2017 Survey of Nebraska Soybean Farmers’ Adoption of Dicamba Tolerant Soybean Technology and Off-Site Dicamba Movement

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**Abstract:** The launching of new herbicide-tolerant traits allows farmers to spray synthetic auxin herbicides (e.g., dicamba) for POST-emergence weed control in cotton and soybeans. The first year of dicamba adoption in the US was controversial and numerous dicamba injury was reported on sensitive vegetation. The objective of this study is to present the farmers awareness of potential problems and their perspective on the adoption of dicamba tolerant soybean varieties in Nebraska in 2017. Over three hundred farmers representing 60 Nebraska counties answered questions from a survey regarding the dicamba-tolerant (DT) soybean technology. Results showed that, in 2017, 20% of soybean hectares was DT-soybean varieties and it is likely double in 2018. Majority of farmers (71%) are responsible for the herbicide application in Nebraska and they are likely to rely on POST-application on dicamba for weed control. Eighteen percent of farmers answered that dicamba application injured neighboring non-DT soybean varieties and they believe that herbicide volatilization (69%) was the main cause for damaging sensitive vegetation. An estimation based on farmers answers showed that dicamba injury on sensitive vegetation is likely to occur on late POST-applications. The results documented here highlighted the need for dicamba application training and the necessity of stewardship programs for the long-term use of the DT-soybean technology.

**Keywords:** auxin, benzoic acid, drift, herbicide.

**Introduction**

Dicamba (3, 6-dichloro-o-anisic acid) is a synthetic auxin herbicide in the benzoic acid chemical family (WSSA group 4). In past 60 years, dicamba has been an important component of weed management in corn, wheat, turfgrass, pastures and rangeland (Keelin and Abernathy 1988, Schroeder and Banks 1989, Spandl et al. 1997, Wehtje 2008). Through genetic engineering, soybeans have been transformed to withstand post-emergence (POST) application of dicamba (Behrens et al. 2007). Fully available to farmers in 2017 [i.e., dicamba-tolerant (DT) trait and labeled POST dicamba application], DT soybean varieties will offer an additional POST option for controlling troublesome broadleaf weed species in soybeans fields (Johnson et al. 2010, Vink et al. 2012).

Weed management have always been a major challenge in cropping systems. The results of a study conducted from 2007 to 2013 showed that uncontrolled weeds can cause, on average, nearly 50% soybean yield loss in North America (Soltani et al. 2017). Additionally, herbicide-resistant (HR) weeds dramatically increased in the past 20 years (Heap 2014). For example, pigweed species (e.g., Palmer amaranth (*Amaranthus palmeri*) and waterhemp (*Amaranthus tuberculatus* var. *rudis*)) populations infesting soybean fields have evolved resistance to ALS- (Heap, 2018a), EPSPS- (Vieira et al. 2017), and PPO-inhibitor (Vieira et al., 2017) herbicide sites-of-action (SOA) in Nebraska. These three herbicide SOA represent the available options for POST control of pigweed species in soybeans. Therefore, the complexity of pigweed management in soybeans is likely to increase due to less effective herbicide options. POST-application of dicamba on DT soybean varieties might be a valuable tool for managing glyphosate-resistant (GR) broadleaf weeds in Nebraska and beyond.

The expected high adoption of DT soybean technology has raised concerns regarding the un-intended movement of dicamba towards sensitive vegetation via vapor or physical particle drift (Young, 2017). The dicamba herbicide has high vapor pressure (volatile compound), which could increase the chances for off-target movement via vapor drift under certain environmental conditions, including high temperature and low humidity (Behrens and Lueschen 1979, Egan and Mortensen 2012). Off-target movement of dicamba via particle drift is more likely to occur due to wrong nozzle selection, high spray pressure and/or high wind speeds (Carlsen et al. 2006). The impact of micro-rates of dicamba is well documented in grapes (Mohseni-Moghadam et al. 2016), soybeans (Auch and Arnold 1978, Griffin et al. 2013), vegetables (Mohseni-Moghadam and Doohan 2015), and cotton (Egan et al. 2014). Despite newer dicamba formulations and equipment (e.g., nozzle) reduce the likelihood of vapor and particle drift (Alves et al. 2017, Egan and Mortensen 2012), dicamba injury on sensitive vegetation was reported across the north-central US in 2017. It was estimated that 1.4 million hectares of non-DT soybeans across US states showed symptoms of dicamba injury (Hager, 2017). It remains controversial whether crop damage was caused by vapor drift, physical particle drift, or both (Steckel, 2017).

