CHAPTER II

DETERMINING EFFECT OF TANK MIXTURES OF CHLOROACETAMIDE HERBICIDES AND GLYPHOSATE ON DICAMBA VOLATILITY

44-2020

Abstract

Soybean injury by off-target-movement (OTM) of dicamba has become more widespread since introduction of the dicamba-resistant cropping system. Volatility is one form of dicamba OTM. Volatility is affected by an array of diverse factors ranging from environmental conditions, tank-mix partners, and application timing. With increasing use of tank-mix partners with dicamba and use in pre-mixed products, further research of tank-mix effects on dicamba volatility is needed. Field and greenhouse experiments were conducted in 2019 and 2020 to evaluate the effects of common chloroacetamide tank-mix partners and glyphosate on diglycolamine (DGA) dicamba with VaporGrip® volatility. Experiments were conducted as a two-level factorial with Factor A levels consisting of dicamba alone, dicamba plus emulsifiable concentrate (EC) *S*-metolachlor, dicamba plus EC acetochlor, a premixed product containing dicamba plus capsule suspension (CS) *S*-metolachlor, and dicamba plus microencapsulated (ME) acetochlor. Factor B levels consisted of the presence or absence of K salt of glyphosate. Field treatments were applied at 4X labeled rates to greenhouse flats filled with soil wetted prior to application. Treated flats were placed between two rows of non-dicamba-resistant soybean at the center of each 15.3 m plot containing a 6.2 x 1.5 14m low tunnel dome covered with plastic.

Visible injury (%) and plant heights (cm) were recorded in the most visibly injured quadrant every 30 cm 14 and 28 days after conclusion of the 48-hour exposure period. Each low tunnel contained an air pump sampling air through a polyurethane foam tube (PUF) to catch dicamba molecules that vaporize from the treated soil surfaces. Humidome treatments contained identical factors applied at labeled rates to greenhouse flats contained in humidome systems. Air samplers pulled air through the sealed system and PUF to captured and quantify dicamba volatility from treated soil. Field PUF data suggest separation in dicamba volatility is dependent upon chloroacetamide formulation in field settings, but no differences in chloroacetamide effects were found in humidome experiments. Tank-mixed glyphosate increased quantifiable dicamba volatility in both field and humidome PUF samples. The EC chloroacetamide formulations were found to increase extent and distance of volatility injury when compared to non-EC formulations of the same active ingredient 14 days after treatment (DAT). Glyphosate increased vapor injury severity and distance when tank mixed at both rating timings. No effect on plant height was observed between factors or as main effects.

Nomenclature:

Acetochlor; diglycolamine salt of dicamba; potassium salt of glyphosate; *S*-metolachlor; soybean, *Glycine max* (L.) Merr.

Key Words:

Emulsifiable concentrate, microencapsulated; capsule suspension; volatility.

Introduction

Since release of the dicamba-resistant (DR) cropping system, POST use of dicamba has increased (Wechsler et al. 2019, Werle et al. 2018). The ability to manage problematic glyphosate-resistant (GR) weed species with dicamba has resulted in rapid adoption of the technology since its 2016 release (Shergill et al. 2018,Wechsler et al. 2019). Between 2016 and 2018, DR soybean hectares increased 43% nationally (Wechsler et al. 2019). Areas with increased observance of GR weed species have seen widespread adoption of DR soybean (Wechsler et al. 2019). In the 2018 Mississippi cropping season, 79% of the soybean hectarage was planted with DR soybean (Wechsler et. al 2019). Alongside increased adoption came an increase in dicamba application frequency during the cropping season (Wechsler et al. 2019). Although not every hectare of DR soybean receives a POST application of dicamba, the option is available and utilized by many growers (Wechsler et al. 2019). In the 2018 Mississippi soybean crop, approximately 54% of the DR soybean hectares received a dicamba application (Wechsler et al. 2019). Increased dicamba application frequency has resulted in increased dicamba injury from off-target-movement (OTM) (Bish and Bradley 2017, Mueller and Steckel 2019).

