**Survey of Nebraska Farmers’ Adoption of Dicamba-Resistant Soybean Technology and Dicamba Off-target Movement**

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**Abstract**

In 2017, dicamba-resistant soybean was commercially available to producers in the United States. In August and September of 2017, a survey of 312 producers from 60 Nebraska soybean-producing counties was conducted by e-mail or during extension meetings. The objective of this survey was to understand adoption and perceptions regarding dicamba-resistant soybean technology in Nebraska. The survey contained 17 questions and was divided in three parts: i) demographics, ii) dicamba application, and iii) dicamba off-target injury to sensitive soybean cultivars. According to results, 20% of soybean ha represented by the survey were planted to dicamba-resistant soybean in 2017; the dicamba-resistant soybean ha are likely to double in 2018. Approximately 70% of survey respondents own a sprayer and apply their herbicide programs. More than 90% of respondents who adopted the dicamba-resistant technology reported significant improvement in weed control. Nearly 60% of respondents used dicamba alone or glyphosate + dicamba for POST weed control in dicamba-resistant soybean; the remaining 40% added an additional herbicide with alternate site-of-action (SOA) to the POST application. All survey respondents used one of the approved dicamba formulations for application in dicamba-resistant soybeans. Survey results indicate that late POST dicamba applications (after late-June) were more likely to result in injury to neighboring non-dicamba-resistant soybean compared to early POST applications (e.g., May and early June). According to respondents, off-target dicamba movement resulted both from applications in dicamba-resistant soybean and dicamba-based herbicides applied in corn. Although 50% of respondents noted dicamba injury on non-dicamba-resistant soybean, about 7% filed an official complaint with the Nebraska Department of Agriculture. Although dicamba-resistant soybean technology allowed producers to achieve better weed control in the 2017 growing season, it is apparent that off-target movement and resistance management need to be addressed in order to maintain the viability and effectiveness of the technology.

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

Dicamba is a synthetic auxin herbicide in the benzoic acid chemical family (WSSA group 4 site of action classification). 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 withstand POST application of dicamba (Behrens et al. 2007). This technology, 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 always been a major challenge to productive 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 have dramatically increased in the past 20 years, which only adds to the challenge of effective weed control (Heap 2014). For example, populations of Palmer amaranth (*Amaranthus palmeri*) and common waterhemp (*Amaranthus tuberculatus* var. *rudis*)] infesting soybean fields have evolved resistance to acetolactate synthase (ALS)- (Heap, 2018a), enolpyruvylshikimate-3-phosphate synthase (EPSPS)- (Vieira et al. 2017), and protoporphyrinogen oxidase (PPO)-inhibitor (Vieira et al., 2017) herbicide sites-of-action (SOA) in Nebraska. These three herbicide SOA represent all the available options for POST control of pigweed species in glyphosate-resistant soybean. Therefore, the complexity of pigweed management in soybean is likely to increase due to fewer effective POST herbicide options. As a result, dicamba use on DR soybean varieties might be a valuable tool for managing herbicide-resistant broadleaf weeds.

The high rate of adoption of DR soybean technology has raised concerns regarding the off-target movement of dicamba onto sensitive vegetation via particle or vapor 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 due to improper nozzle selection, boom height, high spray pressure and/or high wind speed at the time of application (Carlsen et al. 2006). The negative impact from micro-rates (vapor or particle drift) of dicamba is well documented in grape (Mohseni-Moghadam et al. 2016), soybean (Auch and Arnold 1978, Griffin et al. 2013), vegetables (Mohseni-Moghadam and Doohan 2015), and cotton (Egan et al. 2014). Despite newer dicamba formulations with reduced volatility and improved equipment technology (e.g., large-droplet spray nozzle, automated spray controllers, etc.) (Alves et al. 2017, Egan and Mortensen 2012) off-target movement and dicamba injury on sensitive vegetation was still reported across the US (Bradley, 2017). It was estimated that 1.4 million ha of non-DR soybean across United States showed symptoms of dicamba injury (Hager, 2017). However, it remains controversial whether 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-NASS, 2017). The majority (>95%) of soybean ha were planted with HR cultivars (e.g., glyphosate, dicamba, and/or glufosinate), but conventional (non-HR) and organic soybean cultivars are also grown in the state (<5% of total soybean ha). With weed management challenges, controversy over dicamba off-target movement and the estimated 200,000 ha of DR soybean varieties planted in Nebraska in 2017 (Jhala, personal communication), documenting the experience and perception of soybean farmers regarding the adoption of this new technology is valuable.

