

# Weed Technology

## Survey of Nebraska Farmers' Adoption of Dicamba-Resistant Soybean Technology and Dicamba Off-Target Movement --Manuscript Draft--

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<b>Abstract:</b>	<p>In 2017, dicamba-resistant (DR) soybeans were commercially available to farmers in the United States. In August and September of 2017, a survey of 312 farmers from 60 soybean-producing counties was conducted in Nebraska. The objective of this survey was to understand farmers' perceptions regarding DR soybean technology. The survey contained 16 questions and was divided in three parts: i) demographics, ii) dicamba application, and iii) dicamba off-target injury to sensitive soybean cultivars. According to the results, 20% of soybean ha represented by the survey were planted to DR soybean in 2017, and this number will likely double in 2018. Approximately 70% of survey respondents own a sprayer and apply their own herbicide programs. More than 90% of respondents who adopted DR soybean technology reported significant improvement in weed control. Nearly 60% of respondents used dicamba alone or glyphosate + dicamba for POST weed control in DR soybean; the remaining 40% added an additional herbicide with an alternative site-of-action (SOA) to the POST application. All survey respondents used one of the approved dicamba formulations for application in DR soybean. Survey results indicated that late POST dicamba applications (after late June) were more likely to result in injury to non-DR soybean compared to early POST applications (e.g., May and early June) in 2017. According to respondents, off-target dicamba movement resulted both from applications in DR soybeans and dicamba-based herbicides applied in corn. Although 51% of respondents noted dicamba injury on non-DR soybeans, about 7% of those who noted injury filed an official complaint with the Nebraska Department of Agriculture. While DR soybean technology allowed farmers to achieve better weed control during the 2017 than previous growing seasons, it is apparent that off-target movement and resistance</p>

	management need to be addressed to maintain the viability and effectiveness of the technology in the future.
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# **Survey of Nebraska Farmers' Adoption of Dicamba-Resistant Soybean Technology and Dicamba Off-Target Movement**

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## Abstract

In 2017, dicamba-resistant (DR) soybeans were commercially available to farmers in the United States. In August and September of 2017, a survey of 312 farmers from 60 Nebraska soybean-producing counties was conducted during extension field days or online. The objective of this survey was to understand farmers' adoption and perceptions regarding DR soybean technology in Nebraska. The survey contained 16 questions and was divided in three parts: i) demographics, ii) dicamba application, and iii) dicamba off-target injury to sensitive soybean cultivars. According to the results, 20% of soybean ha represented by the survey were planted to DR soybean in 2017, and this number will likely double in 2018. Approximately 70% of survey respondents own a sprayer and apply their own herbicide programs. More than 90% of respondents who adopted DR soybean technology reported significant improvement in weed control. Nearly 60% of respondents used dicamba alone or glyphosate + dicamba for POST weed control in DR soybean; the remaining 40% added an additional herbicide with an alternative site-of-action (SOA) to the POST application. All survey respondents used one of the approved dicamba formulations for application in DR soybean. Survey results indicated that late POST dicamba applications (after late June) were more likely to result in injury to non-DR soybean compared to early POST applications (e.g., May and early June) in 2017. According to respondents, off-target dicamba movement resulted both from applications in DR soybeans and dicamba-based herbicides applied in corn. Although 51% of respondents noted dicamba injury on non-DR soybeans, about 7% of those who noted injury filed an official complaint with the Nebraska Department of Agriculture. While DR soybean technology allowed farmers to achieve better weed control during the 2017 than previous growing seasons, it is apparent that off-target

39 movement and resistance management need to be addressed to maintain the viability and  
40 effectiveness of the technology in the future.

41 **Nomenclature:** acetochlor; clethodim; dicamba; dimethenamid-P; fomesafen; *S*-metolachlor;  
42 soybean, *Glycine max* (L.) Merr.

43 **Keywords:** benzoic acid, crop injury, particle drift, synthetic auxin, vapor drift.