The total soybean production area in Nebraska in 2017 was estimated at 2.3 million hectares (USDA-NASS, 2017). The vast majority (>95%) of the soybean hectares were planted with HR varieties (e.g., glyphosate, dicamba, and/or glufosinate), but conventional and organic varieties are also grown in the state (<5% of total soybean hectares). It is estimated that more than 200,000 hectares of DT soybean varieties were planted in Nebraska in 2017 (Jhala, personal communication); therefore, documenting the perception of soybean farmers regarding the introduction of this new technology is of value for the future of this and future technologies that are yet to become available (e.g., Enlist, Balance GT).

Survey is a useful method to obtain knowledge or perception of a situation or fact and assist with future decisions and directions (Givens et al. 2009, Rankins et al. 2005, Webster and Macdonald 2001). For example, a survey conducted in 2016 by (Bish and Bradley 2017) showed that < 82% and < 50% of pesticide applicators from Missouri were aware that temperature and vapor pressure influence herbicide volatilization, respectively. These results indicate the importance of training for those who spray synthetic auxin herbicides such as dicamba and 2,4-D. Therefore, our objective was to conduct a survey to evaluate Nebraska farmers’ perspective on dicamba use and DT soybean technology during the 2017 growing season, year when the technology became fully available to soybean farmers in the US. Results from our survey will provide documentation regarding Nebraska famers perception in the first year of DT soybean technology, which can support or assist with future regulatory and management decisions regarding this and/or new technologies.

**Material and Methods**

A survey was developed to investigate Nebraska farmers’ perspective on dicamba use and DT soybean varieties during the 2017 growing season, first year of the full launch of the DT technology in the United States (Table 1). To reach a representative audience, the survey was conducted in two formats; Table 1: i) hard-copies were handed out during the 2017 Soybean Management Field Days (which had >400 participants), held at four major soybean growing areas of Nebraska (August 08-11, 2017 at North Platte, Ord, Auburn, and Tekamah, respectively); and ii) online using SurveyMonkey ([www.surveynokey.com](http://www.surveynokey.com)) linked to University of Nebraska-Lincoln (UNL) CropWatch website (central resource for UNL Extension information on crop production and pest management; [www.cropwatch.unl.edu](http://www.cropwatch.unl.edu)). The online survey was available from August 18 through September 18, 2017. For consistency in data entry, results from the hard copies from the field days were entered in the online system by a student. All results were exported from SurveyMonkey as an Excel file with the answers to each question in separate columns.

The survey comprised three sections (Table 1). Questions in the first section focused on demographic information such as county, whether participants own a sprayer and spray their herbicide programs, and number of soybean hectares, DT soybean hectares, DT hectares sprayed with dicamba in 2017 and expected for 2018. The second section of the survey was designed to collect data from farmers who adopted the DT technology and sprayed dicamba during the 2017 growing season. Respondents were asked questions about selected dicamba product, use of additional tank mix products, whether the technology helped improve weed management and if their dicamba application led to injury in neighboring soybean fields. The third section of the survey focused on injury observed in non-DT soybeans. Farmers were asked questions pertaining to dicamba injury patterns, whether an official complaint was filed with the Nebraska Department of Agriculture ([www.nda.nebraska.gov](http://www.nda.nebraska.gov)), and what they believed was the main cause for dicamba injury (i.e., tank-contamination, physical drift, volatilization, temperature inversion) and whether it was the result from dicamba applied in DT soybeans or corn.