Surveys are 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, respectively, influence herbicide volatilization. Results from previous surveys help indicate the importance of training for those who spray synthetic auxin herbicides. Therefore, the objective of this survey was to evaluate Nebraska farmers’ perspective on dicamba use and DR soybean technology during the 2017 growing season, year when the technology became fully available to soybean farmers in the United States. We hypothesized that outcomes from the survey will provide information regarding Nebraska famers perception in the first year of DR soybean technology, which can support or assist with future regulatory and management decisions regarding new technologies.

**Material and Methods**

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

The survey comprised of three sections (Table 1). Questions in the first section focused on demographic information. The second section of the survey was designed to collect data from farmers who adopted the DR technology and sprayed dicamba during the 2017 growing season and The third section of the survey focused on off-target injury observed in non-DR soybean.

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 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. 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 DR soybean ha is expected to increase in 2018, only answers from respondents that completely answered survey questions 2 and 3 were used (Table 1). A logistic model was fit to the farmers’ responses whether their application of dicamba on DR soybean resulted in injury to neighboring non-DR soybean fields (YES or NO; binomial data) regressed on date of application. The likelihood of dicamba injury on neighboring non-DR soybean was estimated using the *popbio* package in R statistical software using the *logi.hist.plot* function (Stubben and Milligan, 2007). The model’s probability of injury is expressed on the left y-axis and the frequency of responses given the application time the year is 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 soybean 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%, representing 33,235 ha [43% of total ha]) were obtained from the online survey. According to USDA-NASS (2017), approximately 2.3 million ha of soybean 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 soybean ha in 2017 and expect to plant 63,768 ha in 2018 (a 7% reduction in soybean ha (includes DR and non-DR soybean) 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 soybean 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 DT soybeans in 2017. According to 210 participants, the amount 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 DT soybean (ranging from 2.5 to 100%; data not shown). When asked how many DR soybean ha were treated with dicamba in 2017, 109 farmers indicated that 11,113 out of 13,817 were (80% of total DR ha; Q3&4, Table 1). On a per farm basis, an average of 73.4% of their DR ha were treated. In 2018, 86 farmers indicated that 17,375 out of 19,169 DR ha will likely be sprayed with dicamba (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 soybean ha planted with the DR soybean and sprayed with labeled dicamba products will significantly increase in 2018.

Monsanto representatives anticipate nearly 16.2 million ha planted with DR soybean varieties in 2018, which represents approximately half of the total soybean area in the United States (X, personal communication). Historically, farmers have been more likely to adopt genetically engineered crops with herbicide resistant traits compared to other technologies (e.g., insect and disease resistant traits) (Fernandez-Cornejo et al. 2014, Perry et al. 2016, Service 2007). Herbicide-resistant traits have enhanced weed management strategies, offered economic savings, improved herbicide efficacy, and increase crop yields (Duke 2015). For example, glyphosate-resistant (GR) crops (Roundup® Ready technology) was 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 introduction of GT soybean varieties, over 95% of soybean ha 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 has greater potential for off-target movement injury because of the high sensitivity of susceptible crops to dicamba. Therefore, the use of DR soybean might not be a simple solution for management of GR weeds. Additionally, dicamba will require farmers’ willingness to adopt application requirements and potential risks (e.g., off-target movement and injury).

