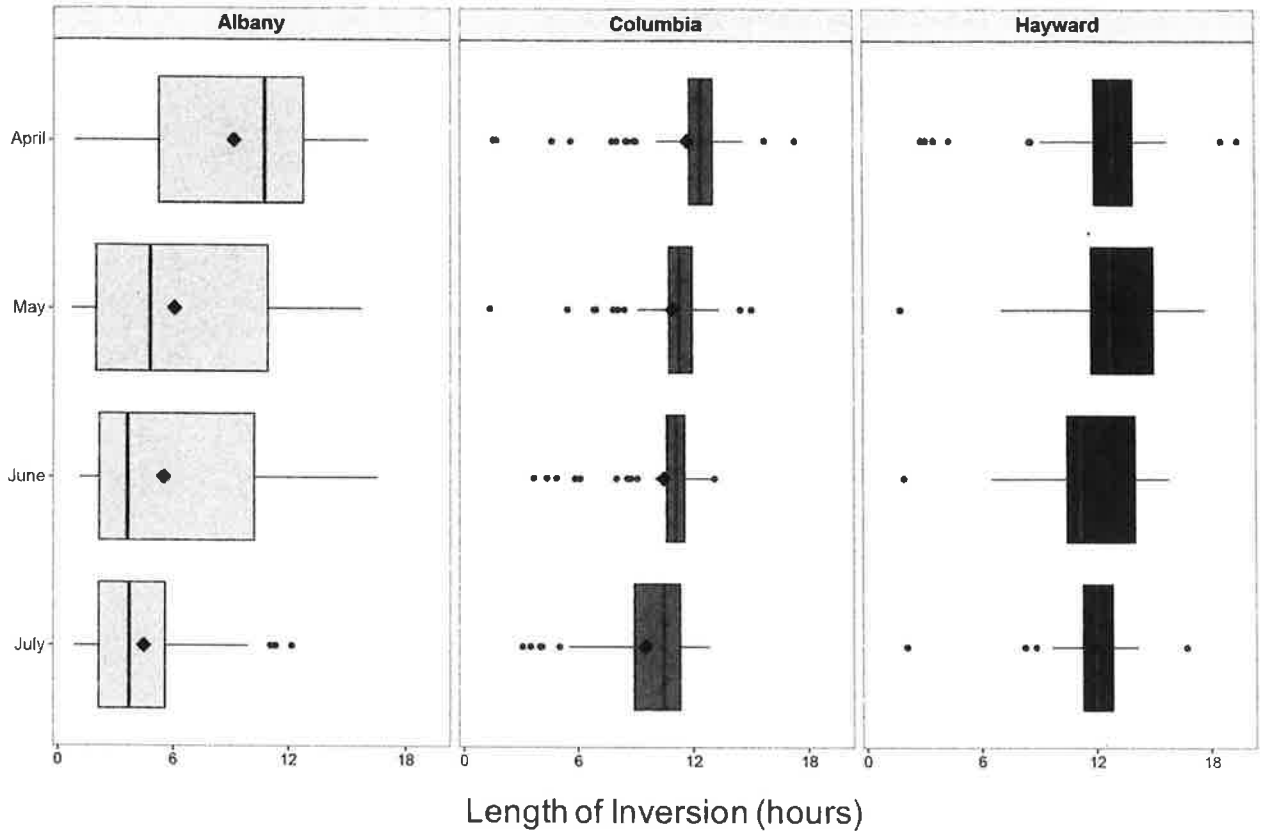

FIG. 8. Boxplot showing typical duration of inversions at each location over the course of the growing season from 2015 to 2017. The vertical black line in each box represents median duration time. Mean inversion duration is represented by a black diamond; boxes represent the interquartile range (IQR), with the left and right edges representing the lower (25%) and upper (75%) quartiles, respectively. Horizontal lines represent the reasonable extreme distances of the data from the IQR (1.5 × IQR). Filled circles represent outliers.

across all months studied; the mean and median start time ranged from 1730 to 1830 LT, depending on month.

3) DURATIONS OF INVERSIONS AND INVERSION END

Duration of inversion events varied by site as shown in the boxplot in Fig. 8. The longest inversions recorded at each site occurred in April. An inversion of 16 h 5 min was recorded in Albany, 17 h 15 min in Columbia, and 19 h 25 min in Hayward (Fig. 8). However, differences in inversion duration were observed among the sites and months. At the Albany location, the average inversion duration was typically longest in April, with a mean duration of 9 h 38 min and decreased across months: May inversions averaged 6 h 4 min in length; June averaged 5 h 30 min, and July averaged 4 h 28 min. In Columbia, a similar trend occurred over the months; however, differences were less pronounced. The mean inversion duration in April was 11 h 40 min, in May was 10 h 53 min, June was 10 h 28 min, and July was 9 h 30 min. Duration of inversions at Hayward did not decline in the same fashion as Albany and Columbia, and mean duration ranged from 11 h 26 min to 13 h 1 min depending on month. The Hayward site is the most sheltered station with a tree corridor to the south and a building to the west. Prevailing winds are from the south during the growing season, and the shelters reduce that wind, which would impact the timings of inversion formation and dissipation (appendix A). Reduced wind speeds may be indicative of less vertical air mixing, which could coincide with a longer duration of inverted temperatures. One possible explanation for the variation observed at Albany is the trend observed for the air temperatures at 46- and 168-cm heights as shown in Fig. 3. These air temperatures tend to be similar, with the 168-cm height being cooler than the 46-cm height at some point during the evening and disrupting the inversion.

Inversion end time was defined as the time at which air temperature at 46 cm became warmer than the air temperature at 305 cm. This typically occurred near sunrise (Table 2). The Albany location again had the most variation as conveyed by the differences in mean in

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TABLE 2. Basic statistics describing 3-yr trends in inversion end time (LT) at each site over each month of the soybean growing season (2015–17).

	Month	n	Mean ± h:min[a]	Median	Mode	Earliest	Latest
Albany	Apr	64	0722 ± 5:26	0640	0640	0035	2355
	May	70	0801 ± 6:15	0630	0635	0005	2355
	Jun	66	1034 ± 8:21	0625	0620	0015	2345
	Jul	33	0757 ± 9:04	0540	0105	0005	2350
Columbia	Apr	58	0618 ± 2:46	0625	0635	0055	2305
	May	52	0612 ± 3:20	0555	0545	0105	2305
	Jun	48	0608 ± 3:43	0545	050	0030	2305
	Jul	42	0648 ± 5:30	0545	05:45	0000	2315
Hayward	Apr	64	0648 ± 2:47	0630	0615	0035	2025
	May	60	0649 ± 2:07	0630	0555	0045	1835
	Jun[b]	32	0553 ± 1:20	0540	0220	0220	0800
	Jul	43	0634 ± 1:55	0630	0640	0325	1745

[a] Statistics were run in SAS 9.4, which converts hour and minutes to seconds and runs the analysis, and then the data are converted back to hours and minutes.

[b] June 2017 was excluded from the analysis because of interference of the 46-cm air temperature probe by shading from a pollinator plot.

comparison with the median and mode end times. With the exception of mode for July, which was 0105 LT, all median and mode dissipation times were within 0540–0640 LT Columbia had the least variation in end time; mean, median, and mode values for dissipation were between 0545 and 0648 LT regardless of month. Inversion end times at Hayward were also consistent with the exception of mode in June, which was 0220 LT. Mean, median, and mode dissipation times fell within 0540–0649 LT. A closer look at the June data indicated two inversion events on 26 and 27 June 2016 that dissipated at 0220 LT. Given the smaller sample size for June inversions at

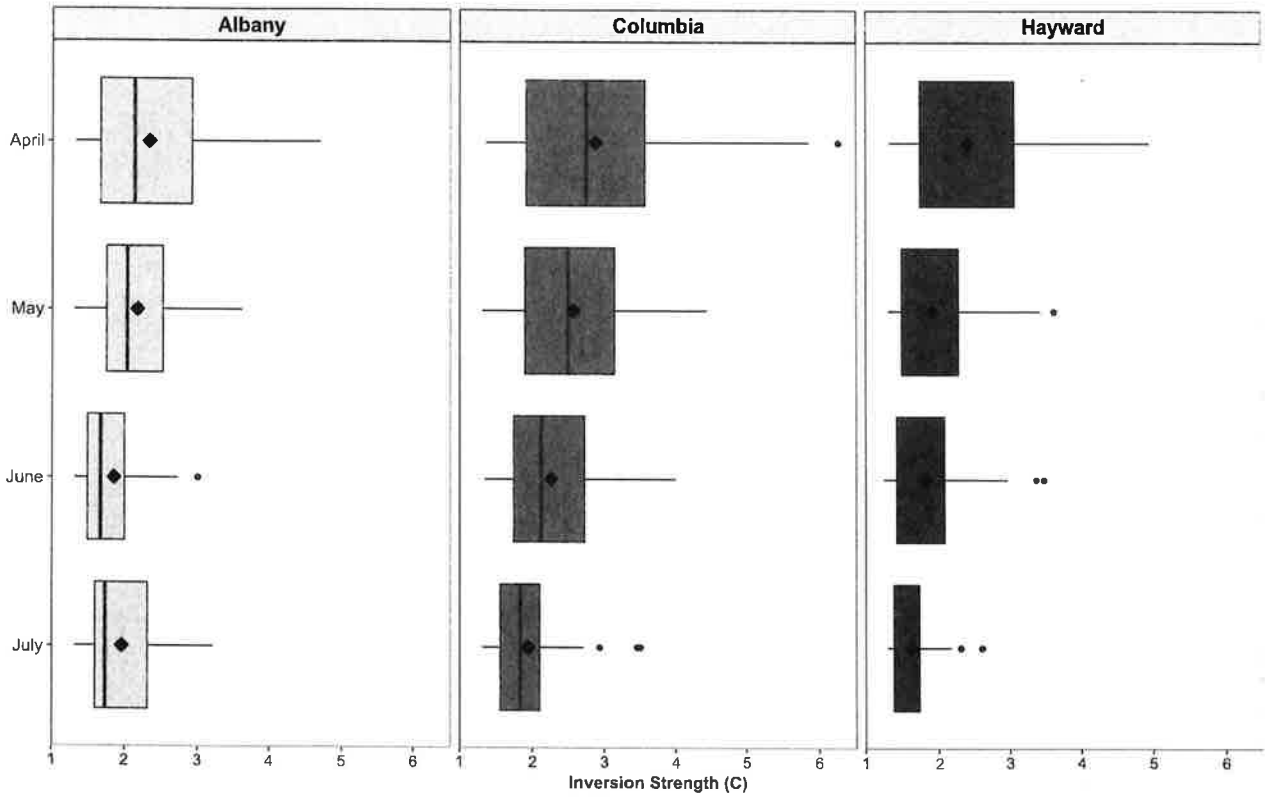

FIG. 9. As in Fig. 8, but showing the maximum ΔT between the 305- and 46-cm heights during each inversion event; here the vertical black line in each box represents median strength.