## Introduction

Dicamba is a synthetic auxin herbicide in the benzoic acid chemical family (WSSA group 4 site of action). In the past 60 years, dicamba has been an important component of broadleaf weed management in corn, small grains, turfgrass, pasture, rangeland, conservation reserve programs, and non-cropland areas (Keelin and Abernathy 1988, Schroeder and Banks 1989, Spandl et al. 1997, Wehtje 2008). Through genetic engineering, soybeans have been transformed to tolerate POST applications of dicamba (Behrens et al. 2007). This technology (Roundup Ready 2 Xtend,<sup>®</sup> Monsanto Company, St Louis, MO), fully available to farmers in 2017 (i.e., dicamba-resistant [DR] soybean trait and labeled POST dicamba application), offers an additional POST option for controlling broadleaf weeds in soybean fields (Johnson et al. 2010, Vink et al. 2012).

Weed management has long been a major challenge in row crop production. The results of a study conducted from 2007 to 2013 showed that uncontrolled weeds can cause on average 50% soybean yield loss in North America (Soltani et al. 2017). Herbicide-resistant (HR) weeds have dramatically increased over the past 20 years, only adding to the challenge of successful weed management (Heap 2014). For example, populations of Palmer amaranth (*Amaranthus palmeri*) and waterhemp (*Amaranthus tuberculatus* var. *rudis*) infesting soybean fields in Nebraska have evolved resistance to acetolactate synthase (ALS)- (Heap, 2018a), enolpyruvylshikimate-3-phosphate synthase (EPSPS)- (Vieira et al. 2017b), and protoporphyrinogen oxidase (PPO)-inhibitor (Vieira et al. 2017a) herbicide sites-of-action (SOA). These three herbicide SOA represent the available chemical options for POST control of pigweed species in glyphosate-resistant soybean (Roundup Ready<sup>®</sup>, Monsanto Company, St Louis, MO). Therefore, the complexity of pigweed management in soybeans is likely to increase

as additional populations become resistant due to there being fewer effective POST herbicide options. As a result, dicamba use on DR soybeans might be a valuable tool for managing HR pigweeds and other troublesome broadleaf species that have evolved resistance to glyphosate in Nebraska [i.e., kochia (*Kochia scoparia*), giant ragweed (*Ambrosia trifida*), common ragweed (*Ambrosia artemisiifolia*), and horseweed (*Conyza canadensis*)].

The adoption of DR soybean technology has raised concerns due to the unintended off-target movement of dicamba onto sensitive vegetation via vapor and/or particle drift (Young, 2017). Dicamba 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 from improper nozzle selection, high boom height, high spray pressure, and/or high wind speed at the time of application (Carlsen et al. 2006). Spray tank contamination could also result in off-target dicamba injury if spray tanks following dicamba application are not properly cleaned. The negative impact from micro-rates (vapor or particle drift) of dicamba is well documented in grape (*Vitis vinifera*, Mohseni-Moghadam et al. 2016), soybeans (Auch and Arnold 1978, Griffin et al. 2013), vegetables (Mohseni-Moghadam and Doohan 2015), and cotton (*Gossipium hirsutum*, Egan et al. 2014). Despite there being newer dicamba formulations (Xtendimax,<sup>®</sup> Monsanto Company, St Louis, MO; FeXapan,<sup>®</sup> Corteva Agriscience, Wilmilton, DE; and Engenia,<sup>®</sup> BASF, Research Triangle Park, NC) with reduced volatility and improved application equipment (e.g., large-droplet spray nozzles, automated spray controllers, etc.) (Alves et al. 2017, Egan and Mortensen 2012), off-target movement and dicamba injury on sensitive vegetation was widely reported across the United States in 2017. It was estimated that 1.4

million ha of non-DR soybean across the United States showed symptoms of dicamba injury (Hager, 2017). However, it remains controversial whether this damage from off-target movement was primarily caused by physical particle drift, vapor drift, or tank contamination (Steckel, 2017).

The total soybean production area in Nebraska in 2017 was estimated at 2.3 million ha (USDA, 2017). The majority (> 95%) of soybean ha were planted with HR cultivars (e.g., glyphosate-, glyphosate and dicamba-, or glufosinate-resistant [Liberty® Link, Bayer Crop Science, Research Triangle Park, NC]), with the remaining (< 5% of total soybean ha) ha consisting of conventional (non-HR) and organic soybean cultivars. As weed management challenges increase, controversy over dicamba off-target movement, and the fact that an estimated 200,000 ha of DR soybean were planted in Nebraska in 2017 (Jhala, personal communication), documenting the perceptions and experiences of soybean farmers regarding the adoption of this new technology is essential.

