WSSA Research Workshop for Managing Dicamba Off-Target Movement: Final Report

EXECUTIVE SUMMARY

The Weed Science Society of America (WSSA) sponsored a research workshop on off-target movement of dicamba on April 16 -17, 2018 in Arlington, VA. WSSA invited a broad group of subject experts including weed scientists, state and federal regulators, application technology specialists, and representatives of dicamba registrants to discuss technical issues related to the off-target movement of dicamba observed and reported in 2016 and 2017, and to identify potential research objectives. The research workshop agenda was divided into four topic areas: I) Non-target impacts; II) Volatility; III) Application; and IV) Formulation. Within each topic area, presentations were made to provide an overview and to identify information that was not known and data gaps to be addressed going forward. Following the presentations, discussion was facilitated among participants to identify areas of concern and research questions that were subsequently ranked in order of importance. Following this compilation, suggested action items within each topic area were identified and included the following:

- Compile a comprehensive account of areas planted in dicamba-resistant crop cultivars by county, and quantities of all formulations of dicamba sold at minimum by state.
- Relate reported damage complaints to terrain and weather conditions.
- Improve deficiencies with herbicide labels to address: 1) lack of uniformity in label organization; 2) difficulty in finding and interpreting use instructions; 3) names of dicamba sensitive crops, landscape and native plants, and trees; 4) "neighboring distance" for sensitive crops; 5) descriptions of conditions leading to atmospheric inversions to protect applicators and neighbors.
- Coordinate applicator training such that all trainers present the same detailed message.
- Perform research to better characterize the potential volatility of new herbicide formulations.
- Perform research to better determine: 1) dose vs. damage relationships for key crops; 2) how to protect growers, property owners, and the public from off-target movement; and 3) modes of dicamba movement that are not currently accounted for.

There was sentiment from the group that the widespread non-target movement of dicamba was egregious and resulted in damage to crops, private properties, and native vegetation. Although amelioration of this situation was partly outside of research, attribution of liability should be addressed by appropriate authorities, particularly for horticultural growers who are suffering heavy financial losses. More funding for public research is needed. Concern was expressed that USDA-ARS and USDA-NIFA were not funding the type of research needed to manage off-target pesticide movement.

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Research Workshop Participants (Appendix 1)
WSSA Environmental Aspects of Weed Management Committee
WSSA Formulation, Adjuvant, and Application Technology Committee

Citation

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About the Weed Science Society of America

The Weed Science Society of America, a nonprofit scientific society, was founded in 1956 to encourage and promote the development of knowledge concerning weeds and their impact on the environment. The Society promotes research, education and extension outreach activities related to weeds, provides science-based information to the public and policy makers, fosters awareness of weeds and their impact on managed and natural ecosystems, and promotes cooperation among weed science organizations across the nation and around the world. For more information, visit www.wssa.net.

INTRODUCTION

The Weed Science Society of America (WSSA) sponsored a research workshop for managing dicamba off-target movement on April 16 -17, 2018 at the AMA Executive Conference Centers in Arlington, VA. WSSA invited a select group of weed scientists, agricultural chemical application specialists, representatives of state agrichemical organizations and regulatory agencies, dicamba registrants, and the U. S. Environmental Protection Agency (EPA) to discuss technical issues related to the off-target movement of dicamba that occurred in 2017 and to identify potential research objectives for 2018. A list of research workshop participants is provided in Appendix 1.

The research workshop agenda (Appendix 2) was divided into four topic areas: I) Non-target impacts; II) Volatility; III) Application; and IV) Formulation.

I. **Non-Target Impacts** – Dicamba is an auxin hormone mimic whose herbicidal effect results from its relative potency as a plant growth regulator. Crops in the Leguminosae; Cucurbitaceae, and Solanaceae families are often highly susceptible. Soybeans are extremely susceptible and may demonstrate epinasty below the limit of detection of many analytical methods. The majority of reports of damage from off-target dicamba movement have been to soybeans. However, there is considerable concern for horticultural crops particularly in the Midwest where potential dicamba-treated soybean acreage is high. Damage has also occurred to home gardens, landscape plants, and natural vegetation including trees – cypress and certain oak species, and native herbaceous ground cover that serves as food for pollinators. Effects of low-rate dicamba exposure on native vegetation remain unquantified.

II. **Volatility** – Compared to other herbicides, the parent acid of dicamba is relatively volatile and has a vapor pressure of 4.5 x 10^{-3} Pa at 25 C (Appendix 3). The new dicamba herbicide products are of two different types. Engenia®, produced by BASF, is intended to reduce volatilization by complexing dicamba acid with a *N*,*N*-Bis-(3-aminopropyl) methylamine (BAPMA) salt that has a higher molecular weight (366.29 g/mole) than other previously registered dicamba salt formulations (Appendix 3). The Monsanto and DuPont herbicides, XtendiMax™ With VaporGrip™ and FeXapan™, respectively, are the same as the dicamba diglycolamine (DGA) salt formulation currently registered in Clarity®. Physical drift and post depositional volatilization are different phenomenon. Whereas the new formulations in some studies have been shown to reduce volatilization in comparison to the un-amended DGA formulation, research in several locations including AR, MO, MS, and TN show that the flux of dicamba from treated areas continues for at least three days. The conclusion from a review of the solution chemistry and from volatilization studies is that post depositional release, i.e., volatilization, occurs from the tested formulations in the type of atmospheric conditions likely to occur in agricultural fields during summer months.

III. **Application Issues** – Requirements for application of the new dicamba formulations are quite explicit. There has been concern that certain applicators failed to follow the label instructions. Over 2,700 official complaints of damage to crops, primarily to soybeans (Appendix 4), but also to other crops and vegetation, including orchards and vegetable crops have been received. State regulatory specialists who spoke indicated that while investigations of only a percentage of the reported incidents were completed, incidents of both misapplication and incidents where no identified cause was evident have been observed. State Extension Weed Scientists estimated there were approximately 3.6 million acres of dicamba-injured soybeans in 2017 (Appendix 5). Percentages of unexplained incidents differed among states, but large percentages of unexplained incidents were reported by some states.

IV. **Formulations** – To this point, there has been no comprehensive accounting of the amount of dicamba-resistant crops planted, nor the use of the various dicamba herbicide formulations (new and old) in the 34 states where the new dicamba formulations are approved for use. A survey of 22 weed scientists from 19 states indicated that about 5% of the off-target injury was attributed to the use of non-labeled dicamba formulations in 2017. The estimates for non-labeled dicamba use in that survey ranged from 0 to 20%. Understanding which formulations were used at what locations during 2017 could assist in better understanding dicamba volatility potential.

Each topic area had the same format: 1) presentations (Table 1) on our current state of knowledge; 2) a facilitated discussion; and 3) prioritization of discussion/action items.

Table 1. List of presenters, affiliation, presentation topic and hyperlink to presentation

Presenter	Affiliation	Presentation Topic and Hyperlink
Bryan Young	Purdue University	Non-Target Impacts: Agronomic Crops
Steve Smith	Red Gold, Inc.	Non-Target Impacts: Horticultural Crops
Dave Mortensen	Penn State University	Non-Target Impacts: Pollinators
Rich Zollinger	AMVAC Chemical Corp.	Volatility: Formulation Chemistry
Dan Reynolds	Mississippi State University	Volatility: Small-Scale Studies
Tom Mueller	University of Tennessee	Volatility: Large-Scale Studies
Stanley Culpepper	University of Georgia	Application Issues: Assessment of Training Programs
Rich Grant	Purdue University	Application Issues: Temperature Inversions
Andrew Hewitt	University of Queensland	Application Issues: Physics of Particle Drift
Kevin Bradley	University of Missouri	Formulations: Assessment of Formulations Used
Jean Payne	Illinois Fertilizer & Chemical Association	Formulations: Assessment of Compliance

Following the presentations within each topic area, Dr. Phil Banks facilitated a discussion among the workshop participants during which they identified areas of concern and research questions that should be considered in order to better manage dicamba off-target movement. These areas of concern and research questions were subsequently ranked in order of importance by the workshop participants (Table 2). Each participant was allowed to select up to two primary areas of concern and two secondary areas of concern within each topic area. Using 2 points for areas of primary concern and 1 point for areas of secondary concern, Dr. Banks tallied the results to determine a ranking of these areas of concern and research questions within each topic area. Differences in the total number of points awarded among the sections reflect in part that the number of participants present were not the same on the two days of the meeting.

TABLE 2. Ranking of the areas of concern and research questions deemed most important by workshop participants to manage dicamba off-target movement.