Survey data were sorted and analyzed using the *sort*, *filter*, and *count* functions of Excel. For most questions, results are presented in two fashions: i) percent answers and ii) percent number of hectares represented. The total number of respondents and hectares for all pertinent questions used for percent calculations are included in the results. Not every respondent answered every question. Results from specific trends we were trying to investigate were only extracted from surveys where respondents answered all pertinent questions. For instance, when trying to estimate whether DT hectares are expected to increase in 2018, only answers from respondents that completely answered survey questions 2 and 3 (Table 1) were used.

A logistic model was fit to the farmers’ responses (YES or NO; binomial data). The frequency of answers given the day of the year is presented on the right y-axis. Total of 30 responses. The likelihood of dicamba injury on neighboring non-DT soybeans was estimated with package *popbio* of R statistical software using *logi.hist.plot* function (Stubben and Milligan, 2007).

**Results and Discussion**

***Demographic information***

Survey results were obtained from 312 farmers from 60 Nebraska counties, representing a total of 77,855 hectares of soybeans grown in 2017 (Figure 1). Sixty three percent of the answers representing 44,620 hectares (57% of total hectares) were obtained during the Soybean Management Field Days. The remaining answers (43%, representing 33,235 hectares [43% of total hectares]) were obtained online. According to USDA-NASS (2017), approximately 2,3 million hectares of soybeans were planted in Nebraska in 2017; therefore, the results of this survey represent approximately 3.4% of the total area planted in the state.

Two hundred and twenty seven participants planted 68,796 soybean hectares in 2017 and expect to plant 63,768 hectares in 2018 (a 7% reduction in soybean hectares expected for 2018 when compared to 2017). According to 299 participants, 13,994 out of 74,948 soybean hectares were planted with DT soybeans in 2017 (19% of total hectares). When evaluated on a per farm basis, 20% was the average number of hectares planted with DT soybeans in 2017. According to 210 participants, the amount of DT soybean hectares will likely double in 2018 in Nebraska; 27,813 out of 55,154 hectares are likely to be planted with DT soybeans (50% of total hectares). On a per farm basis, farmers will likely plant 52% of their soybean hectares with DT soybean (ranging from 2.5 to 100%; data not shown). When asked how many DT soybean hectares were treated with dicamba in 2017, 109 farmers indicated that 11,113 out of 13,817 were (80% of total acres). On a per farm basis, an average of 73.4% of their hectares were treated. In 2018, 86 farmers indicated that 17,375 out of 19,169 hectares will be sprayed with dicamba (89% of total hectares) with an average of 87.5% hectares expected to be treated on a per farm basis. These results indicate that the soybean hectares planted with the DT soybean and sprayed with dicamba will significantly increase in 2018.

Monsanto anticipates nearly 16.2 million hectares planted with DT soybean varieties in 2018, which represents approximately half of the total soybean area in the US. Historically, farmers have been more likely to adopt genetic engineered crops with herbicide tolerance traits when compared to other technologies (e.g., insect and disease tolerance traits) (Fernandez-Cornejo et al. 2014, Perry et al. 2016, Service 2007). Herbicide-tolerant traits have simplified weed management strategies, offered significant economic savings, provided herbicide efficacy, and increase crop yields (Duke 2015). For example, glyphosate-tolerant (GT) crops (Roundup® Ready technology) was the most adopted technology in the history of modern agriculture (Dill et al. 2008, Duke and Powles 2008). Glyphosate is refereed as a “once-in-a century herbicide” (Duke and Powles 2008). Ten years after introduction of GT soybean varieties, over 95% of soybean hectares in the US were treated with glyphosate (Benbrook 2016, Bonny 2008). However, dicamba is not as versatile as glyphosate; it controls only broadleaf weed species and requires more regulation and training. Therefore, the use of DT soybeans might not be a simple solution for management of GR weeds. Also, dicamba will demand farmers’ willingness to adapt to its application restrictions and potential risks (e.g., off-target movement).