Surveys are a useful method for obtaining knowledge or perception regarding a situation or fact and can assist with determining future decisions and directions (Givens et al. 2009, Rankins et al. 2005, Webster and Macdonald 2001). For example, a 2016 Missouri survey conducted by Bish and Bradley (2017) showed that < 82% and < 50% of pesticide applicators were aware that temperature and vapor pressure, respectively, influence herbicide volatilization. These results indicate the importance of training for those who spray synthetic auxin herbicides. Therefore, the objective of this survey was to evaluate Nebraska farmers' perspectives on use-of dicamba and DR soybean technology during the 2017 growing season, the year when the technology became fully available to soybean farmers in the United States. The results from our



survey will provide valuable information to support or assist with future regulatory and management decisions regarding DR soybean and upcoming HR crop technologies.

## **Material and Methods**

A survey was developed to understand Nebraska farmers' experience and perspectives about the use of dicamba and DR soybean technology during the 2017 growing season (Table 1). To reach a uniform representation of soybean growers, the survey was conducted in two formats: i) paper copies handed out during 2017 Soybean Management Field Days (441 participants attended), representing four major soybean growing areas in Nebraska (North Platte, Ord, Auburn, and Tekamah); and ii) online survey using SurveyMonkey ([www.surveymonkey.com](http://www.surveymonkey.com)) linked to the University of Nebraska-Lincoln (UNL) CropWatch website (the 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, completed paper copies from the field days were entered into the online system. All results were exported from SurveyMonkey as a Microsoft Excel (Microsoft Office, Redmond, WA) file with the answers to each question in separate columns.

The survey was comprised of three sections (Table 1). Questions (Q) in the first section focused on demographic information (Q1-5, Table 1). The second section of the survey was designed to collect data from farmers who had adopted the DR soybean and sprayed dicamba during the 2017 growing season (Q6-10). The third section of the survey focused on off-target dicamba injury observed in non-DR soybeans (Q11-16). Survey data were sorted and analyzed using the *sort*, *filter*, and *count* functions in Microsoft Excel. For most questions, results are presented in two fashions: i) percent answered, and ii) percent number of ha represented. The

total number of respondents and ha for all pertinent questions used for percent calculations are included in the results. Not every respondent answered every question. Therefore, results were only extracted from surveys where respondents answered all pertinent questions. For instance, when trying to estimate whether DR soybean ha is expected to increase in 2018, only answers from respondents who completely answered survey Q-2 and 3 were used (Table 1). In addition, a logistic model was fit to the farmers' responses to whether their application of dicamba on DR soybeans resulted in off-target injury to non-DR soybeans (YES or NO; binomial data) regressed on date of application. The likelihood of dicamba injury on non-DR soybeans was estimated using the *pobio* package in R statistical software using the *logi.hist.plot* function (Stubben and Milligan, 2007). The model's probability of injury was expressed on the left y-axis and the frequency of responses given the application time of year was presented on the right y-axis. A total of 30 complete responses were available to fit the model (question [Q] 11, Table 1).

## **Results and Discussion**

### ***Demographics***

Survey results were obtained from 312 farmers from 60 Nebraska counties, representing a total of 77,855 ha of soybeans grown in 2017 (Figure 1; Q1&2, Table 1). Sixty-three percent of the answers representing 44,620 ha (57% of total ha) were obtained during the Soybean Management Field Days. The remaining answers (43% of total ha) were obtained from the online survey. According to USDA (2017), approximately 2.3 million ha of soybeans were planted in Nebraska in 2017; therefore, the results of this survey represent approximately 3.4% of the total soybean area planted in the state.