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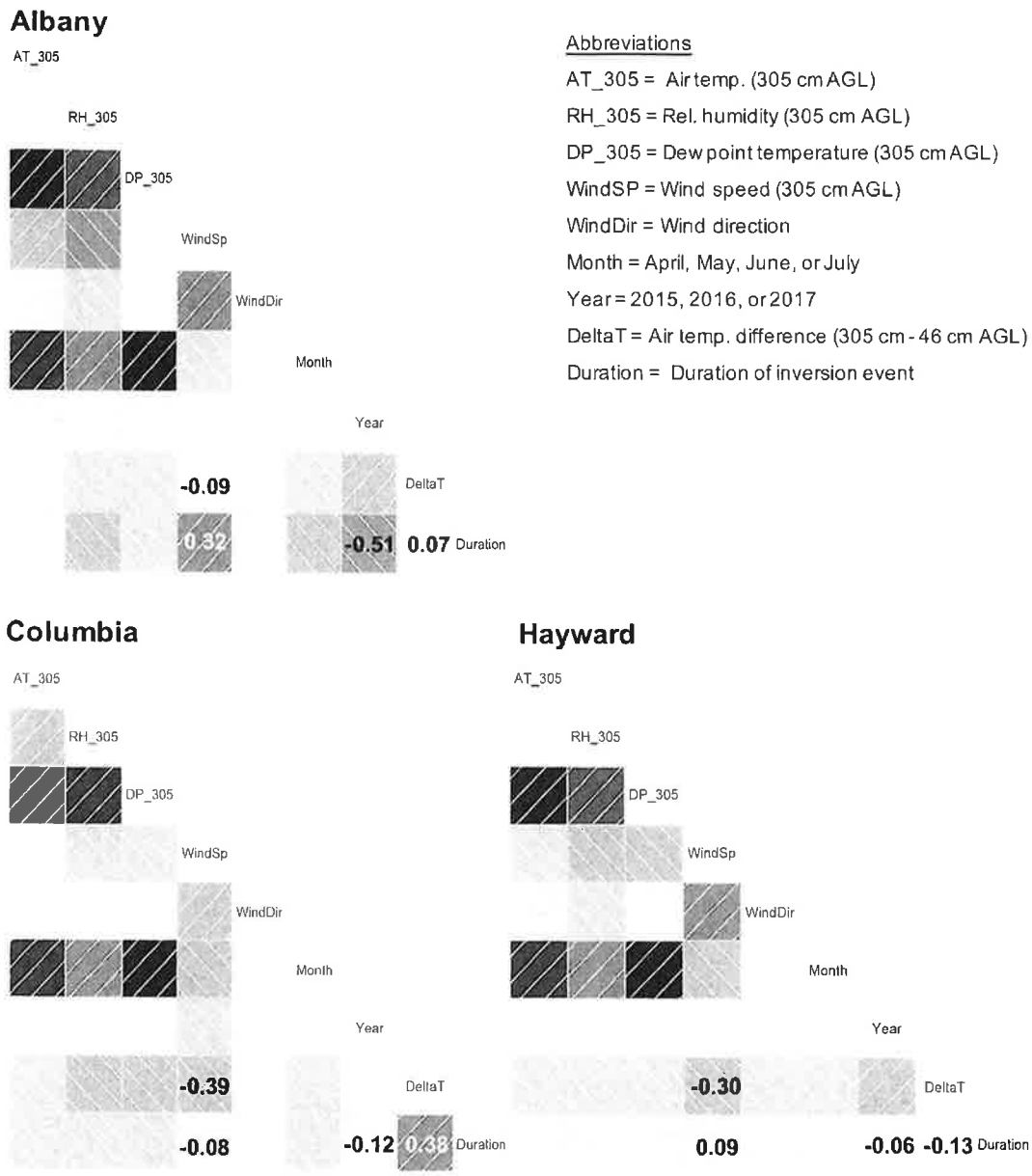

FIG. 10. Correlograms highlighting correlation relationships among variables during inversion conditions. The studied variables are described at the top right. The darker the color of the box is, the stronger is the correlation. Blue signifies a positive correlation relationship, and red indicates a negative relationship. Correlation coefficient values that are included in the boxes are discussed further in the text. All coefficient values are listed in appendix C ($p < 0.001$).

Hayward, because of the aforementioned pollinator plot interference, those two events were enough to affect mode.

4) INVERSION STRENGTH

Changes in the air temperature profile over increasing heights AGL is one indicator of atmospheric stability (Yates et al. 1974; Poulos et al. 2002). As air temperatures higher AGL become warmer, the more stable the atmosphere and less likely particles are to disperse vertically and become more susceptible to horizontal wind movement (Fritz et al. 2008). Maximum air temperature differences between the 305- and 46-cm heights (ΔT) are shown in the boxplot in Fig. 9. The highest ΔT at each location were observed in April. Inversions occurring in April were typically longer in duration than inversions forming in other months, and the longer duration likely allowed more time for the stable air mass to form and contributes to larger ΔT. Columbia had the greatest differences observed for each month, reaching a ΔT of greater than 6°C during one event in April. The

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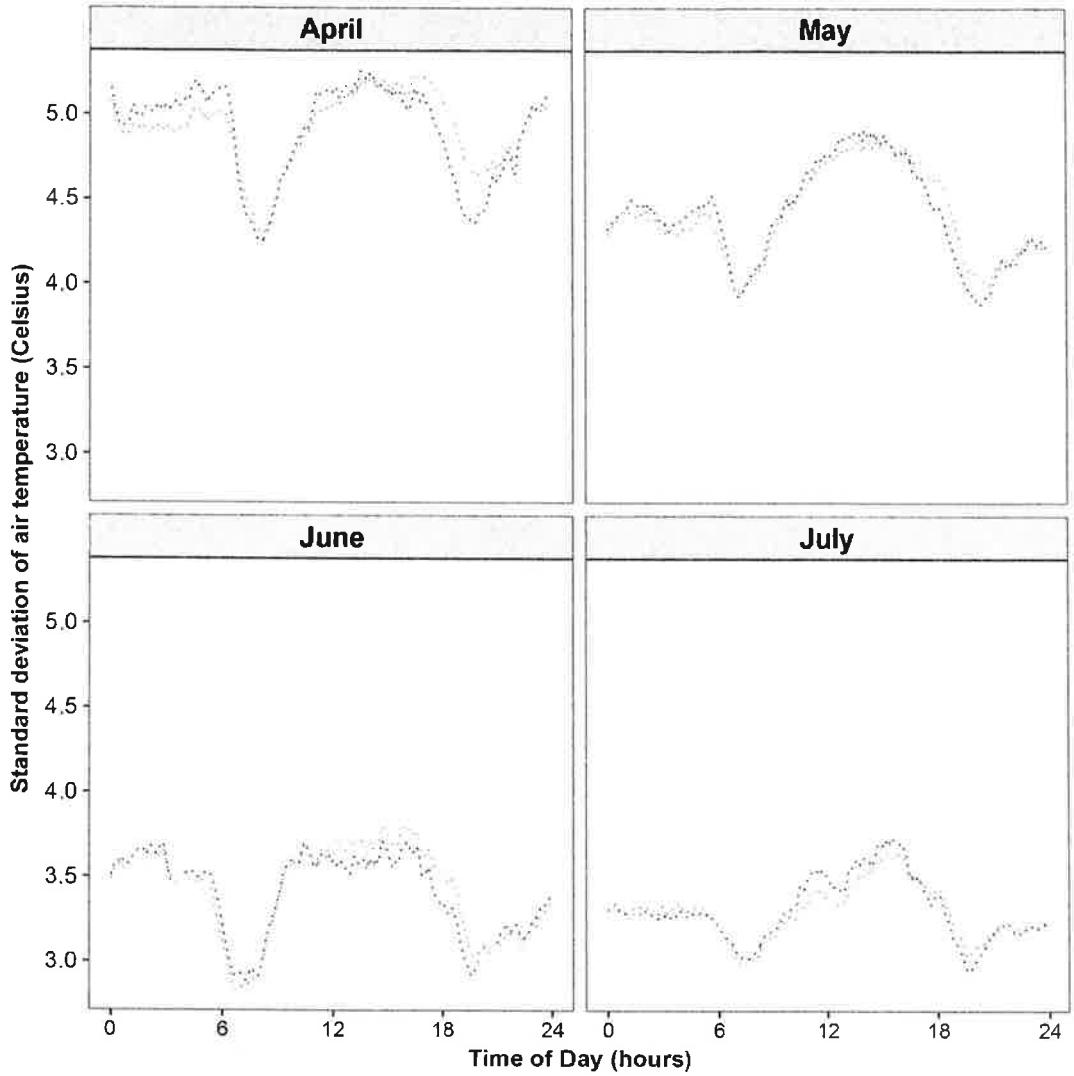

FIG. A1. Standard deviation (SD) of the 5-min air temperatures at each height in Albany from 2015 to 2017 during the growing season. Black, gold, and gray dotted lines indicate the standard deviation at 46, 168, and 305 cm, respectively.

