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 <u>appropriate cutoff</u> and <u>strong proactive enforcement</u>.

- 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

Bish MD, Farrell ST, Lerch RN, Bradley KW (2019) Dicamba losses to air after applications to soybean under stable and nonstable atmospheric conditions. Journal of Environmental Quality doi:10.2134/jeq2019.05.0197

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

Mueller TC, Steckel LC (2019b) Spray mixture pH as affected by dicamba, glyphosate, and spray additives. Weed Technology 33:547-554.