I. Non-Target Impacts	Sub-topic	Primary (2 pts)	Secondary (1 pt)	Total points	Rank
Contrast plant exposure response to dicamba aerosol versus dicamba vapor.	Agronomic	24	3	51	1
Establish dicamba residue tolerance levels in horticultural crops.	Horticulture	10	9	29	2
Quantify dose vs. damage as a function of duration of exposure.	Agronomic	5	18	28	3
Determine effect levels from drift on established pollinator plants.	Pollinators	8	8	24	4
Investigate the interaction of plant stresses and exposure to dicamba.	Agronomic	2	10	14	5
Assemble all drift data on non-target crops.	Horticulture	3	2	8	6
Add a tracer to dicamba to confirm exposure.	Agronomic	2	2	6	7
Populate a map of “hot spots” where dicamba injury has occurred.	Pollinators	1	2	4	8
Identify pollinator habitats serving multiple insect groups.	Pollinators	1	0	2	9
Determine if varieties within a crop respond differently to exposure.	Agronomic	0	1	1	10

II. Volatility	Sub-topic	Primary (2 pts)	Secondary (1 pt)	Total points	Rank
Determine the effect of tank mix partners on dicamba volatilization	Volatility	10	7	27	1
Determine the effect of leaf surface moisture pH on unabsorbed dicamba.	Volatility	12	3	27	2
Conduct large scale environmental monitoring of dicamba flux.	Volatility	6	6	18	3
Utilize information from plant pathology about leaf/dew chemistry.	Volatility	4	9	17	4
Differentiate dicamba flux from soil vs. plant canopies.	Volatility	5	3	13	5
Conduct dicamba absorption studies in controlled environments.	Volatility	3	5	11	6
Determine the influence of irrigation	Volatility	1	9	11	7
Use a system similar to that used for reporting soybean rust to report dicamba damage.	Volatility	4	2	10	8
Correlate landscape-scale condensation patterns with observed dicamba injury.	Volatility	2	2	6	9

III. Application Issues	Sub-topic	Primary (2 pts)	Secondary (1 pt)	Total points	Rank
Standardize pesticide labels.	Training Programs	16	17	49	1
Study large- and small-scale landscape effects on inversions where dicamba injury occurred.	Temperature inversions	10	13	33	2
Quantify the flux and mass-balance of dicamba product from applications.	Physics of particle drift	15	2	32	3
Characterize the particle size distribution of applications from air induction nozzles with tank mixtures.	Physics of particle drift	8	13	29	4
Enhance collaboration between companies of application technology and drift reduction agents (DRAs).	Physics of particle drift	11	5	27	5
Determine how droplet sizes that reduce drift impact efficacy.	Physics of particle drift	7	6	20	6
Enhance farm to farm communication about technology use.	Training Programs	4	4	12	7
Determine if there is a correlation between applicator training and off-target movement.	Training Programs	2	6	10	8
Ground truth phone/computer apps that predict inversions.	Temperature inversions	2	5	9	9

IV. Formulations	Sub-topic	Primary (2 pts)	Secondary (1 pt)	Total points	Rank
Define what is “neighboring distance”	Compliance	vote by show of hands			1
Assess the amount of defensively purchased dicamba-resistant crops.	Compliance				2
Develop a standard volatility assay.	Compliance				2

DISCUSSION NOTES

I. Non-Target Impacts – Agronomic and Horticultural Crops

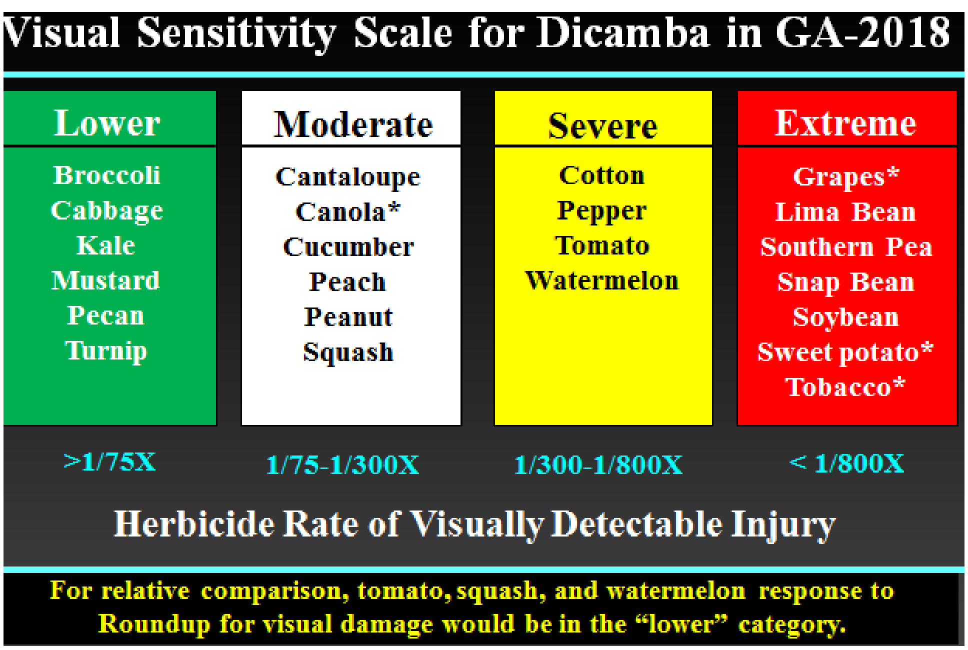
Despite a long history of dicamba use and research, critical questions remain. Dicamba may be reaching agronomic and horticultural crops and natural areas by physical drift and/or post depositional volatilization. Symptoms occur on new growth and may be delayed in appearance depending on the plant growth stage. Since the parent acid of dicamba dissipates fairly quickly in plant tissue (1/2 life of 4 to 20 days), rapid response by the grower, the investigator, and the chemist is needed to identify, collect, and analyze exposed tissue, respectively.

In 2016, the state of Missouri analyzed approximately 1,000 symptomatic plants and found dicamba in only about one half of them. Because of the failure of collection and chemical analysis to detect dicamba when its presence was indicated by visual symptoms, no plants were analyzed in 2017 when there were more symptomatic plants than had occurred in 2016.

The environmental fate of dicamba in soil, water, air and plants is not sufficiently well documented to readily explain the mechanics of exposure from observation of symptomatic plants 2-4 weeks after initial exposure. There is no publicly available experimental information on the buffers (distances) needed to protect susceptible/sensitive crops from dicamba, and only some susceptible/sensitive crops or plants are named on the labels. Moreover, there is little information on the combined effects of prior stress followed by dicamba exposure, or on the relative susceptibility of varieties within crops.

We have a general understanding of the dicamba dose/injury relationship in certain agronomic crops (http://www.arkansas-crops.com/2016/07/07/dicamba-potential-soybean/). However, visual injury symptoms, especially during vegetative stages, are not predictive of final yield loss (Egan et al. 2014). We do not understand dicamba injury relationships well on peanuts and pollinating corn. Crops in the Leguminosae; Cucurbitaceae, and Solanaceae families are often highly susceptible to dicamba (Figure 1). In horticultural crops, dicamba injury can result in financial losses of hundreds of thousands of dollars.

FIGURE 1. (From Dr. Stanley Culpepper presentation)



***Data from literature; all other data generated in over 70 University of Georgia field experiments.**

Exposure to horticultural crops is problematic. Many horticultural crops are sensitive and will lose yield if exposed to dicamba. Certain horticultural and certified organic crops have no dicamba residue tolerance and may be rejected by regulation or their contracted buyers. Tolerances need to be established to protect horticultural and certified organic growers from circumstances beyond their control. Registrants have submitted proposed tolerances to the Environmental Protection Agency for many potentially impacted crops. Similarly, if dicamba is widely dispersed at low, but damaging concentration across the environment, horticulturalists and certified organic growers are unprotected from a general environmental risk through no fault of their own. Dr. Kevin Bradley has conducted studies that show that various tree and ornamental species are also highly susceptible to dicamba (FIGURE 2).

FIGURE 2. Sensitivity of Various Trees and Ornamentals to Injury from Driftable Fractions of Dicamba Products

Low (<10% Injury)	Moderate (10-20% Injury)	Extreme (>20% Injury)
Walnut	Maple	Elderberry
Raspberry	Oak	Peach
Hydrangea	Apple	Grape
Crabapple	Strawberry	Dogwood
	Rose	Redbud
	Sweetgum	Viburnum
	Elm	
	Pecan	

I. Non-Target Impacts – Pollinators

There was considerable concern for pollinator habitats and consequently for the pollinator species. We cannot have a solo concern for honey bees (*Apis mellifera*), because there are many wild bees species (up to 30 different species in a corn field, and up to 150 species in apple orchards). There is much plant diversity in field edges. Wild bees pollinate several plants, and their species composition in an area depends on the specific landscape flora. Bohnenblust et al. 2016 showed that simulated dicamba particle drift (~1% of the field application rate) delayed onset of flowering and reduced the number of flowers in alfalfa and common boneset; however, in the same experiment, plants that flowered produced pollen with similar protein concentrations to those of untreated plants.

Dr. Mortensen estimated that when field margin plants were exposed to dicamba doses from simulated drift, the floral and pollinator resource provisioning capacity of the landscape was reduced by ~20% depending on landscape and crop composition (See Mortensen presentation). However, several parameters strongly influenced the model scenarios, including the relative susceptibilities of pollinator plants to the rate of herbicide drift. There appears to be a need for baseline resource estimates for pollinator use of habitats in agricultural landscapes and a need to identify where the most valuable land areas are for important pollinator plant species. Effects on landscape plants should be included in herbicide drift risk assessment and regulatory policy. No research has been done to correlate 2017 dicamba off-target incidents to floral species/pollinators. Nationally, there is little quantification of dicamba drift impact on anything other than crops. Representatives of state agencies in Arkansas, Minnesota and Indiana reported that they did not collect data on field margins or in Conservation Reserve Program land.