ΔT at Albany and Columbia decreased over the course of the growing season, again possibly because of shortening of the duration of inversion events. At Hayward, where inversion duration was similar across months, there were fewer differences observed in the ΔT across months, although ΔT for June and July were smaller than those observed in April.

b. *Exploring relationships among weather variables*

In addition to air temperatures, measurements of wind speed, wind direction, relative humidity, and dewpoint temperatures were also recorded in 5-min intervals for each location. Relationships among these variables during inversion conditions compared to noninversion conditions were evaluated by calculating Pearson's correlation coefficients. To simplify presentation of the data only air temperature, dewpoint temperature and relative humidity at 305 cm are presented because relationships for the 305-cm data when compared with 46- and 168-cm data were very similar. The correlograms in Fig. 10 show correlation relationships between variables during inversion conditions at each site. A subset of the Pearson's correlation coefficient values that will be discussed are included in the diagram. For a full list of Pearson's correlation coefficient values, see appendix C. A positive correlation was observed at Columbia between ΔT and duration of inversion, which was consistent with the observed decrease in duration and strength across months at Columbia (Figs. 8 and 9). Correlation coefficients

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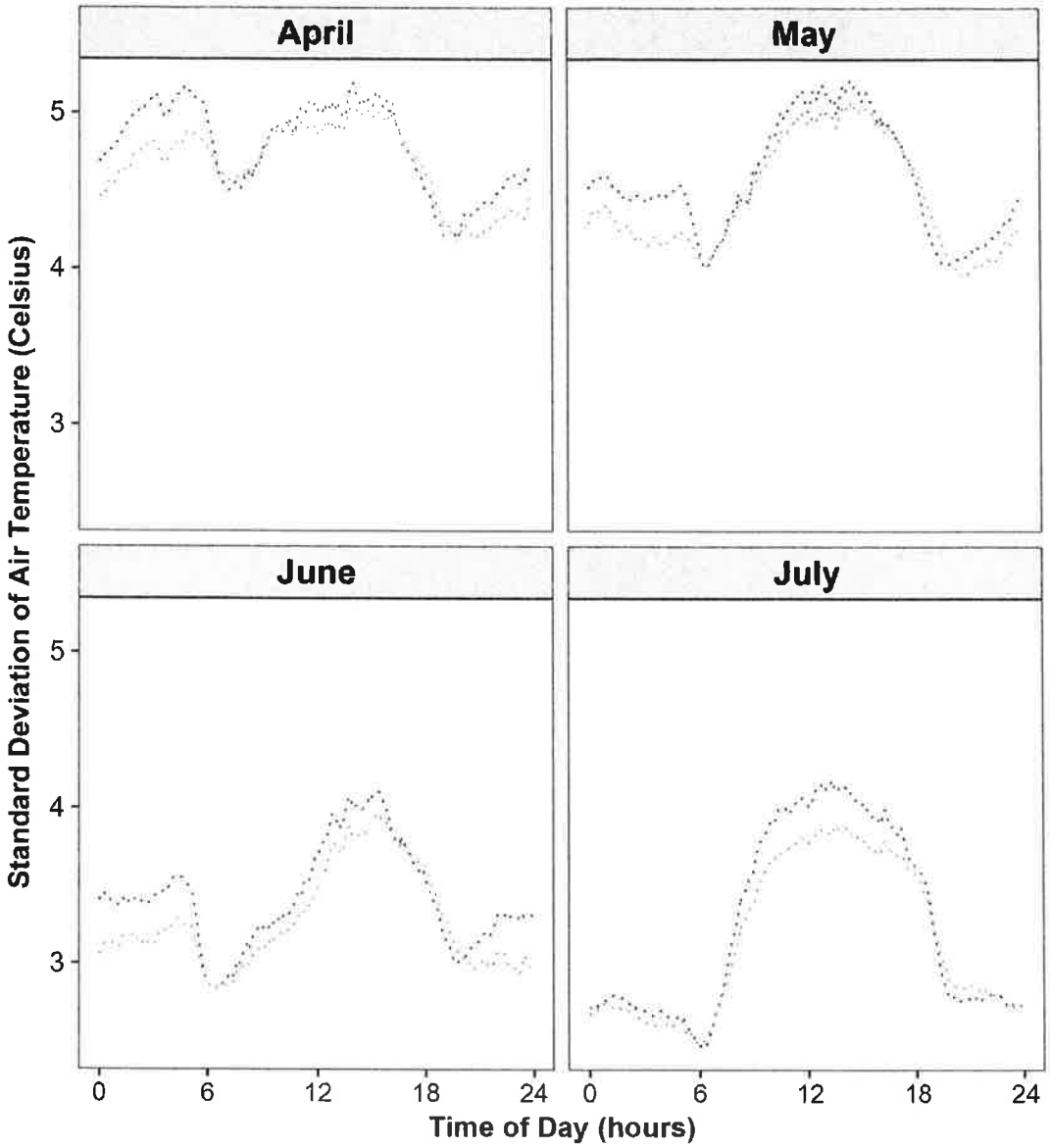

FIG. A2. As in Fig. A1, but in Columbia.

between wind speed and ΔT were negative and similar at Columbia and Hayward sites, suggesting that, as ΔT increased, wind speed decreased. Interestingly, a similar relationship was not observed at Albany as the correlation was almost zero between the two variables. There was a positive relationship between wind speed and inversion duration at Albany that was not observed at the other two sites. The differences in wind speed relationships that were observed at Albany compared to Columbia and Hayward may provide more evidence for a role of drainage winds in cooling air temperatures at the lower heights at the Albany location. The differences between Albany and the other two sites, combined with the strong correlation coefficient for year and duration of inversion at Albany, also suggest that more site years may be needed to understand inversion climatology at Albany compared to the other two sites.

All sites were then combined, and data were analyzed and compared between inversion and noninversion conditions. The strongest correlation observed with all sites combined that was unique for inversion conditions was a coefficient of 0.34 between wind speed and wind direction (appendix C). The correlation was 0.11 for noninversion conditions. The strongest correlation observed that was unique to noninversion conditions was ΔT and relative humidity, which had a coefficient of 0.45. It was nearly opposite of inversion conditions in which the correlation coefficient was -0.29. The negative relationship between

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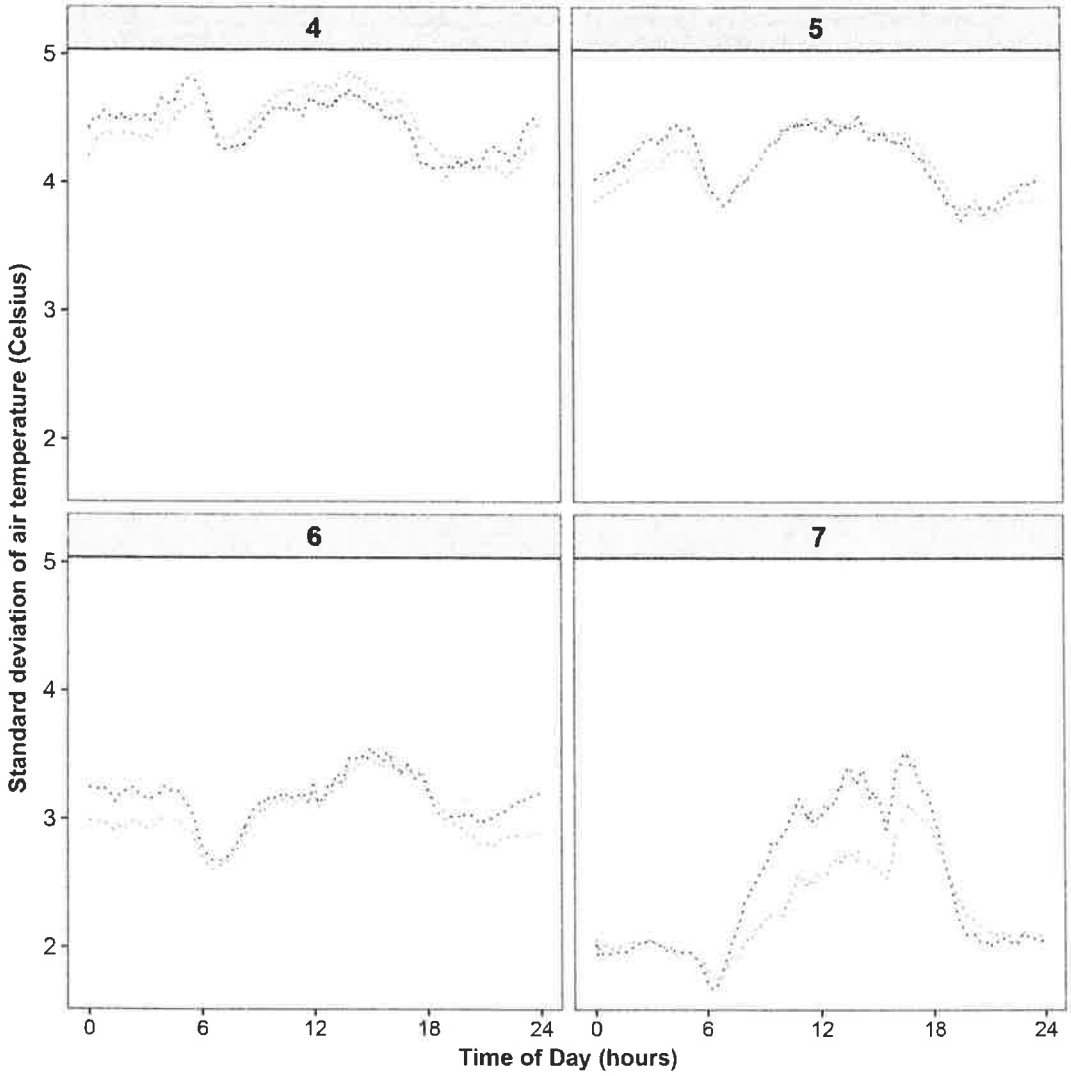

FIG. A3. As in Fig. A1, but in Hayward. Here, 4–7 indicate April–July.

relative humidity and ΔT during inversion conditions was interesting in that pesticide applicators are commonly told to look for the presence of dew or fog as indicators of surface temperature inversions. However, these results would suggest dew and fog are not reliable indicators.

4. Summary and conclusions

There is an increased interest in understanding surface temperature inversions at heights relevant to ground pesticide applications because of the recent commercial introduction of soybean and cotton that are resistant to the synthetic auxin herbicide dicamba (USDA 2015a,b) and the subsequent increase in the number of dicamba-injury investigations. The work presented here provides initial inversion climatology for low-level temperature inversions (46–305 cm) over the course of three soybean growing seasons at three Missouri locations. All inversions identified were nocturnal in nature. There were some similarities among sites such as the times at which inversions began forming—between 1700 and 2000 LT. This is an important finding in that it is common, during the soybean and cotton growing seasons to observe ground pesticide applicators making applications in those hours. Wind becomes less problematic and the possibility of physical drift is reduced. Historically, there has not been such a need for ground pesticide applicators to consider nocturnal temperature inversions, and many are unfamiliar with inversion characteristics (Bish and Bradley 2017).