Dicamba OTM occurs as physical drift, tank contamination, and vapor movement (Soltani et al. 2020, Behrens and Leuschen 1979, Boerboom 2004). Mitigation efforts of physical drift include use of larger droplet size, use of hooded-sprayer design, use of drift reduction agents, reduction of ground speeds, and making applications under favorable weather conditions (Foster et al. 2018, Creech et al. 2015, Womac et al. 1997). Dicamba contamination of spray equipment can be mitigated through segregation of spray equipment by herbicide technology, or selection of sprayer components less likely to sequester the herbicide (Cundiff et al. 2017). Volatility mitigation is attempted through understanding impacts of application timing, understanding of ever-changing environmental conditions at and following application, and understanding of tank mixture effects (Behrens and Leuschen 1979, Mueller and Steckel 2019). The inability to control environmental conditions after application (Mueller et al. 2013), makes tilting the pendulum of dicamba volatility mitigation through tank mix crucial for successful efforts.

Understanding tank-mixing effects allows for applicator-controlled mitigation efforts of dicamba volatility before the sprayer enters the field. Tank-mixing has become a popular method to mitigate resistance development, broaden spectrum of control, and reduce the number of applications (Beckie and Reboud 2009, Norsworthy et al. 2012). With dicamba's lack of activity on grass species and limited residual activity, POST dicamba applications routinely include a tank-mix partner with grass and residual activity (Werle et at. 2018, Spaunhorst and Bradley 2013). With DT soybean systems also exhibiting glyphosate tolerance, glyphosate is frequently included for additional control of susceptible broadleaf species and grasses (Werle et al. 2018). In a 2018 survey in Nebraska, 60% of producers applied dicamba alone or with glyphosate POST, while 40% applied dicamba with herbicides of different modes of action (Werle et al. 2018). Alongside tank-mixed herbicides having foliar activity, soil applied residual herbicides are recommended in POST applications to increase length of control or provide additional control as initial residual control lessens (Norsworthy et al. 2012). Impacts of these residuals on dicamba volatility must be understood for effective stewardship of the environment and neighboring crops.

Diverging from trends beginning in 1996 of decreasing MOA diversification and little residual herbicide use, today's producers are more aware of utilizing additional chemistries to mitigate POST herbicide selection pressure (Beckie et al. 2019, Bonny 2016). Group 15 chloroacetamide herbicides remain popular for residual control in soybean and *Gossypium hirsutum* L. (Butts et al. 2019). Chloroacetamide herbicides are used POST to provide residual soil activity and increase control of GR weeds along with foliar POST herbicides (Clewis et al. 2006, Cahoon et al. 2015, Jhala et al. 2015). Group 15 herbicides work by inhibiting biosynthesis of very long chain fatty acids and other enzymatic reactions within the plant (Fuerst 1987, Matthes et al. 1998). Without successful biosynthesis of fatty acids, cell membrane structure and permeability are lost, and plant death occurs (Matthes and Boger 2002).

Common examples of herbicides in the chloroacetamide family used in soybean and other crops are *S*-metolachlor and acetochlor. *S*-metolachlor and acetochlor were the third and fourth most applied herbicides behind glyphosate and atrazine in 2008 (Fernandez-Cornejo et al. 2014). These molecules control a variety of grasses, broadleaf, and sedge weed species and are available in a variety of formulations and pre-mixes (Anonymous 2012, Anonymous 2015, Anonymous 2019). Many problematic weed species of Mississippi and the surrounding regions, such as Palmer amaranth (*Amaranthus palmeri* S. Watson), waterhemp (*Amaranthus tuberculatus* (Moq.) Sauer), and Italian ryegrass (*Lolium multiflorum* Lam.), are controlled by these molecules (Whitaker et al 2010, Steckel et al. 2002, Bond et al. 2014).

Selection pressure due to increased usage of auxin herbicides is resulting in increased concerns of auxin resistance development (Busi et al. 2018). DR populations of wild mustard *(Brassica kaber* (D.C.) L.C. Wheeler) and kochia (*Kochia scoparia* (L.) Schrad.), have been found in regions of the United States with frequent dicamba use (Cranston et al. 2001, Jasieniuk et al. 1995). Loss of dicamba efficacy to additional weed resistance developments could make targeting problematic broadleaf weeds in DR cropping systems more difficult. To mitigate the development of resistant populations, weed scientists recommend the use of multiple modes of action within single applications (Norsworthy et al. 2012). In tank mixtures with glyphosate, *S*-metolachlor was found to decrease risk of glyphosate resistance in Palmer amaranth to 12%, compared to 74% with glyphosate alone (Neve et al. 2011). Tank mixes containing chloroacetamide herbicides can increase length of control from dicamba applications while mitigating long-term development of additional DR weed populations. The frequency of tank mixing chloroacetamide and glyphosate herbicides in POST applications commonly containing dicamba creates the need to understand impacts of these chemistries on dicamba volatility.