Regarding monarch butterflies (which are not pollinators), Dr. Bob Hartzler's work at Iowa State reported that dicamba drift resulted in leaf distortion on common milkweed, but did not affect the number of monarch butterfly eggs found. No one was aware of anyone else doing this type of research. For perennial plants such as milkweed, it was noted that it's important to use established plants under field conditions and not seedlings. Most common milkweed in the field develops from established rootstocks.

II. Volatility

The parent acid of dicamba has a vapor pressure of 4.5 x 10^{-3} Pa at 25 C (Appendix 3). Vapor pressure increases with increasing temperature thereby increasing the volatility potential for dicamba acid. Soybeans are extremely sensitive and show injury symptoms at 1/20,000th (0.00005) of the labeled rate (Solomon and Bradley 2014).

The most important factors influencing volatilization, a form of secondary drift, are:

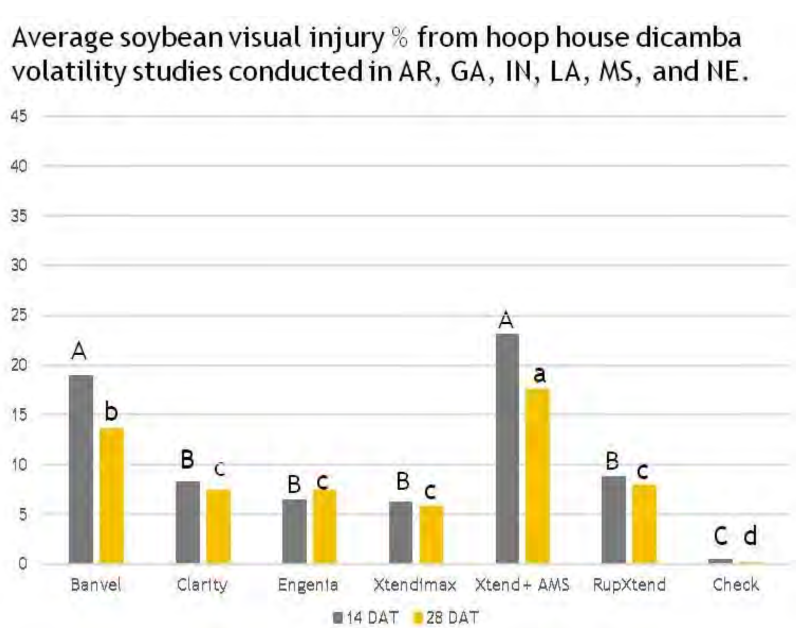
- Formulation – vapor pressure
- Tank-mix additives
- Ambient temperatures during application
- Atmospheric inversions

Methods of measuring volatility:

- Thermogravimetric
- Humidome
- Flux studies / air samplers
- Low tunnels (hoop houses)

Monsanto sponsored a set of dicamba volatilization studies across the South and Midwest in 2017. Studies were done in 20-foot long hoophouses at sites in AR, GA, IN, LA, MS, and NE. Dicamba treated flats of soybeans were placed between two rows of untreated non-dicamba-resistant soybeans in the center of the dome, and plastic sheeting was placed over the dome frame. Dicamba treated flats and plastic sheeting were removed 48 hours after application. Averaged over all sites, soybean injury from Clarity (DGA salt) was the same as from XtendiMax and Engenia (Figure 3). However, the Georgia data set showed more soybean injury from Clarity compared to XtendiMax and Engenia. The Georgia study was the first one established during the growing season. Interpretation of the results will include careful consideration of the environmental data.

FIGURE 3. (From Dr. Dan Reynolds presentation)



Dicamba is a weak acid (pK_a of 1.87, Appendix 3) that will split into positively and negatively charged ions or *dissociate* when mixed in water. The volatility of dicamba formulations is suppressed by keeping the parent molecule of dicamba in solution as an anion. Ammonium sulfate or AMS ($(NH_4)_2SO_4$) is typically used as a spray adjuvant with glyphosate to reduce certain cations in hard water (Ca^{2+}) from antagonizing glyphosate. This antagonism results from the formation of glyphosate salts of low solubility that are not absorbed as readily into plant foliage. However, when AMS + glyphosate is tank mixed with dicamba, the AMS provides a source of hydrogen ions in solution and reduces the spray pH. The higher concentration of hydrogen ions favors the formation of dicamba acid which is the more volatile form of dicamba. Other questions regarding the fate of dicamba on target leaf or soil surfaces include: After water from the spray droplet has evaporated, what is the fate of dicamba crystals? Is the BAPMA cation associated or dissociated with dicamba? What is the active compound in VaporGrip and how long is it associated with dicamba?

Dicamba readily penetrates plant leaves, roots, and stems (Appendix 3). Dicamba formulations differ in the amount of dicamba absorbed by plants both with and without surfactants (Petersen et al. 1985). Dr. Richard Zollinger presented data showing that 38 to 75% of applied dicamba is absorbed by soybean leaves. Therefore, 62 to 25% of the applied dicamba is unaccounted for in the study for soybeans.

Dicamba is weakly adsorbed to soil and is mobile suggesting that dicamba volatilization from soils also contributes to plant injury. However, Burnside and Lavy 1966 showed that the major form of dicamba degradation is due to soil microbial and/or chemical decomposition. Dr. Tom Mueller has preliminary data that shows that dicamba volatility is greater from plant surfaces than from bare soil. Behrens and Lueschen 1979 showed that soybean injury from the volatilization of the dicamba dimethylamine (DMA) salt was approximately twice as great when 3-ft tall corn was treated compared to 1-ft tall corn under field conditions. Rewetting of the leaf surface reinitiates the volatilization process. The effects of leaf surface pH and the pH of rain or dew are unknown. Dr. Dave Mortensen suggested that we utilize information from plant pathology research on the effects of surface chemistry of leaves on spore germination to inform potential effects of leaf surface and dew chemistry to impact the solubility of dicamba in that environment.

Effects of dicamba vapor are relatively unknown because many studies intended to simulate drift are sprayed at 10 to 15 gallons of spray carrier per acre (GPA). Concentrations of dicamba in such treatment solutions are not the same as the concentration of dicamba spray drift; rather the treatments applied in 10 to 15 GPA resemble concentrations found with spray tank contamination. Herbicides in a spray solution at 15 GPA do not necessarily behave the same as herbicides in vapor form. Also, it is difficult to do research with herbicides in the vapor form. The participants asked:

- How can dicamba vapor be generated at known concentrations?
- How can time of dosing be controlled?
- How should air samplers be positioned in a vapor study?
- How long should the vapor experiment be monitored?

Research is needed on important factors affecting vapor drift:

- Temperature (Egan and Mortensen 2012)
- Effect of evaporation surface (vegetation type, soils) on volatilization
- Effect of rainfall / irrigation on volatility (Behrens and Lueschen 1979)
- Tank-mix additives (what do they do to volatility profile of the solution)

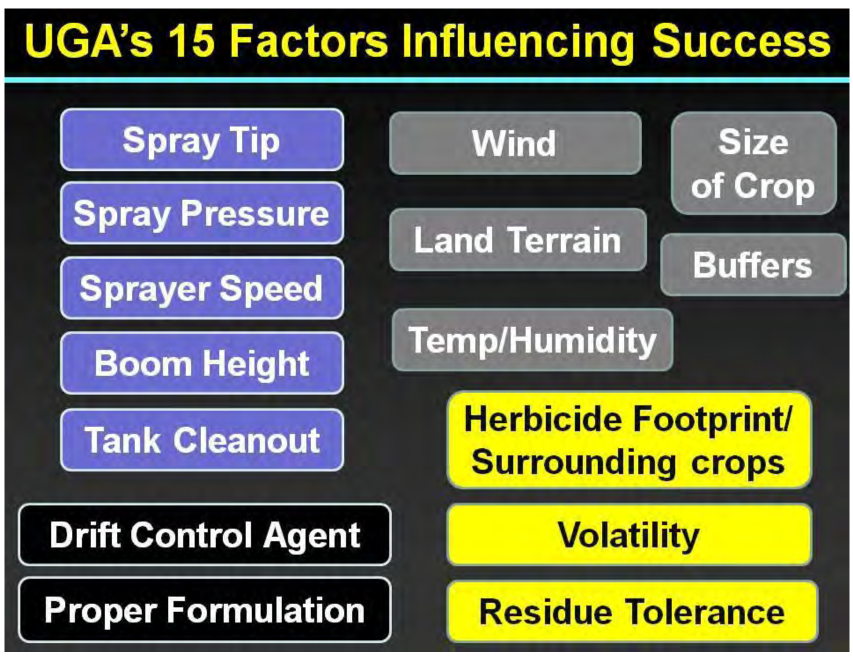
In Northeast AR, the Bootheel of MO, and certain areas of Western TN, entire soybean fields were affected by dicamba with no apparent pattern of drift. Such spatial distributions of symptoms is not consistent with directional drift, but is more consistent with a uniform concentration of dicamba descending upon the fields. Such observations gave rise to the hypothesis of atmospheric loading of dicamba. However, the scale of the possible loading is unknown. Could it have extended over large areas of several thousand acres or parts of counties? The occurrence of dicamba symptoms was so extensive that the same system used for reporting the appearance of soybean rust could be used to report dicamba injury (sbr.ipmpipe.org).