Across all sites studied, the Albany location had the most variation in inversion formation time and duration. This weather station, which is set up in an area subject to cool air drainage, also had a positive correlation

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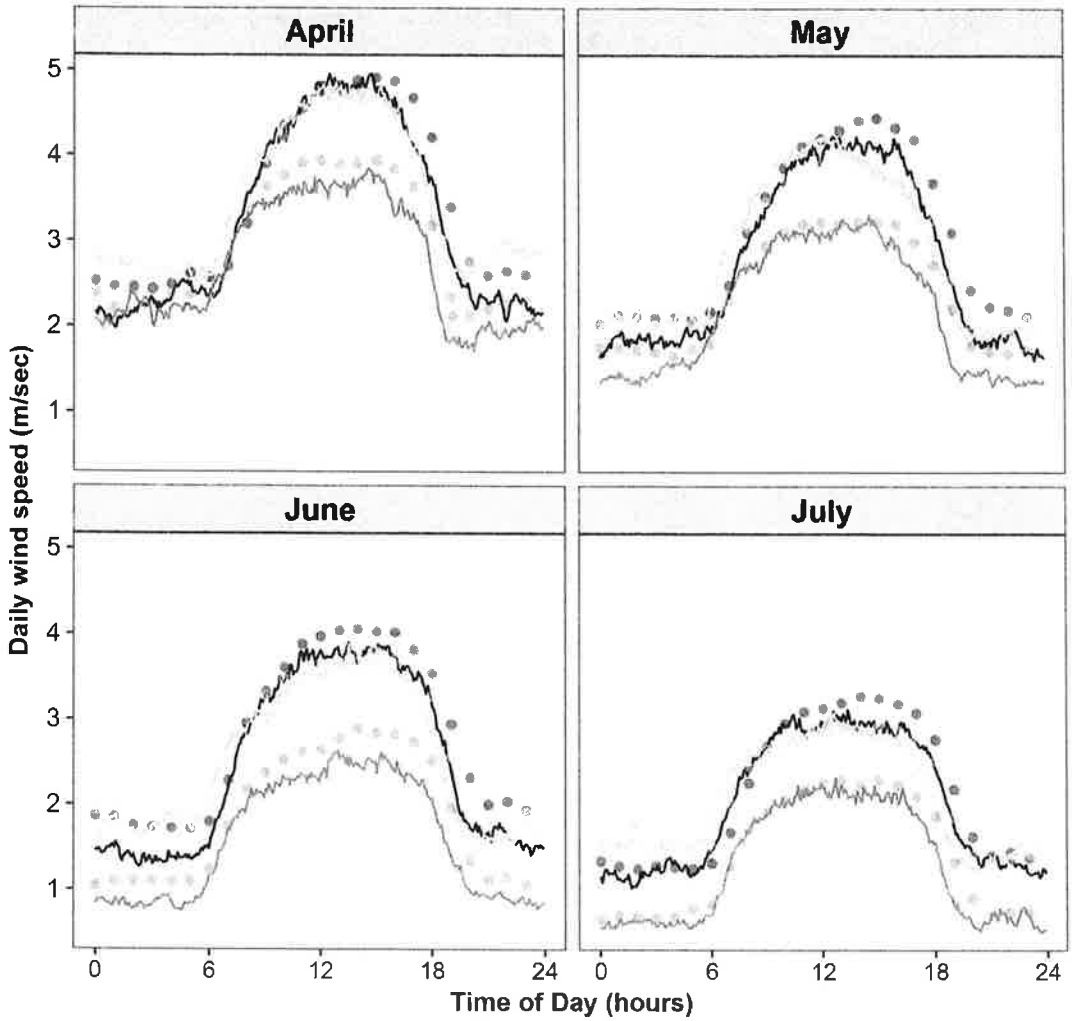

FIG. A4. Five-minute wind speed averages over the course of each studied month. The black solid line represents Albany, gold is Columbia, and gray is Hayward. Dotted lines are the 10-yr trends for hourly average wind speed at each respective site.

between wind speed and ΔT. The other two sites were more consistent with regard to formation time and duration and had negative relationships between wind speed and ΔT. Inversions at Columbia and Hayward began forming near sunset and dissipated near sunrise the next day, similar to previous reports that stable air masses begin forming near sunset and remain until sunrise (van Hooijdonk et al. 2017).

The 3-yr climatology profiles presented here and the differences observed between sites highlight the need to learn more about topography and its effects on low-level inversions relevant to ground pesticide applications. They also provide further support that more data are needed to address challenges associated with developing accurate inversion prediction models. Accurate predictive models are a challenge that has been reported by many groups previously because of the behavior of the lower atmosphere and variation in Earth's surface (van Hooijdonk et al. 2017; Monahan et al. 2015).

Another question that remains unknown is the extent to which these very low-level surface temperature inversions impede the dispersion of dicamba and other pesticides in the atmosphere. Recent work was conducted by Yassin et al. (2018) who collected air samples of pollutants for each hour of one year. From those data, they looked at the diurnal concentrations of specific compounds over a 24-h day. Nitric oxides, carbon monoxide, and nonmethane hydrocarbons were all found to have peak concentrations corresponding to times of day when the least amount of air mixing was occurring and near hour 20 of the day. This would correspond to the time frame in which nocturnal inversions are likely to have formed (Yassin et al. 2018). However, the

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TABLE B1. Three-year trend for (start) time at which inversions began forming (2015–17).

	Month	n[a]	Mean ± h:min	Median	Mode	Earliest	Latest
Albany	Apr	64	1855 ± 2:33	1810	1820	0040	2335
	May	70	1915 ± 2:05	1850	1815	0000	2335
	Jun	66	1911 ± 1:32	1855	1810	0005	2310
	Jul	33	2047 ± 2:21	2005	1930	0000	2240
Columbia	Apr	58	1801 ± 1:03	1800	1800	1550	2325
	May	52	1827 ± 1:03	1825	1845	0015	1925
	Jun	48	1832 ± 0:38	1835	1855	0100	2100
	Jul	42	1900 ± 0:37	1910	1915	1745	2040
Hayward	Apr	64	1730 ± 1:43	1720	1745	0245	2130
	May	60	1717 ± 1:10	1730	1830	1420	1855
	Jun[b]	32	1801 ± 0:53	1820	1830	0330	1905
	Jul	33	1810 ± 1:03	1828	1800	1350	2040

[a] n = number of inversion formations observed.
[b] June 2017 was excluded from this analysis because of interference of the 46-cm air temperature probe by shading from a pollinator plot.

heights AGL at which Yassin was working and at which much work has been done previously are above ground pesticide applications. A question of how herbicide droplets, such as dicamba, may move or be dispersed when applied during an inversion remains unknown, and future research will be needed.

The data generated here can serve as a resource or guide to assist in identifying times for conducting dispersion experiments and be utilized to validate forecasting models of low-level surface temperature inversions. Currently, through the TIPS website, Missouri pesticide applicators have access to real-time data on air temperatures, wind speed, and relative humidity to assist in decision-making with regard to applying chemicals (http://ag3.agebb.missouri.edu/weather/maps/realTime/temperature_inversion/ver2/alb_temperature_inversion_public.png). In addition, multiple weather stations across the Midwestern and midsouthern United States have

TABLE C1. Pearson's correlation coefficients for weather variables during inversion conditions at each site (2015–17; $p < 0.001$). Pearsons's correlation coefficients range from −1 to 1, with a positive number representing a positive correlation and a negative number representing a negative correlation. Values closest to −1 or 1 represent the strongest relationships. Air temperature, relative humidity, dewpoint temperature, and wind speed and direction were all recorded at 305 cm AGL.

Site	Variable	Air temperature	Relative humidity	Dewpoint temperature	Wind speed	Wind direction	ΔT	Duration
Albany	Air temperature	1	−0.14	0.82	0.19	0.02	−0.07	−0.11
	Relative humidity	−0.14	1	0.44	−0.53	−0.25	−0.26	−0.29
	Dewpoint temperature	0.82	0.44	1	−0.12	−0.12	−0.19	−0.26
	Wind speed	0.19	−0.53	−0.12	1	0.42	−0.09	0.32
	Wind direction	0.02	−0.25	−0.12	0.42	1	−0.07	0.13
	ΔT	−0.07	−0.26	−0.19	−0.09	−0.07	1	0.07
	Duration	−0.11	−0.29	−0.26	0.32	0.13	0.07	1
Columbia	Air temperature	1	0.14	0.87	−0.05	−0.06	−0.26	−0.18
	Relative humidity	0.14	1	0.62	−0.26	−0.13	−0.35	−0.28
	Dewpoint temperature	0.87	0.62	1	−0.17	−0.11	−0.37	−0.28
	Wind speed	−0.05	−0.26	−0.17	1	0.25	−0.39	−0.08
	Wind direction	−0.06	−0.13	−0.11	0.25	1	−0.06	−0.01
	ΔT	−0.26	−0.35	−0.37	−0.39	−0.06	1	0.38
	Duration	−0.18	−0.28	−0.28	−0.08	−0.01	0.38	1
Hayward	Air temperature	1	−0.01	0.82	−0.16	0	−0.17	0.01
	Relative humidity	−0.01	1	0.55	−0.38	−0.18	−0.18	0.02
	Dewpoint temperature	0.82	0.55	1	−0.35	−0.10	−0.23	0.01
	Wind speed	−0.16	−0.38	−0.35	1	0.35	−0.30	0.09
	Wind direction	0	−0.18	−0.1	0.35	1	−0.19	0.04
	ΔT	−0.17	−0.18	−0.23	−0.30	−0.19	1	−0.13
	Duration	0.01	0.02	0.01	0.09	0.04	−0.13	1

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TABLE C2. Pearson's correlation coefficients for weather variables during inversion and noninversion conditions (2015–17; $p < 0.001$). Air temperature, relative humidity, dewpoint temperature, and wind speed and direction were all recorded at 305 cm AGL.

Condition	Variable	Air temperature	Relative humidity	Dewpoint temperature	Wind speed	Wind direction	ΔT	Duration[a]
Inversion	Air temperature	1	0.05	0.85	−0.06	−0.03	−0.17	−0.02
	Relative humidity	0.05	1	0.56	−0.32	−0.16	−0.29	−0.17
	Dewpoint temperature	0.85	0.56	1	−0.22	−0.11	−0.28	−0.10
	Wind speed	−0.06	−0.32	−0.22	1	0.34	−0.36	−0.05
	Wind direction	−0.03	−0.16	−0.11	0.34	1	−0.13	−0.02
	ΔT	−0.17	−0.29	−0.28	−0.36	−0.13	1	0.22
	Duration	−0.02	−0.17	−0.1	−0.05	−0.02	0.22	1
Noninversion	Air temperature	1	−0.30	0.72	−0.06	−0.02	−0.22	—
	Relative humidity	−0.30	1	0.53	−0.30	−0.18	0.45	—
	Dewpoint temperature	0.72	0.53	1	−0.26	−0.10	0.10	—
	Wind speed	−0.06	−0.30	−0.26	1	0.11	−0.11	—
	Wind direction	0.02	−0.18	−0.10	0.11	1	−0.04	—
	ΔT	−0.22	0.45	0.10	−0.11	−0.04	1	—
	Duration[a]	—	—	—	—	—	—	—

[a] The duration category is blank for noninversion conditions because duration of a noninversion event was not defined in this study.

been or are currently being outfitted with similar equipment to generate additional data.