Materials and Methods

In 2019 and 2020, experiments were conducted in Starkville, MS, at the R.R. Foil Experiment Station and Brooksville, MS, at the Black Belt Research Station to evaluate the effects of various chloroacetamide herbicides and glyphosate on dicamba volatility. Experiments were conducted using a randomized complete block design with a factorial arrangement of treatments. Factor A consisted of a 4X rate of various chloroacetamide herbicides, while Factor B was the presence or lack of glyphosate within the spray mixture. Plots measured 15.3 m x 0.8 m, with 3 replications separated by alleys measuring 6.1 m. Two unplanted rows of soybean measuring 2.3 m in width separated plots in the same replication to mitigate potential vapor movement between treatments. Two rows of ‘CZ 4539 GTLL’ soybean were planted with a seeding rate of 345,940 seeds ha^{-1} in each plot as indicator plants. Treatments occurred between the V4 and V5 vegetative growth stages to ensure dicamba exposure prior to the initiation of reproductive structures. Treatments were applied to greenhouse flats (Heavy Duty 1020 Tray, Greenhouse Megastore) containing field soil saturated the night before application. Soil-filled greenhouse flats were weed free and uniform in soil surface texture to create a uniform application surface. Applications in the Brooksville location were conducted using a CO^2 propelled backpack sprayer with a carrier volume of 140 L ha^{-1}. Treatments were made with a single application at 4X labeled rates to ensure phytotoxic response of indicator soybean. Applications in Starkville were conducted using an enclosed track sprayer with an identical carrier volume and application rate as the Brooksville location. Soil flat application occurred in a separate location from field experiments in both locations and were transported to the experiment site via truck bed.

Factor A levels contained emulsifiable concentrate (EC) *S*-metolachlor applied as Dual Magnum® (Syngenta, Greensboro, NC) at 4.4 kg ai ha^{-1}, microencapsulated (ME) acetochlor applied as Warrant® (Bayer Crop Science, St. Louis, MO) at 5.06 kg ai ha^{-1}, a capsule suspension (CS) pre-mix of diglycolamine (DGA) salt of dicamba plus *S*-metolachlor applied as Tavium plus VaporGrip® (Syngenta, Greensboro, NC) at 6.69 kg ai ha^{-1}, EC acetochlor applied as Harness® (Bayer Crop Science, St. Louis, MO) at 5.04 kg ai ha^{-1}, and no chloroacetamide addition. Factor B levels consisted of the addition of potassium salt of glyphosate (RoundUp PowerMax®, Bayer Crop Science, St. Louis, MO) applied at 3.47 kg ae ha^{-1} and no glyphosate addition. Each treatment contained DGA salt of dicamba with VaporGrip® (Bayer Crop Science, St. Louis, MO) applied at a rate of 2.24 kg ae ha^{-1} except for treatments containing the pre-mix formulation in Tavium plus VaporGrip®. Solution pH of each treatment was taken after application.

Following herbicide application, greenhouse flats containing treated soil were placed in the center of each experimental unit. A 1.5 m x 4.6 m PVC frame was placed in the center of each experimental unit (Figure 2.1). Contractor’s plastic was draped over the PVC structure and clamped on both ends (Figure 2.2). The ends of the low tunnel remain open to allow for air movement through the tunnel. Treated soil and low tunnels remained in each plot for a 48-hour treatment period. Following that period, all low tunnels, contractor's plastic, and soil flats were removed from the field.

Collection of visible injury and plant heights occurred 14 and 28 days after treatment (DAT). Evaluations were based on the conclusion of the 48-hour exposure period. One to two days prior to the first evaluation, the most injured quadrant from each plot was identified. Ratings occurred within this quadrant at both evaluation intervals. Ratings in the selected quadrant occurred outward from the center of the plot in 30 cm intervals. Plant injury ratings used a percentage scale from 0 to 100% as a percentage of injury compared to the untreated check (Behrens and Leuschen 1979). Plant heights were collected in centimeters at each evaluation.