Two hundred twenty-seven participants planted 68,796 ha of soybean in 2017 and expect to plant 63,768 ha in 2018, a 7% reduction in soybean ha (includes DR and non-DR soybeans) expected for 2018 when compared to 2017 (Q2, Table 1). According to 299 participants, 13,994 out of 74,948 soybean ha were planted with DR soybeans in 2017 (19% of total ha; Q3, Table 1). When evaluated on a per-farm basis, 20% was the average number of ha planted with DR soybeans in 2017. According to 210 participants, the number of DR soybean ha will likely double in 2018 in Nebraska; 27,813 out of 55,154 ha are likely to be planted with DR soybeans (50% of total ha). On a per-farm basis, farmers will likely plant 52% of their soybean ha with DR soybeans (ranging from 2.5 to 100%; data not shown). When asked about the number of DR soybean ha treated with dicamba in 2017, 109 farmers indicated a total of 11,113 ha out of 13,817 ha treated (80% of total DR ha; Q3&4, Table 1). On an average per-farm basis, 73.4% of the farmers' DR ha were treated. In total, 86 farmers indicated that 17,375 out of 19,169 DR ha will likely to be sprayed with dicamba in 2018 (89% of total DR ha) with an average of 87.5% DR ha expected to be treated on a per-farm basis. These results indicate that the number of soybean ha planted with DR soybean and sprayed with dicamba will substantially increase in 2018.

Monsanto representatives anticipate nearly 16.2 million ha planted with DR soybean in 2018, which represents approximately half of the total soybean area in the United States. Historically, farmers have been more likely to adopt genetically engineered crops with HR traits compared to other technologies (e.g., insect- and disease-resistant traits) (Fernandez-Cornejo et al. 2014, Perry et al. 2016, Service 2007). HR traits have enhanced weed management strategies, offered economic savings, and increased crop yields (Duke 2015). For example, GR crops were the most adopted technology in the history of modern agriculture, and glyphosate is often

referred to as a “once-in-a-century herbicide” (Dill et al. 2008, Duke and Powles 2008). Ten years after the introduction of GR soybean in 1996, over 95% of soybean ha in the United States were treated with glyphosate (Benbrook 2016, Bonny 2008). However, dicamba is not as versatile as glyphosate; it controls only broadleaf weed species and has greater potential for off-target movement because of the high sensitivity of susceptible crops to dicamba. Therefore, the use of DR soybean might not be a universal solution for the management of GR weeds. Additionally, dicamba will require farmers’ willingness to comply with strict application requirements and potential risks such as off-target movement and crop injury.

When asked, 65% of respondents reported that they own a sprayer and spray their own herbicide programs (Q5, Table 1) (total response = 218), which equates to 71% of ha (out of a total of 51,950 ha) being sprayed by farmers themselves. Furthermore, out of 90 respondents, 71% reported that they own a sprayer and sprayed dicamba in DR soybean, representing 12,154 ha. The relatively high number of DR soybean ha being sprayed by farmers highlights the importance of pesticide application training, particularly for the application of the new auxin formulations in DR soybean. Results from a survey conducted by Bish and Bradley (2017) demonstrated the benefit of additional training for those spraying dicamba in DR soybean. Extensive applicator training was conducted in some states in 2017, including Alabama, Georgia, and North Carolina, where fewer complaints were filed (Steckel, 2017). Due to the high number of off-target dicamba injury issues, the United States Environmental Protection Agency (EPA) declared three new dicamba formulations restricted use pesticides (RUP), and mandated training for growers wishing to purchase and spray dicamba in DR soybean in the United States (EPA, 2017). Thus, dicamba labels have become more restrictive in an attempt to reduce off-target injury. Moreover, some states have imposed additional restrictions for application; for instance,

in Minnesota, dicamba can only be sprayed before June 20 and if temperatures are below 29 C.  
In the state of Arkansas, dicamba can only be applied until April 15.

### ***Dicamba Application in DR Soybean***

Regarding dicamba formulation (Q6, Table 1), 55, 38, and 7% of total ha represented in the survey (11,664 ha; 86 answers) were treated with XtendiMax<sup>®</sup>, Engenia<sup>®</sup>, and FeXapan<sup>®</sup>, respectively. On a per-farm basis, 58%, 37%, and 5% of respondents used XtendiMax<sup>®</sup>, Engenia<sup>®</sup>, and FeXapan<sup>®</sup>, respectively. No farmer indicated the use of a non-labeled dicamba formulation (e.g., Banvel<sup>®</sup>, Arysta LifeScience, Cary, NC; Clarity<sup>®</sup>, BASF; etc.) on DR soybean in Nebraska during the 2017 growing season.