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APPENDIX A

Variability of the Probes and Anemometers over Time

Air temperatures were recorded every 5 min at 46, 168, and 305 cm above ground level during April, May, June, and July of 2015–17 at Albany, Columbia, and Hayward. Standard deviations for air temperatures at each height are recorded in Figs. A1–A3 to show the similarity among the three air temperature probes. The average 5-min wind speeds from 2015 to 2017 are shown in comparison with 10-yr historical trends of wind speeds at each location in Fig. A4.

APPENDIX B

Basic Summary Statistics for Inversion Formations at Each Site and Month Studied

Table B1 displays the basic summary statistics for inversion start times over a 3-yr period.

APPENDIX C

Exploration of Correlation Relationships among Variables during Inversion and Noninversion Conditions

For the 3-yr period, Table C1 gives a list of Pearson's correlation coefficient values for weather variables at each site. Table C2 gives correlations among weather variables for all sites combined during inversions and when inversions are not present.

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EXHIBIT NO. 12

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

"I can't keep dicamba in the field"

news.utcrops.com/2017/07/cant-keep-dicamba-field/

Larry Steckel, Extension Weed Specialist July 18, 2017

"I can't keep dicamba in the field" has been a frequent comment I have heard from many frustrated folks who have followed the rules and tried their best not to drift on their neighbors. Quite a few good and conscientious farmers have thrown up their hands and gone back to Flexstar to try to control pigweed in soybean. Others have reported that they often have been successful not drifting onto non-target areas. However, judging by all the off-target dicamba injury that seems to be more the exception than the rule.

So what are the reasons for all the drift? After visiting hundreds of dicamba-drifted RR, LL and conventional soybean fields that easily have totaled over 30,000 acres, I can say with certainty that many of the reasons I have heard recently from upper management in Monsanto are NOT the cause of all these dicamba injured broadleaf plants across west Tennessee.

I cannot imagine the hundreds of thousands of acres of non dicamba tolerant (DT) soybeans in Tennessee that have shown dicamba injury could be due to contamination of Liberty jugs with dicamba, calcium deficiency, Dual Magnum burn, and/or surfactant burn. Nor do any of those reasons explain the dicamba injury I have seen in a vineyard, gardens, trees in parks and back yards.....even my backyard.

We do not need speculative reasons to explain all the drift issues as there are plenty of real reasons. Firstly, though it looks straight forward on paper, it is extremely hard to follow the label. The best example of this is that you cannot spray when the wind is above 10 mph or below 3 mph. Just that stipulation when you have crops to spray timely in three different counties makes the logistics a nightmare.

Another reason, which I believe could be the main reason, is dicamba's inherent volatile nature. Dicamba is unique compared to most pesticides in that it is prone to "picking back up" as a gas and departing a field hours after application when temperatures are warm. This is particularly true for the older Banvel and Clarity formulations. There is some evidence that older formulations have been used in Xtend crops which would certainly contribute to the off-target movement. Exactly how much of this is going on is difficult to figure. However, it is hard to believe that old dicamba formulations can possibly explain all of the hundreds of thousands of acres of dicamba injured soybean in this state.

Could Engenia or Xtendimax be volatilizing as well? My colleague, Dr. Tom Mueller, was asked by members of the Tennessee Soybean Promotion Board to test if there was a difference with Engenia volatility if it was tankmixed with Roundup PowerMax. In the attached figures below showing Dr. Mueller's research data, please note the data is presented

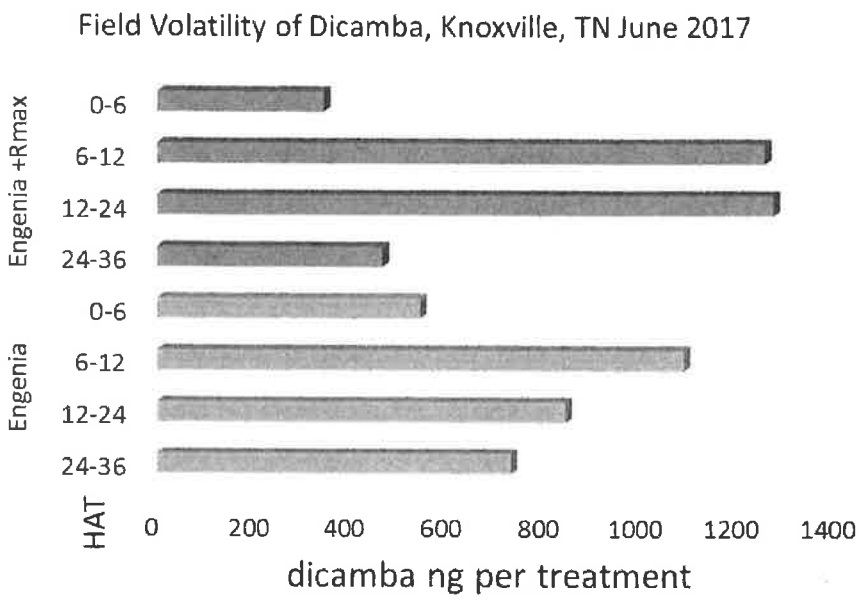
in time intervals following the herbicide application to an acre of soybean. It is presented from 0–6, 6-12, 12-24 and 24 -36 hours after application. Dr. Mueller has said that some of the detection from the first 6 hours could in part be small spray droplets still in the air caught in an inversion which dissipated as the morning warmed up. However, after that 0-6 hour time frame any detection the next 24 hours would be exclusively from volatility.

In short, his data shows that Engenia does volatilize and could depart from the field, albeit at extremely small amounts, many hours after application. It also suggests that Roundup PM does not affect the volatility profile of Engenia to any great extent. The level of volatility for Engenia alone or the Engenia in the tankmix was extremely low but was not zero. I have seen data as well that would suggest that Xtendimax shows similar level of volatility over that same time frame.

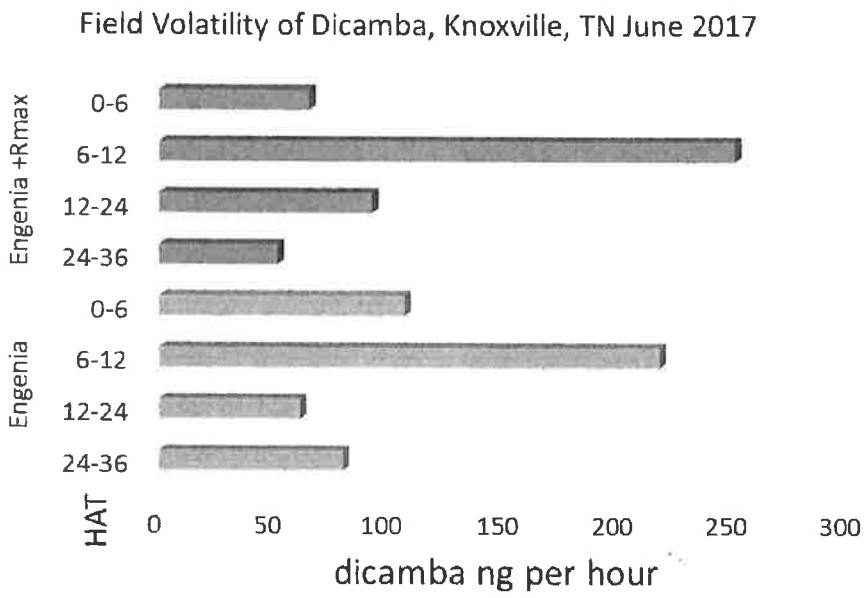
Are numbers that low biologically significant? Probably not in small plots like this or possibly in a 20 acre field. I am not as sure when a good number of farmers spray thousands of acres in a single county in a few days. Could even those small amounts build up when sprayed over that many acres and help cause all the drift we are seeing? I don't know but it is a good question and I am not confident BASF (manufacturer of Engenia) nor Monsanto (manufacturer of Xtendimax) really know.

Finally, inversions are another common reason we may be seeing so much dicamba trespassing across the country side. Inversions occur most days in Tennessee during June and July. Just that fact makes it very hard to not accidently spray into an inversion. Of course, if you spray into an inversion tiny drops can get caught in the cooler air and hang up for some time. Moreover, if dicamba is volatilizing out of a field it likely can get caught in the inversion as well.

There are many moving parts to this issue and I'm not confident we will ever get to the bottom of it. My best guess is that at some time or another all the reasons mentioned above are a cause.



Mueller 2017



Mueller 2017

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CROP MANAGEMENT

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Comparison of weed control technologies for protoporphyrinogen oxidase-resistant Palmer amaranth

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Abstract

Confirmation of protoporphyrinogen oxidase (PPO)-resistant Palmer amaranth (*Amaranthus palmeri* S.Watson) in 2015 limited weed control options for soybean [*Glycine max* (L.) Merr.] producers. With already prevalent 5-enolpyruvyl-shikimate-3-phosphate synthase-, acetolactate synthase-, beta-tubulin-, and very-long-chain fatty acid-resistant Palmer amaranth, there are few remaining effective pre-emergence and postemergence herbicides labeled in soybean. The recent commercialization of soybean varieties resistant to dicamba and 2,4-D give producers effective options to control multiresistant Palmer amaranth. To evaluate new and existing technologies and postemergence herbicide options, two experiments were conducted in 2017. These experiments were conducted in Marion and Crawfordsville, AR, two locations with confirmed PPO-, 5-enolpyruvyl-shikimate-3-phosphate synthase-, acetolactate synthase-, beta-tubulin-, and very-long-chain fatty acid-resistant Palmer amaranth. Each technology was tested over three pre-emergence programs with distinct levels of control (74, 88, and 95%). At 28 d after pre-emergence, the first postemergence applications were made when Palmer amaranth was approximately 4 in in height. Fourteen days later, visible weed control ratings showed that glufosinate-, 2,4-D-, and dicamba-resistant programs resulted in at least 95% control of Palmer amaranth across all pre-emergence treatments, better than the 83% control provided by the glyphosate-resistant soybean program. Visible control ratings taken 14 d after the second postemergence treatment showed separation between the glufosinate- (97%), 2,4-D- (97%), and the dicamba-resistant (96%) programs from the glyphosate-resistant program (59%). The results indicate that effective pre-emergence programs followed by postemergence programs containing glufosinate, 2,4-D, or dicamba will provide extended control of PPO-resistant Palmer amaranth but this may not be feasible in a glyphosate-resistant soybean system.