III. Application Issues – Training Programs

Dr. Stanley Culpepper presented important factors from experience gained in the Georgia grower training program "Using Pesticides Wisely."

1. Understand the sensitivity of crops/plants surrounding treated fields -- i.e., better understanding of the auxin footprint (Figure 4).
2. Research is needed to show how far particle drift can go using grower practices.
3. Coordination among the educational providers (Extension, Department of Ag, Industry, EPA, Consultants) is needed so that growers receive the same message.
4. Face to face training was/is critical.
5. Trainers must have an in depth knowledge of both the positives and negatives of the technologies. Unbiased delivery is critical.

FIGURE 4. (From Dr. Stanley Culpepper presentation)



Data gaps identified from a pesticide applicator trainer survey included:

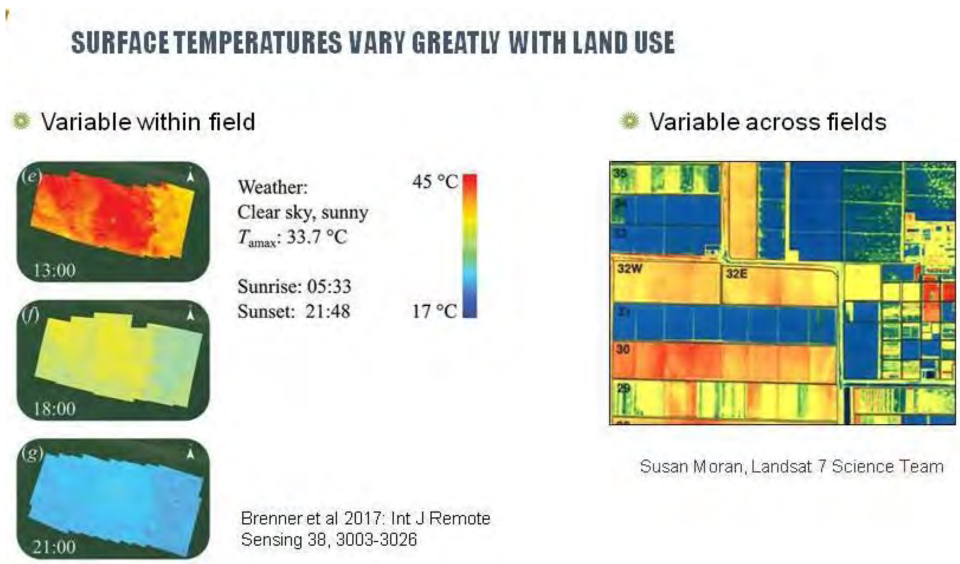
1. Volatility
    a. Data that can be trusted from field experiments
    b. Effects of treating large acreages on neighboring fields
    c. Effects of soil moisture, soil texture, and temperature on off-target movement
2. Has there been any progress in designing spray tips to reduce driftable fines?
3. Tank mixtures

    a. Clearer information on what insecticides and/or fungicides can be safely tank-mixed
    b. When a product is not approved for tank mixing the rationale must be provided to practitioners to understand the basis for the restriction.
4. Time interval that spray droplets remain in the air at lower wind speeds as influenced by the environment.
5. Movement of product in rain water. Since there is a statement on the label, "Do not make application of this product if rain is expected in the next 24 hours", growers asked "Is there danger of dicamba off-target movement through leaching or run-off?"
6. There was general criticism of the complexity of pesticide labels and a call for greater uniformity in the organization of labels. Many participants agreed that the labels for the new dicamba formulations are the most complex ever. Only 25% of Georgia growers were satisfied with being able to find directions on labels and only 32% of the same growers were satisfied with uniformity across labels.

III. Application Issues – Temperature Inversions

Temperature inversions result from surface temperatures decreasing faster than air temperatures, typically as sunset approaches. Inversions vary a great deal across types of landscapes and terrain. Inversions typically develop before, at, or after sunset when there is a 1 to 3 C temperature increase with an increment of height of 2.5 m. Dew usually forms during the spring and summer inversions. Wind moving warm air over cold ground makes advective (horizontal flow) inversions. Because atmospheric temperatures vary greatly with land use (Figure 5), we do not have

FIGURE 5. (From Dr. Rich Grant presentation)



a good understanding of how different surface conditions (i.e. soil characteristics and moisture, various crops, variable terrain) or how small a scale of land use variation can affect inversion formation and hence vapor dispersion across fields and landscapes. We also do not know if dicamba is carried long distances during an inversion and we do not know if it mixes again with the surface air the next morning. We need to measure for the presence of dicamba in the residual layer in the evening and morning and also for its presence in the surface layer in the morning. If dicamba is present, we could develop predictive models using characteristic land use, weather, and winds.

Key questions about dicamba and atmospheric inversions were:

- What forms of dicamba residue reside on the leaf surface?
- What is the potential of these forms to volatilize from the leaf?
- What is their physical behavior – solubility and vapor pressure, when they are re-wetted by dew?
- How and where does the vapor disperse under the inversion?

Dicamba that volatilizes from a leaf surface could move horizontally in an atmospheric inversion. Conditions for such movement may not have been present when the herbicide was applied. Rather different conditions may have prevailed after the product was on the crop and soil surface. Meteorological experts said that conditions producing inversions were known, but could occur over a range of temperatures and wind speeds and were not necessarily predictable from daytime conditions. Terrain elevation affects inversion formation resulting from advection in a predictable manner, but inversion formation was also dependent on heating and cooling of the atmosphere as it interacted with surface temperatures and with broader weather patterns. In general, more inversion events occur during slow moving weather patterns compared to fast moving weather patterns.

A caveat related to use of computer/phone apps that predict temperature inversion was raised. Not all such apps were accurate. Following label guidelines, including only using approved tank-mixtures and avoiding ammonium-containing and acidifying tank-mixtures, helps to maintain the reduced volatility benefits of the new formulations. To reduce local inversion risk at the field scale, Dr. Rich Grant recommended that an applicator measure temperatures at boom height and at the surface and also measure wind speeds at boom height. Several participants noted that atmospheric scientists had developed models for atmospheric movement and had cooperated with EPA to predict movement of air pollutants, however these models have poor predictive ability under surface inversion conditions.

III. Application Issues – Physics of Particle Drift

Spray fate is a complex process. Modeling can help assess the interaction of key factors such as droplet size, spray release position, meteorological conditions, atmospheric stability, canopy interactions, and others. Spray drift is the movement of droplets off-target at the time of application or soon thereafter, prior to the point of the deposition of the droplets. Spray drift exposure to non-target sensitive areas from an application depends on: a) airborne drift; and b) the direction of the sensitive areas relative to the direction (vertical and horizontal) of the wind.

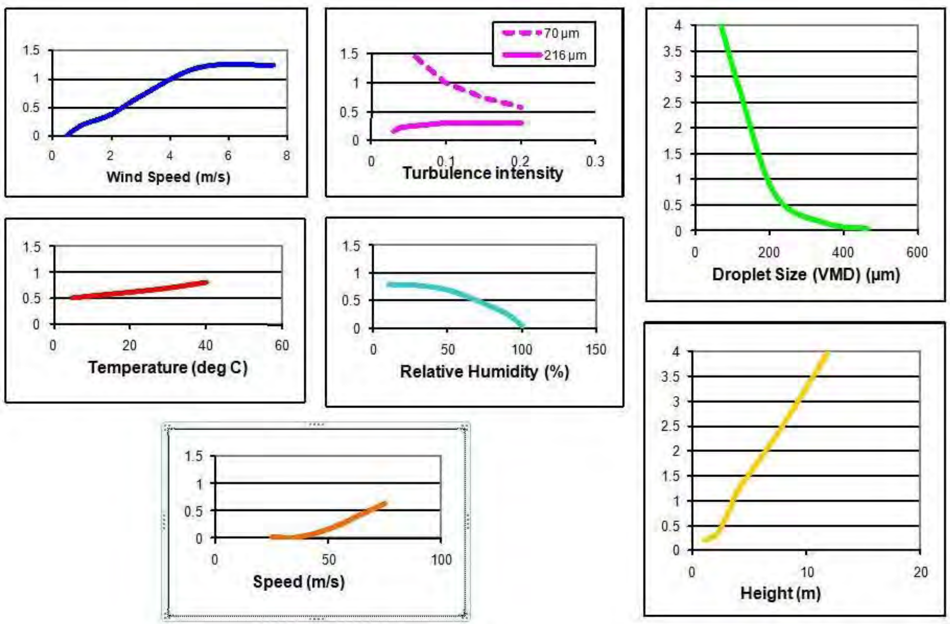
The easy way to avoid spray drift exposure is to not spray small droplets less than 100-150 microns, i.e., *fines*. If there are *fines* in the spray, there can be some mass of the applied spray that can move off-target under unfavorable conditions, but air shields (e.g., spray hoods) can help reduce this. The movement and deposition of *fines* will depend on many factors such as variables associated with the particle size/velocity/shape spectrum, application technique, boom height, sprayer wake/vortices, meteorological and atmospheric conditions, evaporation rate, canopy, barriers, and electrostatic charge (Figure 6).