Complete responses from 89 farmers representing a total of 11,862 ha of DR soybean sprayed with dicamba were selected to investigate the frequency of tank-mix products used with dicamba in DR soybean. When asked whether glyphosate was tank-mixed with dicamba (Q7, Table 1), 82%, 15%, and 3% of respondents reported yes, no, and not sure, respectively, which represented 84%, 15%, and 1% of total ha. When asked whether a POST herbicide other than glyphosate was tank-mixed with dicamba (Q8, Table 1), 28%, 57%, and 15% said yes, no, and not sure, respectively, which represented 29%, 59%, and 12% of total ha. ACCase inhibitor (WSSA group 1; e.g., clethodim) followed by PPO inhibitors (group 14; e.g., fomesafen) were the primary herbicides used in tank-mixture with dicamba (data not shown). When asked whether an herbicide with soil residual activity was added to the tank-mix with dicamba (Q9, Table 1), 25%, 53%, and 22% of farmers reported yes, no, and not sure, respectively, which represented 27%, 52%, and 21% of total ha. Long-chain fatty acid inhibitors (group 15; e.g., acetochlor, S-metolachlor, and dimethenamid-P) were the predominant answer.

Complete responses (Q7-9; Table 1) from 63 farmers representing a total of 9,098 ha of DR soybean sprayed with dicamba indicated that 11%, 48%, 3%, 8%, 17%, 2%, and 11% (14%, 44%, 1%, 8%, 18%, 3%, and 12% ha) sprayed without any other herbicide, with glyphosate, with a POST-emergence herbicide other than glyphosate, with glyphosate and another POST herbicide, with glyphosate and a soil-residual product, with glyphosate plus another POST herbicide and a residual product, respectively. When asked whether the DR technology and dicamba application improved weed management in soybean (Q10, Table 1), 93% of farmers responded yes, representing 95% of total ha surveyed (76 responses and a total of 10,882 ha of DR soybean sprayed with dicamba in 2017).

Results of the survey indicate high reliance on dicamba applied alone or in tank-mixture with glyphosate for POST control of GR weeds (e.g., waterhemp, Palmer amaranth, horseweed, giant ragweed, and kochia). The high reliance on glyphosate applied POST for weed control in GR soybean, corn, and cotton over the last two decades resulted in the evolution of GR weeds in the United States (Heap, 2018b), leading to the development of DR soybean and cotton as a way to provide an additional effective POST option to control GR weeds. As of 2017, 34 weeds have evolved resistance to synthetic auxin herbicides globally (Busi et al. 2018), including DR kochia, common lambsquarters (*Chenopodium album*), prickly lettuce (*Lactuca serriola*), and smooth pigweed (*Amaranthus hybridus*; Heap, 2018c). If farmers do not employ effective herbicide resistance management practices, dicamba and DR soybean will quickly become ineffective tool for managing HR weeds.

#### ***Dicamba Injury in Non-DR Soybean***

When farmers were asked whether their dicamba application in DR soybean injured non-DR soybean fields (Q11, Table 1), 18%, 73%, and 9% responded yes, no, and not sure, respectively (total of 92 answers). Those who confirmed injury in non-DR soybean fields resulting from their dicamba application believed that the primary cause was volatilization (69%), physical drift (23%), and temperature inversion (in combination with volatilization or physical drift) (8%; total of 13 answers).

Conversely, 51% of survey respondents observed dicamba injury in non-DR soybean (total of 211 answers; Q12, Table 1). Respondents reported 6,164 out of a total of 46,515 ha of non-DR soybeans were injured by dicamba (13%; total of 172 answers). Of those who observed dicamba injury in their non-DR soybeans, 53% observed injury over the entire field whereas 47% reported injury only on the edges of the field (total of 85 answers; Q13, Table 1). For those who observed injury on the edges of the fields, 33%, 39%, and 28% reported the injury pattern to be odd-shaped, severe near the edge, and uniform, respectively (18 answers; Q14, Table 1). Of those who observed injury throughout the entire field, 4%, 21%, and 75% reported the injury pattern to be odd-shaped, severe near the edge, and uniform, respectively (28 answers). The primary suspected causes for uniform dicamba injury in an entire field are likely tank-contamination, volatilization, and/or application during a temperature inversion. Physical drift would typically lead to higher levels of injury near the treated areas.