Abbreviations: HR, herbicide resistant; POST 1, postemergence treatment 1; POST 2, postemergence treatment 2; PPO, protoporphyrinogen oxidase; SOA, sites of action.

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1 | INTRODUCTION

Palmer amaranth is the most troublesome weed of agronomic crops in the United States, partly because of its competitiveness, widespread occurrence, and resistance to several herbicide sites of action (SOAs), of which glyphosate [2-(phosphonomethylamino)acetic acid] resistance is likely to be the most important (Heap, 2020; Van Wychen, 2016). In addition to glyphosate, Palmer amaranth in the United States has documented resistance to SOA comprising Weed Science Society of America Groups 2, 3, 5, 14, 27, and (most recently) 15 (Heap, 2020). In Arkansas, Palmer amaranth accessions have been confirmed as resistant to all of these SOAs, except Group 5, severely limiting weed control options in soybean (Heap, 2020; Varanasi et al., 2018). As the number of herbicide-resistant (HR) weed cases increase, new HR soybean traits have been released to provide growers increased herbicide options. In addition to available soybean varieties resistant to glufosinate [2-amino-4-(hydroxy[methyl]phosphoryl)butanoic acid], dicamba (3,6-dichloro-2-methoxybenzoic acid), 2,4-D, and glyphosate, certain 4-hydroxyphenylpyruvate dioxygenase-inhibiting herbicides may become commercially available in select soybean cultivars in the near future. New technologies would be vital to producers, as glyphosate-resistant Palmer amaranth has caused heavy reliance on the limited available residual herbicides.

In multiresistant Palmer amaranth accessions tested by Schwartz-Lazaro, Norsworthy, Scott, and Barber (2017), residual herbicides such as metribuzin (4-amino-6-tert-butyl-3-methylsulfanyl-1,2,4-triazin-5-one), *S*-metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-([2*S*]-1-methoxypropan-2-yl)acetamide], and isoxaflutole [(5-cyclopropyl-1,2-oxazol-4-yl)-(2-methylsulfonyl-4-[trifluoromethyl]phenyl)methanone] result in 60% less control than a susceptible standard accession. Reliance on preemergence programs, paired with declining control from available residual options, has created a dynamic need for HR soybean traits that provide the option to apply an effective postemergence herbicide. Glufosinate-, dicamba-, and 2,4-D-resistant soybean varieties all increase herbicide options for control of multiple-resistant Palmer amaranth both before and after emergence because of their effectiveness on broadleaf weeds (Chahal & Johnson, 2012; Johnson et al., 2010; Merchant et al., 2013). Use of a wider range of herbicides not only provides more options for weed control but also embodies better management practices designed to reduce the risk of new HR cases (Norsworthy et al., 2012).

Control of multiresistant Palmer amaranth with glyphosate alone has become perilous in Midsouth soybean production. In many cases, an early postemergence application of glyphosate plus fomesafen [5-(2-chloro-4-[trifluoromethyl]phenoxy)-*N*-methylsulfonyl-2-nitrobenzamide] will not provide greater than 5% glyphosate-resistant waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] control, even when an effective pre-emergence program is followed (Spaunhorst, Siefert-Higgins, & Bradley, 2014). Fomesafen, one of the most common herbicides to be mixed with glyphosate, has seen an increase in use since the confirmation of glyphosate-resistant Palmer amaranth (Sosnoskie & Culpepper, 2014). The ability of fomesafen to control Palmer amaranth has been diminished in recent years following identification of PPO-resistant biotypes in several U.S. states (Schwartz-Lazaro et al., 2017). Most recently, resistance to metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(1-methoxypropan-2-yl)acetamide] has been documented (Brabham, Norsworthy, Houston, Varanasi, & Barber, 2019), one of the most widely used residual herbicides for Palmer amaranth in the Midsouth. With no effective postemergence herbicide available in glyphosate-only traited soybean technologies, pre-emergence programs became the only option for control of multiresistant Palmer amaranth. Even when effective pre-emergence options were used, control of multiresistant Palmer amaranth may not be sustainable throughout the growing season in glyphosate-resistant soybean. This is because of the high likelihood of Palmer amaranth escaping from residual herbicide applications, paired with precipitation-stimulated Palmer amaranth germination lasting throughout the season, which would cause yield loss from competition with the crop.

Weed control programs containing 2,4-D, glufosinate, and dicamba have been shown to provide similar control of multiresistant *Amaranthus* species, as long as postemergence programs are initiated within 4 wk after a pre-emergence herbicide (Meyer et al., 2015). Although the level of *Amaranthus* control is similar among these postemergence herbicides when applications are timely, some research indicates that both 2,4-D and dicamba can achieve better control of Palmer amaranth than glufosinate, as application is delayed and weed size exceeds

Core Ideas

- Pre-emergence pyroxasulfone + metribuzin controlled multiresistant Palmer amaranth.
- Roundup Ready 2 Xtend, LibertyLink, and Enlist are effective postemergence options.
- Season-long multiresistant Palmer amaranth control is feasible with Roundup Ready 2 Xtend, LibertyLink, and Enlist.

4 in (Cahoon, York, Jordan, Everman, & Seagroves, 2015; Chahal & Johnson, 2012). Control of *Amaranthus* species with postemergence applications of glufosinate alone is possible, but control will vary depending on weed size, air temperature, time of application, and humidity (Anderson, Swanton, & Mersey, 1993; Coetzer, Al-Khatib, & Peterson, 2002; Craigmyle, Ellis, & Bradley, 2013; Hoffner et al., 2012).

Coetzer et al. (2002) reported that 80% Palmer amaranth control could be achieved but only with sequential applications of glufosinate, when a residual postemergence treatment to suppress new emergence is lacking. The variability of weed control with glufosinate alone leads to the addition of herbicides such as fomesafen (a PPO inhibitor) in postemergence programs to ensure Palmer amaranth mortality (Hoffner et al., 2012). In Palmer amaranth populations with confirmed PPO and acetolactate synthase resistance, additional herbicide options like imazethapyr [5-ethyl-2-(4-methyl-5-oxo-4-propan-2-yl-1*H*-imidazol-2-yl)pyridine-3-carboxylic acid] and fomesafen are ineffective. Gardner, York, Jordan, and Monks (2006) found that when no additional postemergence herbicides were added to glufosinate, control was lower on both grasses and *Amaranthus* species. In the same trial, Gardner et al. (2006) concluded that with an effective pre-emergence program followed by glufosinate, only annual grass control declined when another postemergence herbicide was lacking. Hence, in the absence of an effective pre-emergence program, Palmer amaranth control of a glufosinate-based program can become challenging.

Dicamba and 2,4-D, though they are new postemergence options in soybean, have been an effective option for control of broadleaf weed species in crops such as corn (*Zea mays* L.) (Johnson et al., 2010). For control of monocot weed species, postemergence mixtures may be necessary with dicamba and 2,4-D. Dicamba, in combination with glyphosate, controls a larger assortment of weed species, in addition to providing options for glyphosate-resistant *Amaranthus* and giant ragweed (*Ambrosia trifida* L.) (Spaunhorst et al., 2014). In the experiment conducted by Spaunhorst et al. (2014), the postemergence addition of dicamba to glyphosate at one timing resulted in 40% more control of glyphosate-resistant *Amaranthus* and a 60% increase in control when dicamba was added to multiple postemergence timings. High levels of control were achieved with the addition of dicamba, suggesting that dicamba-resistant soybean can provide growers with an effective postemergence tool for the control of multiresistant Palmer amaranth, unlike glyphosate-resistant soybean, even when glyphosate is tank-mixed with fomesafen. There is evidence that points to 2,4-D-resistant *Amaranthus* already in Nebraska, Kansas, and Missouri and reports of a struggle to control some populations in several other states with 2,4-D and dicamba (Crespo et al., 2017; Heap, 2020; Shergill, Barlow, Bish, & Bradley, 2018). The objective of this research was to evaluate soybean technologies for control of Palmer amaranth with multiple resistance to glyphosate, acetolactate synthase inhibitors, PPO inhibitors, beta-tubulin, and very-long-chain fatty acid inhibitor herbicides when pre-emergence programs differ in their levels of efficacy.

2 | MATERIALS AND METHODS

A field experiment was conducted in 2017 at two locations, the first near Crawfordsville, AR, on a Dundee silt loam soil (fine-silty, mixed, active, thermic Typic Endoaqualfs), and the second near Marion, AR, on a Dubbs silt loam soil (fine-silty, mixed, active, thermic Typic Hapludalfs). The soil near Marion had a pH of 5.8 with 1.6% organic matter; the soil near Crawfordsville had a pH of 5.3 with an organic matter content of 1.8%. The soil at Marion has a soil texture of 26% sand, 64% silt, and 10% clay, whereas the soil at Crawfordsville was 11% sand, 77% silt, and 12% clay. Experiments were set up as a split-plot design with four replications, with the postemergence herbicide specific for a soybean technology as the whole-plot factor and the pre-emergence program as the subplot factor. At each location, plots measuring 12.67 ft wide by 25 ft long were established on rows 38 in wide. Plots were established in a location prepared by a preplant burndown herbicide 2 wk prior to planting [paraquat (1-methyl-4-[1-methylpyridin-1-ium-4-yl]pyridin-1-ium) at 0.625 lb a.i. acre^{-1}] and tillage. Pre-emergence herbicides were applied immediately after soybean planting. The first postemergence treatments were applied at 28 d after planting and the second postemergence application was made at 42 d after planting. All herbicide applications in Crawfordsville were made at 15 gal acre^{-1} with a four-nozzle boom attached to a CO_2-pressurized backpack sprayer (Model T, 315 Backpack, R&D Sprayers, Opelousas, LA); applications in Marion were made at 12 gal acre^{-1} with a four-nozzle multi-boom attached to a Bowman Mudmaster sprayer (Bowman Manufacturing, Newport, AR), each at 3 m h^{-1}. Planting dates, varieties, and seeding rates for each location are shown in Table 1. Both locations were dryland sites, making precipitation necessary to activate pre-emergence treatments. Rainfall data from weather stations at both sites are shown in Figure 1.