When asked, 65% of respondents reported they own a sprayer and spray their herbicide programs (Q5, Table 1) (total response = 218), which equates to 71% of ha being sprayed by the farmer (out of a total of 51,950 ha). Furthermore, 71% of respondents (out of 90) reported 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 indicate 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 (USEPA) declared three new dicamba formulations (Xtendimax®, FeXapan®, and Engenia®) restricted use pesticides and attending the auxin training became mandatory in order to purchase and spray them in DR soybean in the United States (EPA, 2017). Thus, labels have become more restrictive in an attempt to reduce off-target injury. 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 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 responses) were treated with XtendiMax®, Engenia®, and FeXapan®, respectively. On a per farm basis, 58%, 37%, and 5% of respondents used XtendiMax®, Engenia®, and FeXapan®, respectively. No farmer indicated the use of a non-labeled dicamba formulation (e.g., Banvel®, Clarity®, etc.) on DR soybean in Nebraska in 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 (Q7-9, Table 1). When asked if 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 ha. When asked whether a POST 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 ha When asked whether a 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 ha. 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 ha of DR soybean sprayed with dicamba indicated that 11%, 48%, 3%, 8%, 17%, 2%, and 11% (14%, 44%, 1%, 8%, 18%, 3%, and 13% ha) 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. When asked whether the DR technology and dicamba application improved weed management in soybeans (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 indicated high reliance on dicamba applied alone or in tank-mixture with glyphosate for POST control of GR weeds [e.g., common waterhemp, Palmer amaranth, horseweed (*Conyza canadensis*, giant ragweed (*Ambrosia trifida*), and kochia (*Kochia scoparia*)]. High reliance on glyphosate applied POST for weed control in GR soybean, corn, and cotton for the last two decades resulted in the evolution of GR weeds in the United States (Heap, 2018b). Therefore, DR soybean and cotton technology were developed, in part, as a response to decreased POST effective control of GR weeds. As of 2017, 34 weeds have evolved resistance to synthetic auxin herbicides globally (Busi et al. 2017), including dicamba-resistant kochia, common lambsquarters (*Chenopodium album*), prickly lettuce (*Lactuca serriola*), and smooth pigweed (*Amaranthus hybridus*; Heap, 2018c). This would suggest if farmers do not employ effective herbicide resistance management practices dicamba and DR soybean will quickly become ineffective as tools to manage resistant weed populations similar to glyphosate and GR crops.

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

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

Fifty-one percent of survey respondents observed dicamba injury in non-DR soybean (total of 211 answers). They reported 6,164 out of a total of 46,515 ha of non-DR soybean 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 on the edges of the field (total of 85 answers). 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 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-shaped, severe near edge, and uniform, respectively (n=28). 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 level of injury near the treated areas.

Farmers who observed dicamba injury in non-DR soybean were asked whether they filed an official complaint with the Nebraska Department of Agriculture (NDA); 7% responded yes and 93% no. The average injured area of those who filed an official complaint with NDA was 179±35 ha (6 answers) and for those who did not was 135±77 ha (80 answers). Therefore, there was no correlation between injured area and likelihood of filing an official complaint. When asked what they believed was the main cause of injury in their non-DR soybeans, 6%, 19%, 31%, 14%, 9%, 18%, and 4% believed it was because of tank-contamination, physical drift from dicamba application in DR soybeans, volatilization from dicamba application in DR soybean, temperature inversion following dicamba application in DR soybean, 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). Although results indicate dicamba applications in DR soybean as a contributing factor to off-target injury, it is interesting to note that 31% of respondents believe dicamba injury in non-DR soybean resulted from dicamba application in corn. With widespread occurrence of glyphosate-resistant common waterhemp, and Palmer amaranth in Nebraska, producers are relying more on dicamba applied later in the season for POST control in corn (R. Werle; personal communication). Additionally, dicamba-based herbicides in corn are often applied with ammonium sulfate, which may lead to increased volatility. This change in use pattern of dicamba-based herbicides in corn for aforementioned weed control in Nebraska and potential off-target dicamba movement from their applications need to be further investigated. Preliminary observations from weed science extension specialist from 26 states in the 2017 growing season suggested that off-target injury to soybean from dicamba was due to physical spray drift, illegal dicamba formulation, sprayer tank contamination, and volatilization (Hager, 2017; Steckel et al., 2017).