Spray dynamics are affected by nozzle type, energy input (e.g., spray pressure, rotation rate, air shear) and the physical properties of the tank mix that result from the sum of all the components of the tank mix. Such properties are not always intuitive. Additional data on spray dynamics is always valuable, given the ever-expanding range of nozzles, tank mixes and application scenarios. Further work is ongoing on modeling of ground-based applications. With EPA's Drift Reduction Technology (DRT) program, opportunities exist for new and verified application systems and techniques to avoid/manage spray drift exposure to non-target sensitive areas.

Key questions and concerns about dicamba and physical particle drift were:

- Can we eliminate *fines* with a nozzle? Workshop participants agreed that engineering is narrowing the relative range of particle sizes emitted from the nozzle, but dispersion physics argues against the possibility of totally eliminating *fines*.
- Tank mix solutions play a large factor in the distribution of droplet size. Adjuvant and nozzle manufacturers need to work together.
- How do complex tank mix solutions behave when coming from air induction (AI) nozzles? What is the fate of the air bubbles produced?
- Are Drift Reduction Agents (DRAs) keeping spray droplets intact longer, and are they helping or hurting?
- Quantify the flux and mass-balance of dicamba product from applications to quantify secondary drift dispersion. However, not all dicamba is absorbed; there is no information on where the unabsorbed dicamba is deposited. AgDRIFT does not account for evaporation of volatile compounds.

FIGURE 6. AgDRIFT Sensitivity Analysis. Relative sensitivity (y-axis) of application parameters on spray drift deposition. (From Dr. Andrew Hewitt presentation)



IV. Formulations – Assessment of Formulation Use and Compliance

There has been no comprehensive accounting of the amount of dicamba-resistant crops planted, nor the use of the various dicamba herbicide formulations (new and old) in the 34 states where the new dicamba formulations are approved for use. Based on a survey of 22 weed scientists from 19 states conducted by Dr. Kevin Bradley, estimates of dicamba formulations used on dicamba-resistant soybeans and cotton in 2017 were: Engenia: 50%; XtendiMax: 40%; non-labeled formulations: 5%; and FeXapan: 4%. The estimates for non-labeled dicamba use in that survey ranged from 0 to 20%.

In Arkansas, the only approved formulation for use on dicamba-resistant soybeans and cotton in 2017 was Engenia. A survey of consultants in the Arkansas Agricultural Consultants Association estimated that growers across Arkansas used Engenia 95% of the time. Results from the 2017 Illinois Fertilizer and Chemical Association (IFCA) survey presented by Jean Payne indicated that 89% of IFCA retailers believed that the use of non-labeled dicamba formulations to soybeans was not a major contributor to injury on non-resistant soybeans. Approximately 85% of IFCA retailers experienced dicamba injury symptoms in adjacent sensitive soybean fields, even when the wind was not blowing toward the field at the time of application. Understanding which formulations were used at what locations during 2017 could assist in better understanding which factors are important for managing dicamba off-target movement.

In Missouri, a large agricultural retailer made 330 applications of labeled-dicamba formulations across the state in 2017, but 16% or 55 of those applications resulted in dicamba off-target movement events. Twenty percent or 11 of those off-target events were attributable to off-label conditions such as inappropriate buffer size, wind speed, etc., however, the remaining 80% of those off-target movement events that resulted in dicamba injury (44 cases or 13% of their total applications) could not be explained and thus were likely due to volatilization and/or temperature inversions.

The Illinois Department of Agriculture received 246 dicamba related complaints in 2017 where complaints increased in the latter half of July and first week of August, which corresponded with dicamba applications made 3 to 4 weeks earlier. Illinois had completed 90% of its investigations and sent out 200 violation letters with 65% going to private applicators and 35% to commercial applicators. The primary violation (a warning letter) was wind speed and direction, followed by downwind susceptible species, but no violations were due to generic (non-approved) dicamba use.

The perception from IFCA retailers was that they had to take on all the risk. The three new dicamba formulations labeled for use in dicamba- resistant cotton and soybeans all clearly state: "*AVOIDING SPRAY DRIFT AT THE APPLICATION SITE IS THE RESPONSIBILITY OF THE APPLICATOR*". Complying with regulations and risk exposure from applying dicamba is too expensive. In order to be licensed as a commercial applicator in Illinois, you have to have insurance. Insurance rates are higher for retailers if they are spraying dicamba. Insurance will cover retailers if they made an accident, but it will not cover them if they made the application according to the label, but dicamba injury still occurred in non-target areas. Insurers say that if no wrongful application is found, it is a product problem. There is also the requirement for third party verification of damage for insurance to cover.

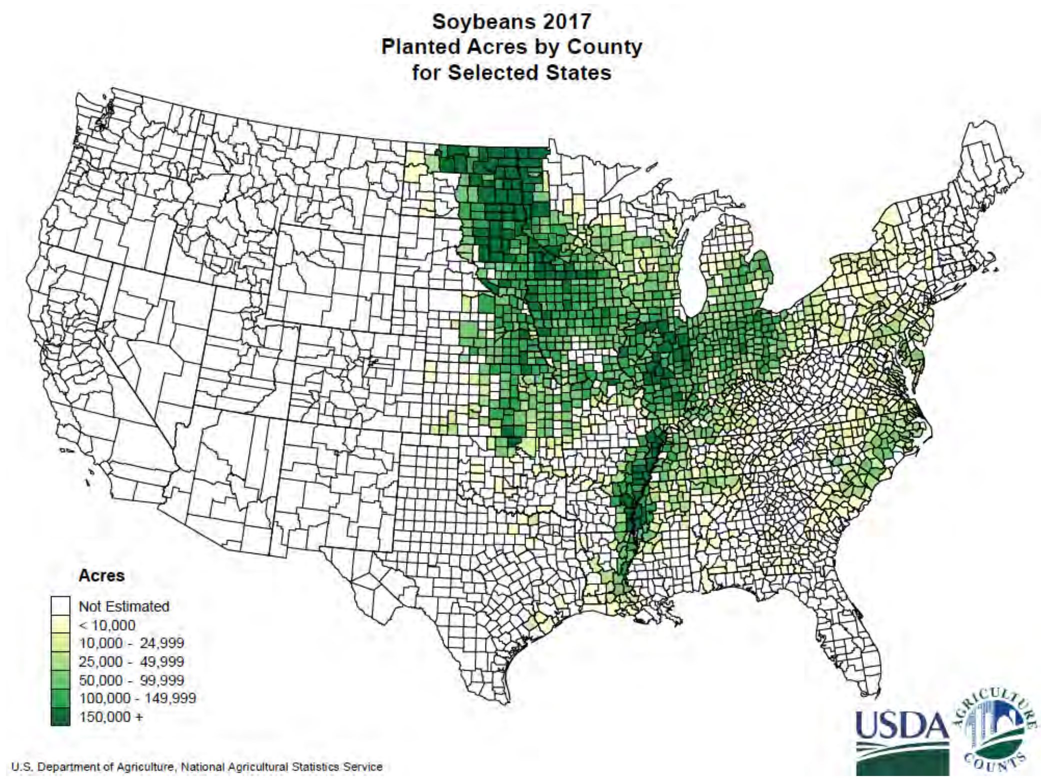
IFCA retailer concerns and suggestions expressed:

- Manufacturers need to share in the responsibility when all other label conditions are followed.
- This is a good weed control tool, if volatility can be addressed. More research should be required to improve the product.
- The additional expense with specialized equipment and insurance costs make it cost-prohibitive for most custom applicators. However, more farmer application of the product will cause bigger problems.
- Specify that the new dicamba formulations should not be used later than 21 days after soybeans are planted. Greater soybean leaf area increases the chance for post depositional movement.
- Include temperature and humidity restrictions. Lower temperatures and higher humidity reduce both physical drift and volatilization.
- Define a longer setback to sensitive crops. Engenia, XtendiMax, and FeXapan labels state "DO NOT APPLY" when the wind is blowing toward/in the direction of adjacent/neighboring susceptible/sensitive crops.
    - What are the susceptible/sensitive crops and plants? The labels state: "Susceptible/sensitive crops include, but are not limited to …"
    - How far is downwind, i.e., "neighboring distance"? Defining neighboring distance means understanding several factors affecting movement. Registrants say the applicator determines distance based on experience. However, experience is risk. Safety should not be left up to determination of liability.

Certain states have taken efforts to classify stand-alone dicamba products as restricted use products (RUPs). An RUP classification under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) mandates that private and commercial pesticide applicators and pesticide dealers legally maintain records of use and sales that will provide a comprehensive accounting of dicamba formulations used. The point was made that it's very difficult to determine which dicamba product was used once it has been applied. In addition, certain state agencies investigating dicamba complaints reported that they have not seen sufficient paperwork from the dicamba registrants investigating their complaints. Several workshop participants said that industry investigations of dicamba complaints were not typically at the same level of detail as state investigations. It was also noted that there is not a universally accepted procedure for a dicamba volatility assay, but progress is being made.