2.1 | Pre-emergence residual programs

Preemergence programs consisted of three options, which were expected to provide distinctly different levels of Palmer amaranth control (excellent, fair or poor) according to previous research at these sites. The pre-emergence

TABLE 1 Soybean variety, planting dates, and seeding rate for Crawfordsville and Marion locations

Location	Variety	Postemergence technology[a]	Planting date	Seeding rate
				seed acre^{-1}
Crawfordsville	'PR 4909'	Roundup Ready	23 May 2017	140,000
	'P48T67 LL'	LibertyLink		
	'AG 46 × 6'	Xtend		
	'51E16H2'	Enlist		
Marion	'AG 47 × 6'	Roundup Ready	10 May 2017	150,00
	'HBK 4953LL'	LibertyLink		
	AG 47 × 6	Xtend		
	51E16H2	Enlist		

[a]The active ingredients of each technology are listed in Table 3.

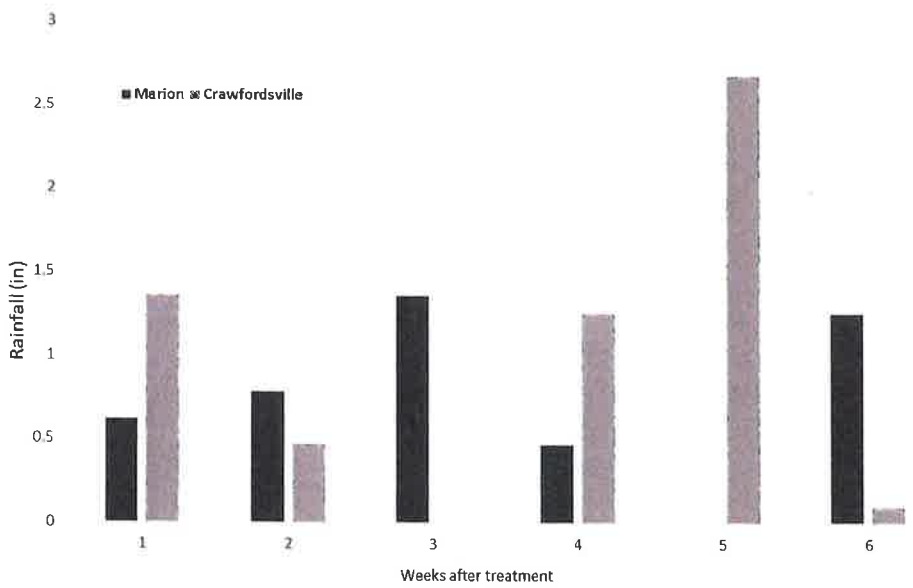

FIGURE 1 Rainfall data for Marion and Crawfordsville, Arkansas each week after planting in 2017

programs consisted of saflufenacil [2-chloro-4-fluoro-5-(3-methyl-2,6-dioxo-4-[trifluoromethyl]pyrimidin-1-yl)-*N*-(methyl[propan-2-yl]sulfamoyl)benzamide] (0.022 lb a.i. acre^{-1}) + dimethenamid-p [2-chloro-*N*-(2,4-dimethylthiophen-3-yl)-*N*-([2*S*]-1-methoxypropan-2-yl)acetamide] (0.195 lb acre^{-1}) + pyroxasulfone [3-([5-(difluoromethoxy)-1-methyl-3-(trifluoromethyl)pyrazol-4-yl]methylsulfonyl)-5,5-dimethyl-4*H*-1,2-oxazole] (0.133 lb acre^{-1}) + metribuzin (0.28 lb A^{-1}), *S*-metolachlor (0.986 lb acre^{-1}) + metribuzin (0.216 lb acre^{-1}), and flumioxazin [2-(7-fluoro-3-oxo-4-prop-2-ynyl-1,4-benzoxazin-6-yl)-4,5,6,7-tetrahydroisoindole-1,3-dione] (0.064 lb acre^{-1}) alone (Table 2). Pre-emergence treatments were applied with 110015 TeeJet air induction extended range nozzles (TeeJet Technologies, Wheaton, IL). Pre-emergence programs were assessed at 28 d after pre-emergence with ratings based on a 0 to 100% scale of control, where 0% was no control and 100% was complete weed mortality relative to the nontreated control (Frans & Talbert, 1977). A nontreated control was included for each HR soybean trait. Weed densities, which were taken as two separate counts per 1.64 ft^2 in each plot, were recorded at 28 d after pre-emergence at Marion but not Crawfordsville.

2.2 | Foliar programs

Seed technologies included were: glyphosate-, glufosinate-, dicamba-, and 2,4-D-resistant cultivars (Table 1). Each HR soybean seed technology received one postemergence treatment, but the dicamba- and glufosinate-resistant soybean received a second postemergence treatment. Postemergence treatments were applied 28 d after the pre-emergence application (POST 1) or at 14 d after POST 1 (POST 2). Postemergence treatments included for

TABLE 2 Pre-emergence (PRE) Palmer amaranth control and density reduction across postemergence (POST) technologies averaged over experiments conducted at Crawfordsville and Marion, AR, in 2017

Herbicide	Rate	Control			Density reduction[a]	
		28 DA PRE	14 DA POST 1	14 DA POST 2	28 DA PRE[b]	14 DA POST 2
	lb a.i. acre^{-1}	%				
Flumioxazin	0.064	74[c] b	86 b	83 b	72	89 b
S-metolachlor + metribuzin	0.986 + 0.216	88 a	94 a	88 a	82	97 a
Saflufenacil + dimethenamid-p + pyroxasulfone + metribuzin	0.022 + 0.195 + 0.133 + 0.280	95 a	96 a	91 a	87	97 a
PRE (*p*-value)		<.0001	.0060	.0071	.2572	.0238

[a]Average Palmer amaranth density for the nontreated control was 10 per ft^2 at 28 d after (DA) PRE and 7 per ft^2 at 14 DA POST 2.
[b]Density reduction ratings for 28 DA PRE include only Marion, AR.
[c]Means within a column followed by the same lowercase letter are not different according to Fisher's protected LSD ($P = .05$).

this experiment were based on currently labeled recommended programs for their respective HR soybean trait. The postemergence program containing dicamba did not include additional herbicides, such as glyphosate or *S*-metolachlor, because of label restrictions in Arkansas at the time of the trial's initiation (Monsanto, 2018). For POST 1 applications, treatments consisted of glyphosate (0.63 lb a.i. acre^{-1}) + fomesafen (0.237 lb acre^{-1}) + *S*-metolachlor (1.081 lb acre^{-1}), glufosinate (0.53 lb acre^{-1}) + fomesafen (0.237 lb acre^{-1}) + *S*-metolachlor (1.081 lb acre^{-1}), dicamba (0.5 lb a.i. acre^{-1}), and 2,4-D (0.949 lb a.i. acre^{-1}) + glyphosate (0.9 lb acre^{-1}) + *S*-metolachlor (0.949 lb acre^{-1}) (Table 3). Dicamba- and 2,4-D-containing treatments were applied with 110015 turbo Teejet induction nozzles (TeeJet Technologies, Wheaton, IL), to minimize particle drift and subsequent damage to neighboring plots of soybean that were not resistant to dicamba or 2,4-D (Monsanto, 2018). Glufosinate and glyphosate treatments were applied with 110015 air induction extended range nozzles. Postemergence applications were made to the middle two rows of the four-row plot to minimize off-target movement of postemergence herbicides to neighboring soybean technologies and provide relative control between the postemergence treatments and the pre-emergence programs. Visible estimates of weed control for the postemergence applications were taken at 14 d after POST 1 and 14 d after POST 2. Trials at both locations were destroyed prior to soybean maturity to minimize Palmer amaranth seed production at both on-farm sites.

All data were analyzed in SAS version 9.4 (SAS Institute Inc., Cary, NC) via the GLIMMIX procedure to evaluate each timing as proportions with a beta distribution. Locations, replication (nested within locations), and all interactions containing these effects were considered random effects in the model. The whole-plot (postemergence), subplot (pre-emergence), and the interaction between the two were considered as the fixed effects in this model. Palmer amaranth densities were analyzed as the percentage of reduction from the nontreated control. Nontreated weed control rating data were removed from analysis because of 0% control in all replications at both locations. All means were separated via Fisher's protected LSD ($P = .05$).

3 | RESULTS AND DISCUSSION

From the analysis previously mentioned, a postemergence × pre-emergence interaction was not observed at any point throughout the experiment (Table 3). The absence of an interaction between postemergence and pre-emergence was not surprising, as postemergence herbicides applied to the glufosinate-, 2,4-D-, and dicamba-resistant soybean resulted in similar control across all pre-emergence

TABLE 3 Influence of postemergence (POST) herbicide programs on Palmer amaranth control and density reduction across pre-emergence (PRE) treatments averaged over experiments conducted at Marion and Crawfordsville, AR, in 2017

POST program	Herbicide		Rate	Control		Density reduction[a]
	POST 1	POST 2		14 DA POST 1	14 DA POST 2	
			lb a.i. acre^{-1}	%		
Roundup Ready	Glyphosate + fomesafen + *S*-metolachlor	–	0.630 + 0.237 + 1.081	83[b] b	59 b	87 b
Enlist	2,4-D + glyphosate + *S*-metolachlor	–	0.949 + 0.900 + 0.949	95 a	96 a	98 a
Roundup Ready 2 Xtend	Dicamba	Dicamba	0.499 fb 0.499	95 a	97 a	94 ab
LibertyLink	Glufosinate + fomesafen + *S*-metolachlor	Glufosinate	0.529 + 0.237 + 1.081 fb 0.529	96 a	97 a	98 a
POST (*p*-value)				<.0001	<.0001	.0095
POST × PRE (*p*-value)				.8936	.7959	.1140

[a]Means within a column followed by the same lowercase letter are not different according to Fisher's protected LSD ($P = .05$).
[b]Average Palmer amaranth density for the nontreated control was 7 per ft^2 at 14 d after (DA) POST 2.

treatments at both 14 d after both postemergence treatments . Hence, the following results are focused on each split-plot factor separately.