Farmers who observed dicamba injury in non-DR soybeans were asked whether they filed an official complaint with the Nebraska Department of Agriculture (NDA; Q15, Table 1); 7% responded yes and 93% reported no (86 answers). The average injured area of those who filed an official complaint with the NDA was  $179 \pm 35$  ha (6 answers) and the average injured area for those who did not was  $135 \pm 77$  ha (80 answers). Therefore, there was no correlation

between injured area and the likelihood of filing an official complaint. When asked what they believed to be the main cause of injury in their non-DR soybeans (Q 16, Table 1), respondents reported: tank-contamination (6%), physical drift from dicamba application in DR soybean (19%), volatilization from dicamba application in DR soybean (31%), temperature inversion following dicamba application in DR soybean (14%), physical drift from dicamba application in corn (9%), volatilization from dicamba application in corn (17%), and temperature inversion following dicamba application in corn (4%) as their believed cause for dicamba injury (total of 85 answers). Although results indicate dicamba applications in DR soybean as a contributing factor to off-target injury, it is interesting to note that 30% of respondents believe that dicamba injury in non-DR soybeans resulted from dicamba applications in corn. With the widespread occurrence of GR common waterhemp and Palmer amaranth in Nebraska, farmers are relying more on dicamba applied later in the season for POST control in corn (R. Werle; personal communication). This change in use pattern of dicamba-based herbicides in corn for the aforementioned weed control in Nebraska and potential off-target dicamba movement from their applications need to be further investigated.

The likelihood of dicamba injury in non-DR soybeans increased with late-season applications in 2017 (Q11, Table 1; Figure 2). Dicamba applications in DR soybean made after late June/early July in 2017 were more likely (> 50% chance) to cause injury to adjacent non-DR soybean in Nebraska. We hypothesize that most late-season dicamba applications in 2017 were performed during less-than-ideal environmental conditions (e.g., higher wind speeds, temperature inversion, high temperatures). Given this increased risk of off-target movement from late-season applications, the current labels allow dicamba to be sprayed up to the R1 growth stage in DR soybeans, farmers should consider using this herbicide early in the season as part of



a preplant, PRE and/or early-POST program to minimize the risk for off-target movement. Moreover, neighboring non-DR soybean become more vulnerable to dicamba injury at the late vegetative to flowering stages. In a multi-location study by Griffin et al. (2013), soybean showed 2.5 times more sensitivity to dicamba micro-rates at the flowering stage than at the vegetative stage. According to a meta-analysis conducted by Egan et al. (2014), dicamba physical particle drift ( $5.6 \text{ g ai ha}^{-1}$ ) at the vegetative and flowering stages could cause 3.7 and 8.7% soybean yield loss, respectively, whereas Kniss (2018) estimated that for 8% dicamba injury observed at the flowering stage (V1 and V2) in non-DR soybeans, 2.5% yield loss is likely to occur. Therefore, avoiding dicamba application when soybeans are at advanced growth stages may reduce the likelihood of damage (i.e., soybean yield loss) from off-target movement.

Survey responses mainly associated off-target dicamba movement to dicamba use in DR soybean, but also indicated that dicamba applications in corn may have played a role. Thus, farmers should be mindful of nearby dicamba-susceptible crops when making any dicamba applications. Results show that farmers need and are willing to adopt DR soybean technology and that the number of DR soybean ha planted will significantly increase in 2018. According to our survey, most soybean ha are sprayed by non-commercial applicators in Nebraska, highlighting the importance of state- or region-specific applicator training programs. In addition to concerns over off-target movement and injury, the adoption of resistance management strategies is critical to maintain dicamba as an effective tool for controlling troublesome GR-weeds. Effective weed management is becoming more complicated and the challenges related to dicamba in 2017 have only highlighted this reality. Now, with stricter dicamba labels, increased training requirements, and additional ha to be planted with DR soybean, the hope is that off-target injury in non-DR soybean will decrease in 2018, though preliminary research suggests that

317 the new low-volatility restricted-use dicamba formulations can volatilize (Mueller, 2017; Young,  
318 2017). Also, late-season application with older formulations of dicamba in corn may also  
319 contribute to off-target movement and injury. Given these factors, the use of surveys to  
320 understand farmers' experiences and perceptions is vital to assist scientists in developing  
321 research and education efforts so that farmers can more effectively utilize and protect the weed  
322 management tools available to them. Further surveys will be also aid researchers in monitoring  
323 the status and impact of DR soybean technology in Nebraska and beyond.