Seed suppliers and registrants have sales information pertaining to Roundup Ready Xtend cotton and soybean seed, and Engenia, XtendiMax, and FeXapan herbicides. Such information will be (and would have been) very helpful in researching factors to manage dicamba off-target movement. In 2018, Monsanto expects about 40 million acres of Roundup Ready Xtend soybeans and 7 million acres of Roundup Ready Xtend cotton to be planted. It was requested that suppliers of dicamba-resistant cotton and soybean seed provide county-level sales data and that registrants of dicamba formulations (both generic and new) provide state-level sales data from 2016 forward.

FIGURE 7. USDA Estimated Soybean Acres Planted by County in 2017



The point was made that the issue of legal vs. illegal use of dicamba formulations remains contentious. If only 5% of the dicamba applications to dicamba-resistant crops were from illegal formulations, then the majority of the damage must be explained by some kind of failure with the registered formulations. Concern was also expressed about soybean growers having to plant dicamba-resistant soybeans defensively.

SUMMARY

Extensive damage to plants has been documented in claims of off-target movement of dicamba. Anecdotal evidence from multiple state sources suggests that the actual damage to crops may be 5 to 10 times greater than documented in official claims. In addition, damage was also inflicted on public and private gardens, landscape plantings, trees, natural vegetation areas, and pollinator habitats. While use of illegal dicamba formulations was estimated to have occurred in about 5% of the instances where dicamba was actually applied to dicamba-resistant cotton and soybeans, more significant sources of dicamba injury symptoms were attributed to:

1. Volatilization
2. Temperature inversions
3. Physical drift
4. Tank or sprayer contamination
5. Some type of applicator error (incorrect buffer, wind speed, boom height, wrong nozzles, etc.)

In addition, IFCA retail applicators noted that they also observed injury symptoms on non-resistant soybeans from dicamba applications made to corn, since many acres of corn were re-planted in Illinois in 2017 while soybeans were also planted or developing at the same time as the corn. They believe that soybean planting will continue to occur earlier and it is a challenge as a retailer to treat both soybeans and corn in the same time period (it used to be they sprayed corn first, and then switched over to beans). Trends are now for soybeans to be planted earlier.

No data account for the quantitative distribution of dicamba from application to decomposition in a crop system, nor of the dose response relationship between dicamba as applied and the response of sensitive model crops. Crop response data is needed minimally for a legume (alfalfa), a solanaceous crop (tomato), and a cucurbit (cucumber). In addition there is legitimate concern for the effect of exposure and of multiple in-season and multiple annual exposures to herbaceous plants servicing pollinators and to both cultivated and native tree species.

Most university weed scientists expressed concern that there was not adequate public research on the new dicamba formulations prior to product approval. The problems that occurred in 2017 speak for themselves: rising difficulties with weed resistance make retention of this technology important, but we also need answers. More funding for public research is needed. The true cost of the dicamba-resistant crop technology is not being reflected in the price. Cotton and soybean commodity groups are funding some research projects. Concern was expressed that USDA-ARS and USDA-NIFA were not funding the type of research needed to manage off-target pesticide movement as well as other weed science issues, except maybe for pollinator impact. Overall federal funding for weed science research is very small compared to other pest management disciplines and the biggest problem we are facing in the future is herbicide resistance.

- Is there a need for a "registration fee" to support research to help manage dicamba off-target movement?
- Is there a need for an industry led research task force, such as the 2,4-D Task Force, to help manage dicamba off-target movement?

ACTION ITEMS

- Use of New Formulations:
    - We need a comprehensive accounting of areas planted in the dicamba-resistance trait by county and sales of all formulations of dicamba at minimum by state. Data from registrants and compilation of state data should be reconciled. Funding is needed to compile, analyze, and report these data and link to the reports of damage and damage resolution.
    - There is also a need to relate damage complaints to terrain and weather conditions.

- Application - Deficiencies with labels:
    - Provide uniformity in label organization among herbicides to make instructions on herbicide use easier to find
    - Identify dicamba-sensitive crops, landscape and native plants and trees
    - Define neighboring distance for sensitive crops
    - Delineate conditions leading to atmospheric inversions to protect applicators and neighbors from off-target movement.

- Application - Coordination of Training: All sources should have the same message in detail.

- Volatilization: The potential for the new formulations to volatilize after application is insufficiently characterized and should be revisited.

- Off-Target Damage:
    - More information on dose vs. damage is needed for key crops.
    - Address insufficient protection for growers (particularly of horticultural crops), property owners, and the public from off-target movement.
    - Address ways to assess damage that has occurred with respect to determination of liability.
    - Determine how dicamba is moving in the environment.

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APPENDIX 1: Workshop Participants

Last Name	First Name	Affiliation
Asmus	Chad	BASF
Banks	Phil	WORKSHOP FACILITATOR
Baris	Reuben	EPA Registration Division
Basu	Bilin	EPA Pesticide Re-evaluation Division
Bradley	Kevin	University of Missouri
Bruss	Bob	Nufarm Americas
Bunting	Jeff	GROWMARK
Chism	Bill	EPA Biological and Economic Analysis Division
Cotie	Arlene	Bayer
Culpepper	Stanley	University of Georgia
Fleitz	Nick	Pentair - Hypro
Frieden	John	Wilbur-Ellis
Fritz	Brad	USDA Agricultural Research Service
Golus	Jeff	WORKSHOP SECRETARY
Goodis	Mike	EPA Registration Division
Grant	Rich	Purdue University
Hager	Aaron	University of Illinois
Herfort	Joachim	Agrotop GmbH
Hert	Aaron	Helena Agri-Enterprises
Hewitt	Andrew	University of Queensland
Keigwin	Rick	EPA Office of Pesticide Programs
Kenny	Dan	EPA Registration Division
Kruger	Greg	University of Nebraska
Ledson	Mark	Syngenta
Mortensen	Dave	Penn State University
Mueller	Thomas	University of Tennessee
Nichols	Susie	Arkansas State Plant Board
Nichols	Bob	Cotton Incorporated
Norsworthy	Jason	University of Arkansas
Payne	Jean	Illinois Fertilizer & Chemical Association
Pearson	Steve	TeeJet Technologies
Peck	Chuck	EPA Environmental Fate and Effects Division
Reiss	Jim	Precision Laboratories
Reynolds	Dan	Mississippi State University
Schleier	Jerome	Dow AgroSciences
Schroeder	Jill	USDA Office of Pest Management Policy
Scott	Dave	Office of Indiana State Chemist

Senseman	Scott	University of Tennessee
Smith	Steve	Red Gold Inc.
Stamper	Josh	Minnesota Department of Agriculture
Steckel	Larry	University of Tennessee
Sun	Susan	Croda Inc.
Thistle	Harold	USDA Forest Service
Van Wychen	Lee	Weed Science Society of America
Weirich	Jason	MFA Incorporated
Whiting	Kelly	United Soybean Board
Witten	Ty	Monsanto
Young	Bryan	Purdue University
Zollinger	Richard	AMVAC Chemical Corporation

APPENDIX 2: Workshop Goal, Logistics, and Agenda

GOAL
A facilitated, constructive discussion among weed scientists, state and federal regulators, application technology specialists, and dicamba vendors to identify the information needed to understand and manage factors leading to off-target movement of dicamba formulations currently registered for use in Roundup Ready Xtend® cotton and soybean cultivars.

LOGISTICS
WHO- Key public weed scientists, regulatory officials, pesticide application technology specialists, and representatives of dicamba vendors. The meeting will be in-person, closed-door, for invited participants only. Dr. Phil Banks will serve as the workshop facilitator.

WHEN- April 16-17, 2018. Monday, April 16: meet 1:00-5:00 pm followed by dinner at 5:30 p.m. Tuesday, April 17: meet 8:00 a.m. – 12:00 pm.

WHERE- AMA Executive Conference Centers, 2345 Crystal Drive, Suite 200, Arlington, VA 22202. Participants are expected to cover their own travel and lodging cost.

AGENDA: April 16, Monday

1:00 – 1:15 pm. Introductions- Scott Senseman, WSSA President. "What is the science we are missing?"

1:15 – 3:00 pm. Objective 1) Non-Target Impacts – Critical descriptions of damage/yield loss for sensitive crops and non-crops. Research needed to address impacts on pollinators, monarchs, and endangered species.

- 1:15 - 1:25 pm: Bryan Young - Agronomic Crops
- 1:25 - 1:35 pm: Steve Smith - Horticulture Crops
- 1:35 - 1:45 pm: Dave Mortensen - Pollinators
- 1:45 - 2:15 pm: Facilitated Discussion
- 2:15 - 3:00 pm: Action Items

3:00 – 3:15 pm. Break

3:15 – 5:00 pm. Objective 2) Volatility – Coordinated, public, multi-state research program on potential volatilization of dicamba.