When asked whether they own a sprayer and spray their herbicide programs, 65% of respondents (total response = 218) reported they do. In terms of acreage, 71% of the hectares surveyed were sprayed by the farmer (out of a total of 51,950 hectares). When sorting the data and evaluating whether those who sprayed dicamba in DT soybeans in 2017 own a sprayer (total of 90 answers), 71% of respondents reported they do, representing 81% of the hectares surveyed (total of 12,154 hectares). These results indicate the importance of pesticide application training, particularly for the application of the new auxin formulations in DT soybeans, to non-commercial applicators. Results from a survey conducted by Bish and Bradley (2017) demonstrated the necessity for additional training for those spraying dicamba in DT soybeans. Extensive applicator training was conducted in some US states in 2017 (Alabama, Georgia and North Carolina) where fewer complaints were filed (Steckel, 2017). After the 2017 growing season, Xtendimax®, FeXapan®, and Engenia® became restricted use pesticides and attending the auxin training became mandatory in order to purchase and spray dicamba in DT soybeans in the US (EPA, 2017). The labels have become even more restrictive in an attempt to reduce particle drift (e.g., nozzle selection, wind speed, boom height, time of the day, temperature inversion, etc.). Moreover, some states imposed additional restrictions; for instance, in Minnesota, dicamba can only be sprayed if temperatures are below 29 C and before June 20. In the state of Arkansas, dicamba can only be applied until April 15.

***Dicamba Tolerant soybean technology and dicamba-sprayed acres during the 2017 growing season***

*Nozzle selection – application related*

Regarding dicamba formulation, 55, 38 and 7% of total hectares represented in the survey (11,664 hectares; 86 responses) were treated with Xtendimax®, Engenia®, and FeXapan® herbicides, respectively. On a per farm basis, 58%, 37%, and 5% of respondents used Xtendimax®, Engenia®, and FeXapan®, respectively. These three are the only commercial products labeled for application in DT soybeans. No farmer indicated the use of a non-labeled dicamba formulation (e.g., Banvel®, Clarity®, etc.) in DT soybeans in Nebraska during the 2017 growing season.

***Dicamba sprayed acres***

Complete responses from 89 farmers representing a total of 11,862 DT soybean hectares sprayed with dicamba were selected to investigate tank-mix product used alongside dicamba in DT soybeans POST-emergence applications. When asked whether glyphosate was tank-mixed with dicamba, 82%, 15% and 3% of respondents reported yes, no and not sure, respectively, which represented 84%, 15% and 1% of total hectares. When asked whether a POST-emergence herbicide other than glyphosate was tank-mixed with dicamba, 28%, 57%, and 15% said yes, no and not sure, respectively, which represented 29%, 59%, and 12% of total hectares. ACCase inhibitors (WSSA Group 1; e.g., clethodim) followed by PPO inhibitors (WSSA Group 14; e.g., fomesafen) were the main answers (data not shown). When asked whether an herbicide with soil residual activity was added to the tank mix with dicamba, 25%, 53% and 22% of farmers reported yes, no, and not sure, respectively, which represented 27%, 52% and 21% of total hectares. Long-chain fatty acid inhibitors (group 15; e.g., acetochlor, *S*-metolachlor, and dimethenamid-P) were the predominant answer. Complete responses from 63 farmers representing a total of 9,098 DT soybean hectares sprayed with dicamba indicated that 11%, 48%, 3%, 8%, 17%, 2% and 11% sprayed dicamba alone, with glyphosate, with a POST-emergence other than glyphosate, with glyphosate and another POST-emergence, with glyphosate and a soil-residual product, with glyphosate plus another POST and a residual product, respectively. In terms of hectares surveyed, 14%, 44%, 1%, 8%, 18%, 3%, and 13% were sprayed with the aforementioned tank-mixes, respectively. When asked whether the DT technology and dicamba application improved weed management in soybeans, 93% of farmers responded yes, representing 95% of total hectares surveyed (76 responses and a total of 10,882 hectares of DT soybeans sprayed with dicamba in 2017).