3.1 | Pre-emergence residual control

Visible estimates of control for Palmer amaranth at 28 d after pre-emergence show that pre-emergence programs differed in effectiveness (Table 2). Flumioxazin, a PPO-inhibiting herbicide, resulted in less than 74% control of PPO-resistant Palmer amaranth. Flumioxazin, as noted in previous research, controlled some Palmer amaranth by segregating PPO-resistant *Amaranthus* populations (Schwartz-Lazaro et al., 2017). *S*-metolachlor + metribuzin resulted in 88% control, significantly better than flumioxazin. The best pre-emergence program for control of PPO-resistant Palmer amaranth was saflufenacil + dimethenamid-p + pyroxasulfone + metribuzin at 95%, significantly higher than both other options (Table 2). Density reductions, which are shown as a percentage of the nontreated control, showed similar numerical trends but the treatments were not statistically different (Table 2). The majority of the survivors of the pre-emergence flumioxazin treatment did not appear to be injured compared with the nontreated, other than some very slight stunting. This confirms both a segregating PPO-resistant Palmer amaranth population, as previously mentioned, and the presence of one or both target-site-resistant mechanisms (ΔG210 and R128G/M) at these locations, as discussed by Varanasi et al. (2018).

Residual control improved as the number of applied SOAs increased, suggesting that a PPO-inhibiting herbicide alone applied pre-emergence will not effectively control these Palmer amaranth populations, as reported previously (Schwartz-Lazaro et al., 2017). Visible weed control for 14 d after POST 2 declined slightly across all pre-emergence programs, each down 3 to 6% percentage points, but maintained a significant trend (Table 2). At each rating, pre-emergence treatments with metribuzin in the mixture increased the control of PPO-resistant Palmer amaranth over the single flumioxazin application; control was increased even more when metribuzin was combined with a very long-chain fatty acid inhibitor herbicide. Even though *S*-metolachlor proved to be an effective mixture with metribuzin throughout the pre-emergence evaluations, recent research have found *S*-metolachlor-resistant Palmer amaranth populations at both of the study locations, putting an emphasis on finding an efficacious very-long-chain fatty acid inhibitor herbicide if these are considered for use (Brabham et al., 2019). Densities separated statistically as well, with flumioxazin (89%) providing

less control than the other pre-emergence programs (both 97%).

3.2 | Foliar applications

Glufosinate + fomesafen + *S*-metolachlor (96%), 2,4-D + glyphosate + *S*-metolachlor (95%), and dicamba (95%) resulted in more Palmer amaranth control than glyphosate + fomesafen + *S*-metolachlor (83%) at 14 d after POST 1 (Table 3). The glufosinate-, 2,4-D-, and dicamba-resistant soybean programs did not differ for Palmer amaranth control at 14 d after POST 1. In the glyphosate + fomesafen + *S*-metolachlor postemergence program, there was no effective foliar herbicide because of the multiresistant Palmer amaranth population. Because this program has no effective postemergence control, the ratings are mainly a product of the residual herbicides applied. At 14 d after POST 2, the glufosinate-, 2,4-D-, and dicamba-resistant soybean programs provided 37 to 38% more Palmer amaranth control than the glyphosate-resistant soybean technology, as both foliar and residual herbicides failed to control PPO-resistant Palmer amaranth. Significant differences in density reduction occurred for the glyphosate- (87%) vs. 2,4-D- (98%) technologies and the glufosinate-resistant (98%) soybean program at 14 d after POST 2. As expected, the glyphosate-resistant soybean technology did not provide an effective postemergence option for control of these multiresistant Palmer amaranth populations (Meyer et al., 2015; Norsworthy, Griffith, Scott, Smith, & Oliver, 2008).

3.3 | Practical implications

Preemergence programs that do not include multiple effective SOAs did not provide above 80% control of PPO-resistant Palmer amaranth. Although postemergence programs in glufosinate-, 2,4-D, and dicamba-resistant soybean regained some lost control in the least effective pre-emergence program, pre-emergence programs like flumioxazin alone are not recommended. These programs would increase selection for resistance to postemergence herbicides and result in the possible failure of a postemergence program because of large weed sizes and high weed densities when environmental conditions are not conducive to a timely application. Residual herbicides are also recommended to be included in early postemergence applications to suppress emerging Palmer amaranth until canopy formation is achieved (Loux et al., 2017). Glufosinate, 2,4-D, and dicamba all have excellent activity on PPO-resistant Palmer amaranth; these programs were shown here to provide an extended period of weed control. There is no effective postemergence herbicide option available in glyphosate-resistant soybean when the Palmer amaranth population exhibits resistance to glyphosate as well as acetolactate synthase- and PPO-inhibiting herbicides. Regardless of pre-emergence program, extended Palmer amaranth control was not possible and suggests a lack of viability in the glyphosate-resistant technology. Producers should consider glufosinate-, 2,4-D-, and dicamba-resistant soybean as the only technologies with viable postemergence options in areas where Palmer amaranth with the abovementioned resistance portfolio has been confirmed or confirmation is likely.

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CONFLICT OF INTEREST

The authors report no conflicts of interest.

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EXHIBIT NO. 14

COMMENTS OF

RICHARD MAYS LAW FIRM PLLC

TO ARKANSAS PLANT BOARD

RE: DICAMBA REGULATIONS

April 22, 2021

Office of
INDIANA STATE CHEMIST AND SEED COMMISSIONER

Protecting Indiana's Agriculture and Environment - Feed, Fertilizer, Pesticide and Seed

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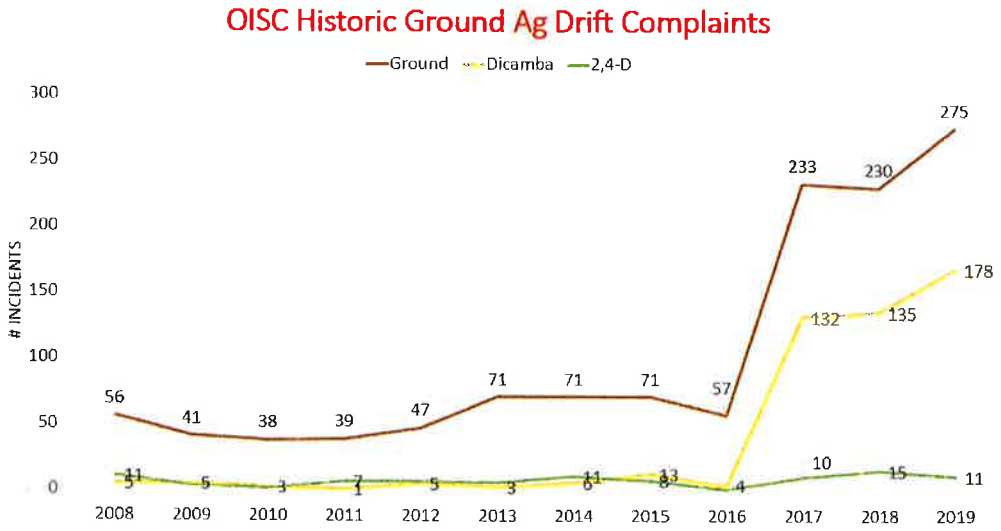
Robert D. Waltz, Ph.D.
State Chemist &
Seed Commissioner

October 30, 2019
Analysis of Off-Target Movement of Dicamba Herbicides in Indiana

The Office of Indiana State Chemist (OISC) has done a detailed review and analysis of off-target movement incidents of dicamba herbicide in Indiana for a period covering more than a decade, up to and including 2017 through 2019. These products include Engenia Herbicide (EPA Reg. No. 7969-345), DuPont Fexapan Herbicide with VaporGrip Technology (EPA Reg. No. 352-913), Xtendimax with VaporGrip Technology (EPA Reg. No. 524-617), and Tavium Plus VaporGrip Technology Herbicide (EPA Reg. No. 100-1623). As a result, OISC has determined that dicamba-containing herbicides intended for post emergence application are not adequately labeled to sufficiently prevent unreasonable adverse effects from occurring to non-target crops and plants. The OISC analysis included the following:

1. Annual off-target movement complaints to OISC for agricultural ground applications of dicamba herbicides for the period of 2008 -2016 averaged five but never exceeded 13. By contrast, since the introduction of the post emergence use of dicamba on soybeans, the period 2017-2019, the annual average number of dicamba complaints investigated by OISC has risen sharply to 153, with the highest number 178, occurring in 2019. This unprecedented triple digit increase in the number of off-target movement complaints and investigations appears to continue to be trending upward each year since the formal introduction of these product uses in 2017.



2. Mandatory annual product-specific applicator and handler training and other product stewardship activities conducted by product registrants, pesticide state lead agencies, the Cooperative Extension Service, university weed scientists, and other stakeholders since the introduction of these products in

2016-2019 have not been successful in significantly reducing the incidents of off-target movement in Indiana and most other major soybean producing states.

3. Exhaustively detailed and specific drift management restrictions on the current labels of these products have not been successful in normalizing the incidence of off-target movement of dicamba to a reasonable level comparative with other herbicide applications, including the application of older formulations of dicamba. Some of the more critical drift management requirements on the label, including: 1) precise and continuous wind speed and direction monitoring throughout an entire application; 2) field level prediction and measurement of temperature inversion conditions; 3) extensive application equipment cleaning; 4) identifying all sensitive downwind crops and plants; and 5) determining how far damaging levels of dicamba may move from the target site, are not technically feasible or practical for many dicamba applicators, regardless of the applicator's level of training and competency.

4. Several attempts by U.S. EPA to refine label use restrictions on the dicamba products beyond the 2017 and 2018 restrictions have not markedly mitigated the incidence of off-target movement in Indiana or most other major soybean producing states. Based on the minimal formal engagement of U.S. EPA with impacted states during the 2019 application season, it appears that that the U.S. EPA is unwilling or unable to recognize and react to the fact that these products have not been adequately labeled to minimize adverse effects from occurring in most of the nation's top soybean producing states.

5. Since 2017, OISC has increased product application compliance scrutiny and the level of enforcement response for non-compliant applications, but this has been largely unsuccessful in reducing the incidence of off-target movement.

6. University research conducted since 2016 for some of these products is demonstrating or suggesting the following: 1) some common label-permitted tank mixes may increase volatility of applications of these products; 2) application of these products to low pH soils may increase the likelihood of post application volatility and off-target movement; 3) field level temperature inversions are more common than previously realized by pesticide applicators and are difficult to measure and document with any precision; and 4) some glyphosate resistant weed species are also developing resistance to dicamba.

7. Several glyphosate resistant weed control options and technologies other than dicamba are currently available in the marketplace. Rotating between herbicide chemistries and modes of action is currently highly recommended on most dicamba and other herbicide labels.

8. Based on application dates of dicamba complaints investigated by OISC in 2017 through 2019, setting an application cut-off date of June 20, 2020 could reduce dicamba off-target movement incidents in 2020 by a projected 50% or more. While a 50% reduction would represent a step in a positive direction, it might still be inadequate in achieving the objective of normalizing dicamba off-target movement incidents to a scale similar to that of other widely used ground applied agricultural herbicides in Indiana.

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