The likelihood of dicamba injury on non-DR soybean increased with late-season applications in 2017 (Figure 2). Further analysis demonstrated that dicamba applications to 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) because label restrictions require farmers to spray for weed control before the R2 soybean growth stage or V9 corn growth stage. Moreover, at this time, non-DR soybean was also at late vegetative to flowering stages when they were most vulnerable to dicamba injury. In a multi-location study by Griffin et al. (2013), soybeans showed 2.5 times more sensitivity to dicamba micro-rates at flowering (R1 to R2) than at vegetative stage. According to a meta-analysis conducted by Egan et al. (2014), dicamba physical particle drift (5.6 g ai ha-1) at flowering stage could cause 8.7% soybean yield loss. Whereas, Kniss (2018) estimated that for 8% dicamba injury observed at flowering stage in non-DR soybean, noticeable yield loss is likely to occur. Therefore, avoiding dicamba application when soybeans are at advanced growth stages may reduce the likelihood of injury from off-target movement and soybean yield loss.

Survey responses mainly associated off-target dicamba movement to dicamba use in DR soybean, but also indicated dicamba applications in corn may have also played a role. Thus, farmers should be mindful of near-by dicamba-susceptible crops when making any dicamba applications. Results show that farmers need and are willing to adopt the DR soybean technology and the number of ha planted will significantly increase in 2018. According to our survey, most soybean ha are sprayed by non-commercial applicators in Nebraska, which highlights the importance of state or region-specific applicator training. In addition to concerns over off-target movement and injury, herbicide resistance management is critical to maintain dicamba as an effective tool for controlling GR and troublesome weeds. Effective weed management is becoming more complicated and the challenges related to dicamba in 2017 have only highlighted this reality. Now with restricted use labels, increase training requirements, and additional ha to be planted with DR soybean, the hope is off-target injury on soybean is likely to decrease in 2018. However, preliminary research suggests there is potential for volatilization of the new restricted use dicamba formulations (Young, 2017) and late-season application with older formulations of dicamba in corn may also be contributing to off-target movement and injury. Given all these factors, the use of surveys to understand farmers’ experiences and perceptions is important as it helps weed scientists focus research and education efforts so farmers can more effectively utilize and protect weed management tools available to them. Going forward, further surveys will be helpful to monitor the status and impact of the DR soybean technology in Nebraska and beyond.

**References**

Alves GS, Kruger GR, da Cunha JPAR, Vieira BC, Henry RS, Obradovic A, Grujic M (2017) Spray Drift from Dicamba and Glyphosate Applications in a Wind Tunnel. Weed Technol 31:387–395

Auch DE, Arnold WE (1978) Dicamba use and Injury on Soybeans (*Glycine max*) in South Dakota. Weed Sci 26:471–475

Behrens MR, Mutlu N, Chakraborty S, Dumitru R, Jiang WZ, Lavallee BJ, Herman PL, Clemente TE, Weeks DP (2007) Dicamba resistance: enlarging and preserving biotechnology-based weed management strategies. Science (80- ) 316:1185–1188

Behrens R, Lueschen WE (1979) Dicamba Volatility. Weed Sci 27:486–493

Benbrook CM (2016) Trends in glyphosate herbicide use in the United States and globally Background. Environ Sci Eur 28:3

Bish MD, Bradley KW (2017) Survey of Missouri Pesticide Applicator Practices, Knowledge, and Perceptions. Weed Technol 31:165–177

Bonny S (2008) Genetically modified glyphosate-tolerant soybean in the USA: adoption factors, impacts and prospects. A review. Agron Sustain Dev 28:21–32

Busi R, Goggin DE, Heap I, Horak MJ, Jugulam M, Masters RA, Napier R, Riar DS, Satchivi NM, Torra J, Westra P, Wright TR (2017) Weed Resistance to Synthetic Auxin Herbicides. Pest Manag Sci add page numbers