Our results indicate high reliance on dicamba applied POST for control of troublesome GR weeds (e.g., waterhemp, Palmer amaranth, horseweed, giant ragweed, kochia, etc.). In the past decade, less diversity of herbicides and reliance on glyphosate POST in soybeans resulted in the rapid increase of GR weeds (Heap, 2018b). The dramatic evolution of GR weeds in the US was, in part, a reason for launching the DT soybean technology. While POST dicamba application will offer an alternative to control GR weeds in Nebraska, high reliance on dicamba alone could jeopardize the effectiveness of the DT soybean technology. As to date, 34 weeds species have evolved resistance to auxin herbicides (Busi et al. 2017), including dicamba-resistant in kochia (*Kochia scoparia*), common lambsquarters (*Chenopodium album*), prickly lettuce (*Lactuca serriola*), and smooth pigweed (*Amaranthus hybridus*; Heap, 2018c).

***Dicamba injury in non-dicamba tolerant soybeans***

Farmers were asked whether their dicamba application in DT soybeans injured neighboring non-DT soybean fields and 18%, 73% and 9% responded yes, no, and not sure, respectively (total of 92 answers). Those who confirmed injury in neighboring soybean fields because of their dicamba application believe that the main cause of injury was volatilization (69%), physical drift (23%), and temperature inversion (8%; total of 13 answers). Conversely, 51% of survey respondents observed dicamba injury in their non-DT soybeans (total of 211 answers). Farmers reported 6,164 out of a total of 46,515 non-DT hectares (13%; total of 172 answers). Those who observed dicamba injury in their non-DT soybeans, 53% observed injury in the entire field whereas 47% reported injury on the edges of the field (total of 85 answers). Those who observed injury on the edges of the fields, 33%, 39% and 28% reported the injury pattern to be odd-happed, severe near edge, and uniform, respectively (n=18). Those who observed injury in the entire field, 4%, 21% and 75% reported the injury pattern to be odd-happed, severe near edge, and uniform, respectively (n=28).

Farmers who observed dicamba injury in non-DT soybeans were asked whether they filed an official complaint with the Nebraska Department of Agriculture (NDA); 7% responded yes and 93% no. The average injury area of those who filed an official complaint with NDA was 179±35 (6 answers) and for those who did not it was 135±77 hectares (80 answers). Therefore, there was not a correlation between injured area and likelihood of filing an official complaint with the NDA. When asked what they believed was the main cause of injury in their non-DT soybeans, 6%, 19%, 31%, 14%, 9%, 18%, and 4% believed it was because of tank-contamination, physical drift from dicamba application in DT soybeans, volatilization from dicamba application in DT soybeans, temperature inversion following dicamba application in DT soybeans, physical drift from dicamba application in corn, volatilization from dicamba application in corn, and temperature inversion following dicamba application in corn, respectively (total of 85 answers). According to results, 31% of respondents believed dicamba injury in non-DT soybeans resulted from dicamba application in corn. With widespread occurrence of Palmer amaranth in Nebraska, producers are relying more on dicamba applied later in the season for POST control in corn (Werle; personal communication). This change in use pattern of dicamba in corn for Palmer amaranth control in Nebraska and potential off-target dicamba movement from these later applications need to be further investigated. Preliminary observations from weed science extension specialist from 26 US states in the 2017 growing season suggested that crop injury from dicamba was due to spray physical drift, illegal dicamba formulation, sprayer tank contamination, and volatilization (Hager, 2017; Steckel et al., 2017).

The possibility of dicamba injury on neighboring non-DT soybeans increased with later applications (Figure 2). Our modelling approach demonstrated that, after early July, there are over 50% chances of dicamba injury on non-DT soybean in Nebraska. It is likely that higher temperatures and wind speeds in combination with multiple herbicide applications contribute to the higher risk of dicamba injury in July. In addition, at this time, neighboring sensitive crops are established, which increased the chances of receiving un-intended dicamba drift. Other studies corroborated with the potential for dicamba injury with later applications. For example, a study conducted at multiple locations, soybeans showed 2.5 times more sensitivity at flowering (R1 to R2) than at vegetative stage (Griffin et al., 2013). Also, in a meta-analysis study, dicamba physical particle drift (5.6 g ai ha-1) at flowering stage could cause 8.7% soybean yield loss (Egan et al., 2014). An estimation showed that if 8% dicamba injury is observed at flowering stage in non-DT soybean, noticeable yield loss is likely to occur (Kniss, 2018). Therefore, tactics to minimize dicamba drift at begin of soybean flowering period should be implement in Nebraska and elsewhere.