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Table 1. Survey questionnaire conducted with 312 farmers from 60 Nebraska counties, representing a total of 77,855 ha of soybean grown in 2017<sup>a</sup>

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**Demographics**

1. County
  2. Total soybean ha managed in 2017 and expected for 2018?
  3. Total dicamba-resistant (DR) soybean ha managed in 2017 and expected for 2018?
  4. Total DR soybean ha sprayed with dicamba in 2017 and expected for 2018?
  5. Do you own a sprayer and apply your herbicide programs?
- 

**Dicamba application in Xtend soybeans**

6. Which dicamba formulation was applied in your DR soybeans?
    - a) *XtendiMax*<sup>®</sup>
    - b) *Engenia*<sup>®</sup>
    - c) *FeXapan*<sup>®</sup>
    - d) *Other*
  7. Was glyphosate included with the dicamba application?
    - a) *Yes*
    - b) *No*
    - c) *Not sure*
  8. Was an additional POST-emergence herbicide other than glyphosate included with the dicamba application?
    - a) *Yes* [which one(s)?]
    - b) *No*
    - c) *Not sure*
  9. Was a soil-residual herbicide included with the dicamba application?
    - a) *Yes* [which one(s)?]
    - b) *No*
    - c) *Not sure*
  10. Has weed management in soybeans significantly improved with the adoption of this technology?
    - a) *Yes*
    - b) *No*
- 

**Dicamba injury in non-DR soybeans**

11. Did the dicamba application in your DR soybeans injure neighboring soybean fields?
  - a) *Yes* (how many injured ha?)
  - b) *No*
  - c) *Not sure*

*Provide the date of application:*

If Yes, what do you believe was the main cause of dicamba injury:

- a) *physical drift*
- b) *volatilization*
- c) *temperature inversion*

12. Was dicamba injury noticed in your non-DR soybeans?



- a) Yes (how many ha?)
  - b) No (the survey ends here)
13. Injury was observed mainly at:
- a) edges of the field
  - b) entire field
14. The injury pattern observed was:
- a) uniform
  - b) severe near field edges
  - c) odd-shaped pattern
15. Did you file an official complaint with the Nebraska Department of Agriculture?
- a) Yes
  - b) No
16. What do you believe was the main cause for dicamba injury in your non-DR soybeans?
- a) Tank-contamination
  - b) Physical drift during application in DR soybeans
  - c) Volatilization from application in soybeans
  - d) Temperature inversion from application in DR soybeans
  - e) Physical drift during application in corn
  - f) Volatilization from application in corn
  - g) Temperature inversion from application in corn

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<sup>a</sup>The survey was conducted in two formats: i) paper copies handed out during 2017 Soybean Management Field Days (441 participants attended the field days), 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.surveymonkey.com](http://www.surveymonkey.com)) linked to the University of Nebraska-Lincoln (UNL) CropWatch website (the central resource for UNL Extension information on crop production and pest management; [www.cropwatch.unl.edu](http://www.cropwatch.unl.edu)). DR = dicamba-resistant soybeans, Xtend<sup>®</sup> technology, Monsanto Company, St Louis, MO.