- 3:15 - 3:25 pm: Rich Zollinger - Chemistry
- 3:25 - 3:35 pm: Dan Reynolds - Small scale
- 3:35 - 3:45 pm: Tom Mueller - Field scale
- 3:45 - 4:15 pm: Facilitated Discussion
- 4:15 - 5:00 pm: Action Items

AGENDA: April 17, Tuesday

8:00 – 9:45 am. Objective 3) Application – Assessment of training programs, temperature inversions, and the physics of physical particle drift.

- 8:00 - 8:10 am: Stanley Culpepper - Assessment of training programs
- 8:10 - 8:20 am: Rich Grant – Temperature Inversions
- 8:20 - 8:30 am: Andrew Hewitt - Physics of Physical Particle Drift
- 8:30 - 9:00 am: Facilitated Discussion
- 9:00 - 9:45 am: Action Items

9:45 – 10:00 am. Break

10:00 – 11:00 am. Objective 4) Formulation – What did applicators use and on how much acreage?

- 10:00 - 10:10 am: Kevin Bradley - Assessment of formulation use
- 10:10 - 10:20 am: Jean Payne - Assessment of compliance
- 10:20 - 10:40 am: Facilitated Discussion
- 10:40 - 11:00 am: Action Items

11:00 am – 12:00 pm. Summarization and Prioritization. List of prioritized areas of concern to go home with workshop participants

APPENDIX 3: Herbicide Handbook – 2014, Tenth Edition. Dicamba

dicamba

3,6-dichloro-2-methoxybenzoic acid

CAS # Acid: 1918-00-9
Dimethylammonium salt: 2300-66-5
Na salt: 1982-69-0

4(O)

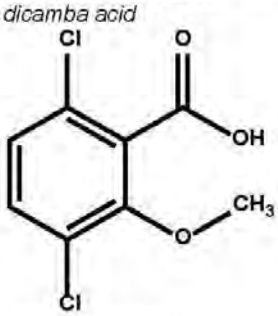
NOMENCLATURE

Common name: dicamba (ANSI, BSI, ISO, WSSA).
Other name(s): VEL-58-CS-11; 3,6-dichloro-2-methoxybenzoic acid (IUPAC); 3,6-dichloro-*o*-anisic acid (IUPAC)
Trade name(s): BANVEL®; BRASH®; CELEBRITY®; CELEBRITY® PLUS; CLARITY®; DISTINCT®; DYVEL®; DYVEL DSp; ENGENIA™; MARKSMAN®; NORTHSTAR®; ONETIME®; OVERDRIVE®; STATUS®; WEEDMASTER®; YUKON®
Chemical family: benzoic acid

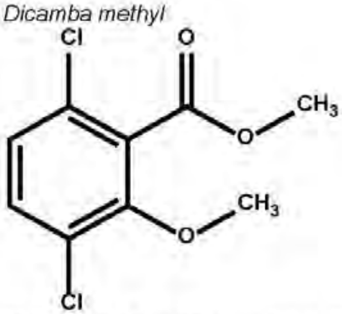
CHEMICAL AND PHYSICAL PROPERTIES

Chemical structure:

dicamba acid



Dicamba methyl



Molecular formula: *Acid* $C_8H_6Cl_2O_3$; *Diglycolamine (diolamine) salt* $C_{12}H_{17}Cl_2NO_5$; *Dimethylammonium (Dma) salt* $C_{10}H_{13}Cl_2NO_3$; *Na salt* $C_8H_5Cl_2NaO_3$; *N, N-Bis-(aminopropyl) methylamine salt* $C_{15}H_{25}Cl_2N_3O_3$
Molecular weight: *Acid* 221.04 g/mole; *Diglycolamine salt* 326.18 g/mole; *Dma salt* 266.12 g/mole; *Na salt* 243.02 g/mole
Description: Crystalline solid, white (reference grade) or brown (technical grade)
Density: 1.35-1.55 g/mL (25 C)
Melting point: 114-116 C
Boiling point: >200 C
Vapor pressure: 4.5 x 10^{-3} Pa (25 C)
Stability: Stable; resists oxidation and hydrolysis under normal conditions

Solubility:
Acid
water 4500 mg/L (25 C)
organic solvents g/100 mL (25 C):

acetone 126	*n*-hexane 0.375
carbon disulfide 127	methanol 137
chloroform 51.6	methyl ethyl ketone soluble
cyclohexanone 91.6	1-octanol 68
diacetone alcohol 91	pentane insoluble
dichloromethane 26	tetrahydrofuran 139
dioxane 118	toluene 13
ethanol 92.2	xylene 20.2

heavy aromatic naphthane solvent 5.2
Dimethylamine salt
water 720,000 mg/L
pK_a: 1.87 (weak acid)
K_{ow}: 0.29

HERBICIDAL USE

Dicamba provides postemergence control of emerged weeds as well as moderate residual control of germinating weeds. Dicamba can be applied preplant and PRE at 0.56 kg ae/ha in corn, POST at 0.28 kg ae/ha in corn and sorghum, preharvest in sorghum at 0.28 kg ae/ha (Texas and Oklahoma only), POST at 0.07-0.14 kg ae/ha in small grains, POST at 0.28-2.24 kg ae/ha in pasture and rangeland, POST at 0.28-2.2 kg ae/ha in grasses and fallow, POST at 0.28-0.56 kg ae/ha in asparagus (California, Oregon, and Washington only), and POST at 0.28-1.1 kg ae/ha in turf. Dicamba is expected to be registered for PRE and POST applications in dicamba-tolerant cotton and soybean. Additional dicamba-tolerant crops are in development. Dicamba is also used for conservation reserve programs, grass grown for seed, sugarcane, turf, and noncropland sites. Many annual broadleaf weeds such as pigweed spp., wild buckwheat, and lambsquarters are controlled at 0.56 kg ae/ha, whereas certain perennial broadleaf weeds such as Canada thistle, perennial sowthistle, and field bindweed are controlled or suppressed at higher rates. To improve postemergence weed control, surfactants, crop oil concentrates, or sprayable fertilizers may be added. A spray system that delivers coarse droplet size is recommended to prevent off-target drift.

USE PRECAUTIONS

Fire hazard: Formulated products are non-flammable.
Corrosiveness: Formulated products are non-corrosive.
Storage stability: All formulated products are stable.
Cleaning glassware/spray equipment: Wash with detergent and rinse. Use acetone rinse for glassware.
Emergency exposure: Flush eyes with water until clear; consult a doctor if irritation persists. Wash contaminated skin with mild soap and water and rinse; get medical attention if

skin irritation persists. If ingested, drink 1-2 glasses of water and induce vomiting.

Incompatibilities: Compatible with most herbicides and may be applied in liquid fertilizers.

BEHAVIOR IN PLANTS

Mechanism of action: Similar to that of endogenous auxin (IAA) and other auxin-mimicking herbicides. (more details on page 12)

Symptomology: Symptoms include twisting and curling of stems and petioles (epinasty), stem swelling (particularly at nodes) and elongation, and leaf cupping. These symptoms are followed by chlorosis at the growing points, growth inhibition, wilting, and necrosis. At low application rates, the tips of new leaves may develop into narrow extensions of the midrib, and puckering of the young leaves may develop.

Absorption: Dicamba readily penetrates plant leaves, roots, and stems, but apparently not as rapidly as the phenoxyacetic acids such as 2,4-D (5). The dimethylamine formulation penetrates plant foliage more than other formulations (3). Dicamba transport across the plasmalemma may occur by passive diffusion as well as by an active, protein-mediated process (1) normally functioning in IAA transport.

Translocation: Dicamba is transported by both symplastic (including phloem) and apoplastic (including xylem) pathways and accumulates at the growing points. Translocation generally is slower in grasses and other tolerant species. Differential translocation among species has been associated with differential sensitivity. Dicamba translocates primarily apoplastically in wheat, but mostly symplastically in susceptible wild buckwheat (4). Following translocation to the roots, substantial percentages of dicamba exit into the surrounding medium (3).

Metabolism in plants: Dicamba metabolism generally is more rapid in tolerant species such as grasses than in susceptible broadleaf species (1). A number of metabolic reactions have been identified, including hydroxylation of dicamba to 5-hydroxy-2-methoxy-3-6-dichlorobenzoic acid, demethylation to salicylic acid derivatives, conjugation of dicamba or the demethylated and hydroxylated metabolites with glucose, and decarboxylation to unidentified metabolites.

Non-herbicidal biological properties: Auxin-like plant growth regulator.

Mechanism of resistance in weeds: A biotype of wild mustard from Western Canada is resistant to dicamba and other auxin herbicides. Although the mechanism of resistance has not been determined, resistance may be due to an insensitive target site (2). Populations of kochia in the U.S. Great Plains have also been documented as resistant to dicamba.

BEHAVIOR IN SOIL

Sorption: Weakly adsorbed to soil

K_{oc}: Average is 2 mL/g (8)

Transformation:

Photodegradation: Dicamba is slowly photodegraded on soil under a xenon lamp, with a half-life equivalent to 269 d (40° N lattitude, springtime sunlight at noon). Thus, the contribution of photolysis to field dissipation likely is negligible (7).