Here we demonstrated the farmers perspective on DT soybean in Nebraska in 2017, the first year of introduction of this technology. Off-target dicamba movement was mainly associated to dicamba use in DT soybeans but also in corn. Thus, farmers should be mindful of neighboring dicamba-susceptible crops regardless of the crop they are spraying dicamba in. Results show that farmers need and are willing to adopt the DT soybean technology and the number of hectares planted will significantly increase in 2018. Despite the already confirmed reports of dicamba-resistant weeds worldwide, farmers will likely rely on POST application of dicamba to control troublesome GR weeds in Nebraska and beyond, repeating what was done with the Roundup® Ready technology. Most soybean hectares are sprayed by non-commercial applicators in Nebraska, which highlight the importance of state educational efforts towards applicator training. With the restrict label regulations, educational training, and more hectares planted with DT soybean varieties, the soybean area injured by dicamba particle drift will likely decrease in 2018. Preliminary studies demonstrate the potential for volatilization of the new dicamba formulations (Young, 2017). Thus, an increase in the dicamba use will likely expose other sensitive vegetation (e.g., vegetables and grapes) and non-crop areas to higher amounts of dicamba particles and/or vapor. Further surveys will be helpful to monitor the status and impact of the DT soybean technology in Nebraska and beyond.



Figure 1. Nebraska counties represented in the survey. Different colors represent the number of answers obtained per county. The soybean production area of Nebraska is concentrated in the east, central and south parts of the state.



Figure 2. Likelihood of injury to neighboring non-DT soybean fields in response to application day of the year of dicamba in DT soybeans.

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| Table 1. Dicamba and DT soybeans survey questionnaire |
| **Demographics** |
| 1. County |
| 1. Total soybean hectares managed in 2017 and expected for 2018? |
| 1. Total DT soybean hectares managed in 2017 and expected for 2018? |
| 1. Total DT d soybean hectares sprayed with dicamba in 2017 and expected for 2018? |
| 1. Do you own a sprayer and apply your herbicide programs? |
|  |
| **Dicamba application in Xtend soybeans** |
| 1. Which dicamba formulation was applied to your DT soybeans?   *a) XtendiMax®*  *b) Engenia®*  *c) FeXapan®*  *d) Other* |
| 1. Was glyphosate included with the dicamba application?   *a) Yes*  *b) No*  *c) Not sure* |
| 1. Was an additional POST-emergence herbicide other than glyphosate included with the dicamba application?   *a) Yes* [which one(s)?]  *b) No*  *c) Not sure* |
| 1. Was a soil-residual herbicide included with the dicamba application?   *a) Yes* [which one(s)?]  *b) No*  *c) Not sure* |
| 1. Has weed management in soybeans significantly improved with the adoption of this technology?   *a) Yes*  *b) No* |
| 1. Did the dicamba application in your DT soybeans injure neighboring soybean fields?   *a) Yes* (how many injured hectares?)  *b) No*  *c) Not sure*  If Yes, what do you believe was the main cause of dicamba injury:  *a) physical drift*  *b) volatilization*  *c) temperature inversion* |
|  |
| **Dicamba injury in non-DT soybeans** |
| 1. Was dicamba injury noticed in your non-DT soybeans?   a) Yes (how many hectares?)  b) No (the survey ends here) |
| 1. Injury was observed mainly at:   a) edges of the field  b) entire field |
| 1. The injury pattern observed was:   a) uniform  b) severe near field edges  c) odd-shaped pattern |
| 1. Did you file an official complaint with the Nebraska Department of Agriculture?   a) Yes  b) No |
| 1. What do you believe was the main cause for dicamba injury in your non-DT soybeans? 2. Tank-contamination 3. Physical drift during application in DT soybeans 4. Volatilization from application in soybeans 5. Temperature inversion from application in DT soybeans 6. Physical drift during application in corn 7. Volatilization from application in corn 8. Temperature inversion from application in corn |
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