## LIST OF FIGURES

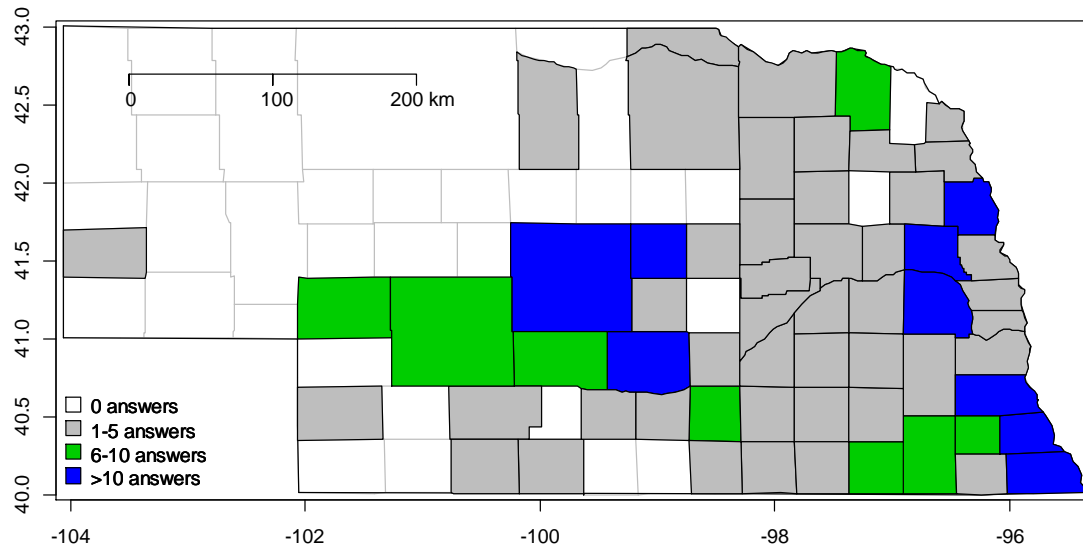


Figure 1. Nebraska counties represented in the survey. Different colors represent the number of answers obtained per county. The soybean production area of Nebraska is concentrated in the east, central and southern parts of the state.

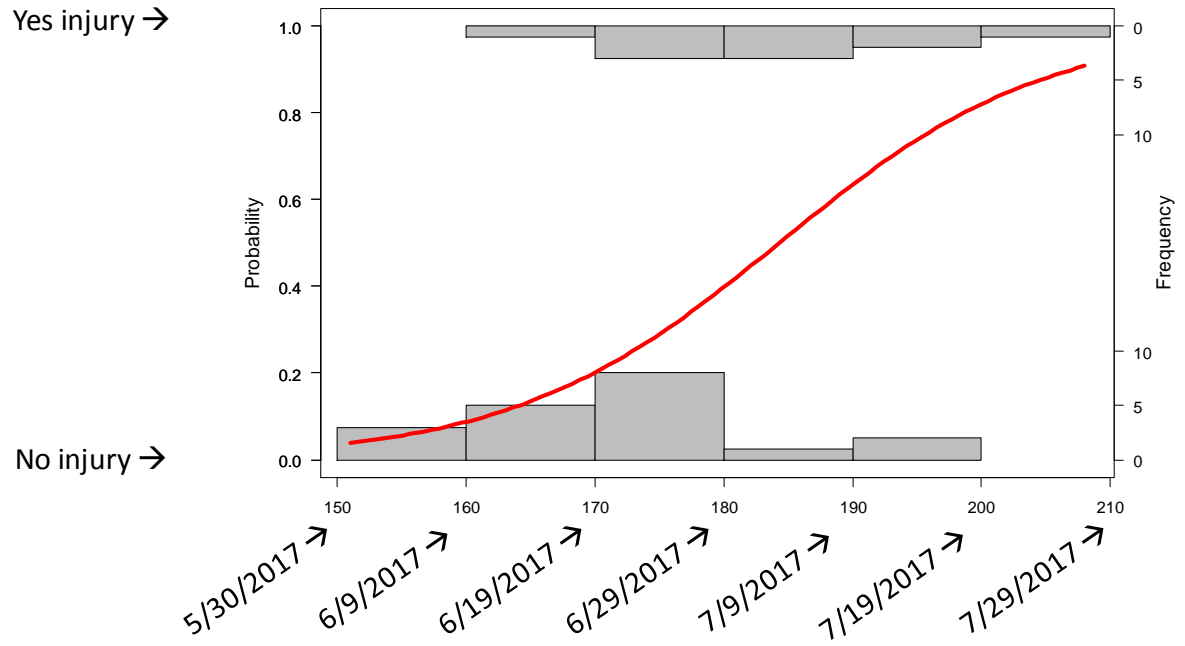


Figure 2. Likelihood (logistic model; red line) of dicamba off-target injury in non-dicamba-resistant (DR) soybean fields in response to dicamba application time (day of the year; x-axis) in DR soybean. Responses from 30 participants were available to fit the model (Q 11, Table 1).