Other degradation: Dicamba is metabolized to CO_2 in aerobic soil, with 3,6-dichlorosalicylic acid as the only major metabolite and low levels of 2,5-dihydroxy-3,6-dichlorosalicylic acid. Dicamba degrades more slowly in anaerobic soils. Non-biological degradation is negligible. At 52 and 95 wk after treatment with ^{14}C-dicamba, 18 and 3%, respectively, of the applied ^{14}C was unextractable.

Persistence: Studies and experience have shown that dicamba may be leached out of the zone of activity in humid regions in a period of 3-12 wk. Dicamba may persist significantly longer under conditions of low soil moisture and rainfall. Dicamba has a half-life of <14 d under conditions amenable to rapid metabolism.

Field experiments: Half-life of 4.4 d in a loam soil in Indiana.

Mobility: Low to medium leaching potential. Dicamba is mobile in soil but degrades rapidly. Low potential for runoff due to rapid degradation.

Volatilization: NA

TOXICOLOGICAL PROPERTIES

Toxicity tests were conducted with technical grade dicamba acid unless otherwise indicated.

Acute toxicity:

Oral LD_{50} rat, 1707 mg/kg; Dermal LD_{50} rabbit, >2000 mg/kg; 4-h inhalation LC_{50} rat, >9.6 mg/L; Skin irritation rabbit, slight; Skin sensitization guinea pig, possible in sensitive individuals; Eye irritation rabbit, extreme

BANVEL: Oral LD_{50} rat, 2629 mg/kg; Dermal LD_{50} rabbit, >2000 mg/kg; 4-h inhalation LC_{50} rat, >5.4 mg/L; Skin irritation rabbit, mild to moderate; Skin sensitization guinea pig, no; Eye irritation rabbit, extreme

WEEDMASTER: Oral LD_{50} rat, >5000 mg/kg; Dermal LD_{50} rabbit, >20,000 mg/kg; 4-h inhalation LC_{50} rat, >20.3 mg/L; Skin irritation rabbit, minimal; Eye irritation rabbit, minimal

Subchronic toxicity:

90-d dietary, rat: NOEL ~250 mg/kg/d (5000 mg/kg); decreased body weight and microscopic liver effects at 10,000 mg/kg

Chronic toxicity:

18-mo dietary, mouse: NOEL 115 mg/kg/d (1000 mg/kg); not oncogenic

24-mo dietary, rat: NOEL 125 mg/kg/d (2500 mg/kg); not oncogenic; no other effects

12-mo dietary, dog: NOEL 60 mg/kg/d (2500 mg/kg); no effects

Teratogenicity:

Rat: NOEL maternal 160 mg/kg/d, fetal 400 mg/kg/d; three pregnant dams treated with 400 mg/kg/d died on or before the second d and one non-gravid female died in this group; not teratogenic

Rabbit: NOEL maternal 30 mg/kg/d, fetal 300 mg/kg/d; abortions among females at 150 and 300 mg/kg/d were associated with maternal toxicity manifested as ataxia, weight loss, and reduced feed consumption; no effects on embryo/fetal viability or development at 300 mg/kg/d; not teratogenic.

Reproduction:

Rat: NOAEL 40 mg/kg/d (500 mg/kg); no effects on reproductive performance at up to 400 mg/kg/d (5000 mg/kg)

Mutagenicity:

Gene mutation: Ames test, negative

Structural chromosome aberration: CHO, negative

DNA damage/repair: *B. subtilis*, positive

Wildlife:

Bobwhite quail oral LD_{50}, 216 mg/kg, 8-d dietary LC_{50}, >10,000 mg/kg; Mallard duck, oral LD_{50} 1373 mg/kg, 8-d dietary LC_{50}, >10,000 mg/kg; Daphnia 48-h TL_{50}, 110 mg/L; Bluegill sunfish 96-h TL_{50}, 135 mg/L; Rainbow trout 96-h TL_{50}, 135 mg/L; Sheepshead minnow 96-h TL_{50}, >180 mg/L; Fiddler crab 96-h TL_{50}, >180 mg/L

BANVEL: Bobwhite quail 8-d dietary LC_{50}, >4640 mg/kg; Mallard duck oral LD_{50}, >2510 mg/kg, 8-d dietary LC_{50}, >4640 mg/kg; Daphnia 48-h LC_{50}, 1600 mg/L; Bluegill sunfish 96-h LC_{50}, >1000 mg/L; Rainbow trout 96-h LC_{50}, 1000 mg/L

WEEDMASTER: Bobwhite quail 8-d dietary LC_{50}, >4640 mg/kg; Mallard duck oral LD_{50}, >4640 mg/kg, 8-d dietary LC_{50}, >4640 mg/kg; Daphnia 48-h LC_{50}, >1800 mg/L; Bluegill sunfish 96-h LC_{50}, >1000 mg/L; Rainbow trout 96-h LC_{50}, >1000 mg/L

Use classification: General use for most products. MARKSMAN is Restricted use because of groundwater contamination concerns with atrazine.

SYNTHESIS AND ANALYTICAL METHODS

Synthesis: NA

Purification of technical: NA

Analytical methods: Residue analysis via extraction with aqueous acid and clean-up using SPE columns. Quantified by GLC of a suitable ester.

Historical: Invented by S. B. Richter. U.S. patent 3,013,054 was awarded in 1958.

MANUFACTURER(S) AND INFORMATION SOURCES:

Industry source(s): Albaugh/Agri Star; Arysta; BASF; DuPont Crop Protection; Gowan; Helena; Loveland; Monsanto; Nufarm; PBI Gordon; Prokoz; Syngenta Crop Protection; Tenkoz; Winfield

Reference(s):

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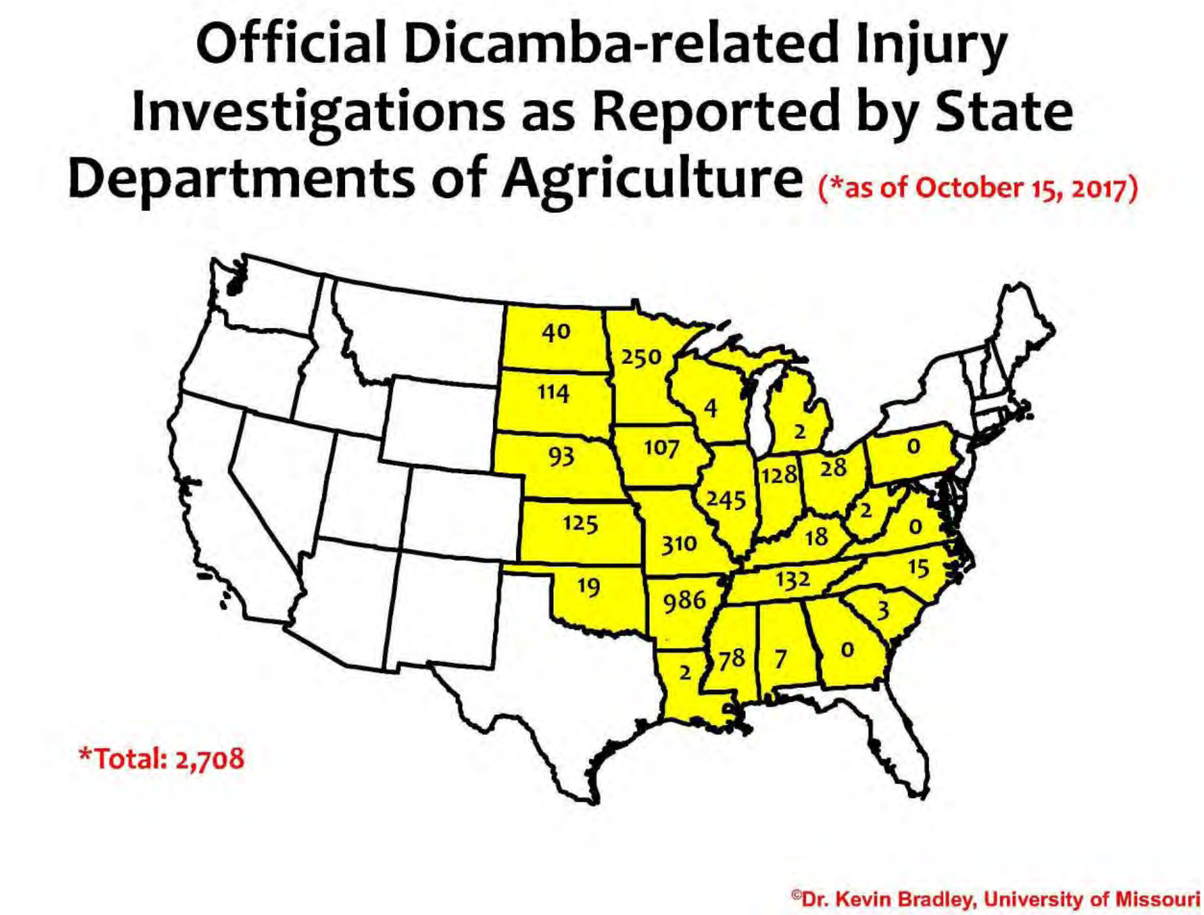
APPENDIX 4: Dicamba-related Injury Investigations - 2017



APPENDIX 5: Estimates of Dicamba-injured Soybean Acreage - 2017