Carlsen SCK, Spliid NH, Svensmark B (2006) Drift of 10 herbicides after tractor spray application. 2. Primary drift (droplet drift). Chemosphere 64:778–786

Dill GM, CaJacob CA, Padgette SR (2008) Glyphosate-resistant crops: adoption, use and future considerations. Pest Manag Sci 64:326–331

Duke SO (2015) Perspectives on transgenic, herbicide-resistant crops in the United States almost 20 years after introduction. Pest Manag Sci 71:652–657

Duke SO, Powles SB (2008) Glyphosate: a once-in-a-century herbicide. Pest Manag Sci 64:319–325

Egan JF, Barlow KM, Mortensen DA (2014) A Meta-Analysis on the Effects of 2,4-D and Dicamba Drift on Soybean and Cotton. Weed Sci 62:193–206

Egan JF, Mortensen DA (2012) Quantifying vapor drift of dicamba herbicides applied to soybean. Environ Toxicol Chem 31:1023–1031

EPA (2017) EPA and states' collective efforts lead to regulatory action on dicamba.

https://www.epa.gov/newsreleases/epa-and-states-collective-efforts-lead-regulatory-action-dicamba. Accessed: January 04, 2018

Fernandez-Cornejo J, Wechsler S, Livingston M, Mitchell L (2014) Genetically Engineered Crops in the United States. Page SSRN Electronic Journal. 42 p

Givens WA, Shaw DR, Kruger GR, Johnson WG, Weller SC, Young BG, Wilson RG, Owen MDK, Jordan D (2009) Survey of Tillage Trends Following the Adoption of Glyphosate-Resistant Crops. Weed Technol 23:150–155

Griffin JL, Bauerle MJ, Stephenson DO, Miller DK, Boudreaux JM (2013) Soybean Response to Dicamba Applied at Vegetative and Reproductive Growth Stages. Weed Technol 27:696–703

Hager A (2017) Observations of the Midwest weed extension scientists. Page 98 *in* Proceedings of the 72nd Annual Meeting of the North Central Weed Science Society. Saint Louis, MO: North Central Weed Science Society.

Heap I (2014) Global perspective of herbicide-resistant weeds. Pest Manag Sci 70:1306–1315

Heap I (2018a) Weeds resistant to ALS inhibitors (B/2). http://www.weedscience.org/Summary/MOA.aspx. Accessed: January 10, 2018

Heap I (2018b) Weeds resistant to the herbicide glyphosate.

http://www.weedscience.org/Summary/ResistbyActive.aspx. Accessed: January 15, 2018

Heap I (2018c) Weeds resistant to the herbicide dicamba.

http://www.weedscience.org/Summary/ResistbyActive.aspx. Accessed: January 24, 2018

Johnson B, Young B, Matthews J, Marquardt P, Slack C, Bradley K, York A, Culpepper S, Hager A, Al-Khatib K, Steckel L, Moechnig M, Loux M, Bernards M, Smeda R (2010) Weed control in dicamba-resistant soybeans. Crop Manag 9:0

Keelin JW, Abernathy JR (1988) Woollyleaf bursage (*Ambrosia grayi*) and Texas blueweed (*Helianthus ciliaris*) Control by Dicamba. Weed Technol 2:12–15

Kniss A (2018) An updated meta-analysis of soybean response to dicamba. In press *in* Proceedings of the 58nd Annual Meeting of the Weed Science Society of America. Arlington, VA: Weed Science Society of America.

Mohseni-Moghadam M, Doohan D (2015) Response of Bell Pepper and Broccoli to Simulated Drift Rates of 2,4-D and Dicamba. Weed Technol 29:226–232

Mohseni-Moghadam M, Wolfe S, Dami I, Doohan D (2016) Response of Wine Grape Cultivars to Simulated Drift Rates of 2,4-D, Dicamba, and Glyphosate, and 2,4-D or Dicamba Plus Glyphosate. Weed Technol 30:807–814

Perry ED, Ciliberto F, Hennessy DA, Moschini G (2016) Genetically engineered crops and pesticide use in U.S. maize and soybeans. Sci Adv 2:e1600850

Rankins AJ, Byrd Jr JD, Mask DB, Barnett JW, Gerard PD (2005) Survey of Soybean Weeds in Mississippi. Weed Technol 19:492–498

Schroeder J, Banks PA (1989) Soft Red Winter Wheat (*Triticum aestivum*) Response to Dicamba and Dicamba Phis 2,4. Weed Technol 3:67–71

Service RF (2007) Agbiotech. A growing threat down on the farm. Science 316:1114–7

Soltani N, Dille JA, Burke IC, Everman WJ, Vangessel MJ, Davis VM, Sikkema PH (2017) Perspectives on potential soybean yield losses from weeds in North America. Weed Technol 31:148–154

Spandl E, Rabaey TL, Kells JJ, Gordon R (1997) Application timing for weed control in corn (*Zea mays*) with dicamba tank mixtures. Weed Teehnol 11:602–607

Steckel L, Bond J, Ducar J, York A, Scott B, Dotray P, Barber T, Bradley K. Pages 98-99 *in* Proceedings of the 72nd Annual Meeting of the North Central Weed Science Society. Saint Louis, MO: North Central Weed Science Society.

Stubben CJ and Milligan BG (2007) Estimating and analyzing demographic models using the popbio package in R. J of Stat Soft 22:1-23.

United States Department of Agriculture-National Agricultural Statistics Service -USDA-NASS (2017) Northern Plains Regional Field Office. https://www.nass.usda.gov/Statistics\_by\_State/Nebraska/index.php. Accessed: January 20, 2017

Vieira BC, Samuelson SL, Alves GS, Gaines TA, Werle R, Kruger GR (2017) Distribution of glyphosate-resistant *Amaranthus* spp. in Nebraska. Pest Manag Sci:in press

Vieira G, Oliveira MC, Giacomini D, Arsenijevic N, Tranel P, Werle R (2017) Molecular screening of PPO and glyphosate resistance in Palmer amaranth populations from Southwest Nebraska. Pages 32-33 *in* Proceedings of the 72nd Annual Meeting of the North Central Weed Science Society. Saint Louis, MO: North Central Weed Science Society.

Vink JP, Soltani N, Robinson DE, Tardif FJ, Lawton MB, Sikkema PH (2012) Glyphosate-resistant giant ragweed (*Ambrosia trifida*) control in dicamba-tolerant soybean. Weed Technol 26:422–428

Webster TM, Macdonald GE (2001) A Survey of weeds in various crops in Georgia. Weed Technol 15:771–790

Wehtje G (2008) Synergism of dicamba with diflufenzopyr with respect to turfgrass weed control. Weed Technol 22:679–684

Young BG, Farrell S, Bradley KW, Latorre DO, Kruger GR, Barber T, Norsworthy JK, Scott B, Reynolds D, Steckel L (2017) University research on dicamba volatility. Pages 100-101 *in* Proceedings of the 72nd Annual Meeting of the North Central Weed Science Society. Saint Louis, MO: North Central Weed Science Society.



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 dicamba off-target injury to non-dicamba-resistant soybean fields in response to dicamba application on dicamba-resistant soybeans.

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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 2017a |
| **Demographics** |
| 1. County |
| 1. Total soybean ha managed in 2017 and expected for 2018? |
| 1. Total DT soybean ha managed in 2017 and expected for 2018? |
| 1. Total DT soybean ha sprayed with dicamba in 2017 and expected for 2018? |
| 1. Do you own a sprayer and apply your herbicide programs? |
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| **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 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* |
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| **Dicamba injury in non-DT soybeans** |
| 1. Was dicamba injury noticed in your non-DT soybeans?   a) Yes (how many ha?)  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 |
| aThe survey was conducted in two formats: i) paper-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)). |