Air sampling occurred at the center of each plot. A low-volume SKC polyurethane foam tube (PUF) (SKC, Eighty-Four, PA) was positioned 30.5 cm above treated soil flats to quantify dicamba molecules volatizing. PUFs were connected to an SKC AirChek 52® (SKC, Eighty-Four, PA) air sampler calibrated to pull air through the PUF at a rate of three Liters per minute. Air sampling occurred for the entirety of the 48-hour incubation period with PUFs collected at its conclusion. Analysis of PUF concentration was conducted by the Mississippi State Chemical Lab using liquid chromatography/mass spectrometry to analyze concentrations of dicamba molecules of each PUF in nanograms.

Dicamba concentration was quantified using an Agilent 1290 liquid chromatograph coupled with an Agilent 6470 triple quadrupole mass spectrometer (Agilent Technologies, Santa Clara, CA). Chromatographic separation was performed using an Agilent Zorbax Eclipse Plus 100 mm column. The mobile phases consisted of 0.1% formic acid in water for the aqueous phase (A) and 0.1% formic acid in acetonitrile as the organic phase. The flow rate 0.3 mL/min with the following gradient program: 0 to 0.5 min of 25% B, 0.5 to 1 min of 50% B, and 1 to 4 min of 60% B. The ionization of dicamba was preformed using electrospray ionization (ESI) in negative mode with an auxiliary gas (N^2), source temperature of 200^{o}C, and a gas flow rate of 10 L/min.

Data were subjected to ANOVA to evaluate significance of main effects and interactions of factors. Injury and plant height evaluation at each collection distance used PROC GLIMMIX with means separated by LSMEANS using an alpha level of 0.05 in SAS 9.4® (SAS Institute Inc, Cary, NC). Percent injury, pH measurements, and PUF concentrations were analyzed over site year using PROC GLIMMIX and means separated by LSMEANS using an alpha level of 0.05 in SAS 9.4. Plant injury and plant height data were also nonlinearly regressed over site year with a 95% confidence band using the loess package in RStudio® (RStudio Inc, Boston, MA) due to non-parametric behavior of the data (Scholtes et al. 2019).

Complimentary humidome experiments were conducted in 2019 in a greenhouse located in Starkville at the R.R. Foil Experiment Station to evaluate the effects of various chloroacetamide herbicides and glyphosate on dicamba volatility under controlled environmental conditions. Experiments were conducted in a randomized complete block design with a factorial arrangement of treatments with three replications. Experimental units consisted of a greenhouse flat (Heavy Duty 1020 Tray®, Greenhouse Megastore) topped with an unvented humidity dome (7" Mini Greenhouse®, Mondi). Within each greenhouse flat, a smaller greenhouse flat (1010 Tray Insert, Greenhouse Megastore) filled with field soil was contained. Soil within the smaller greenhouse flat received the herbicide application.

On each end of the humidity dome, a hole was made through the plastic dome top. A 0.95 cm hole was made on ends closest to treated soil flats. On the opposing end of the dome, a 1.43 cm hole was made to allow for a threaded male fitting through the hole. On the male end of the fitting, located outside of the humidity dome, a 12.7 cm section of neoprene hose was attached to the fitting to allow PUF and air sampler attachment. An SKC AirChek 52 air sampler® was connected to the PUF to pull air through the system at a rate of 3 L/min. Air was pulled from the exterior environment through the 0.95 cm hole and across the treated soil flat. Air inside the humidome was then pulled through the PUF to capture dicamba vapors. Humidome design is displayed in Figures 2.3 and Figure 2.4. The experiment was conducted three times.

Treatment design was identical to field experiments. Factor A treatments contained various chloroacetamide herbicides applied at labeled rates. Factor A levels were EC *S*-metolachlor applied as Dual Magnum® at 1.12 kg ai ha^{-1} , ME acetochlor applied as Warrant® at 1.27 kg ai ha^{-1}, CS pre-mix DGA salt of dicamba + *S*-metolachlor applied as Tavium plus VaporGrip® at 1.68 kg ai ha^{-1}, EC acetochlor applied as Harness® at 1.26 kg ai ha^{-1}, and no chloroacetamide addition. Factor B levels consisted of potassium salt of glyphosate applied at 0.86 kg ae ha^{-1} and no glyphosate addition. Each treatment contained the DGA salt of dicamba with VaporGrip® applied at 0.56 kg ae ha^{-1} except for treatments containing the pre-mix of Tavium plus VaporGrip®. Applications were made using an enclosed track sprayer (Series III, Devries Equipment, New Holland, MN) with a carrier volume of 140 L ha^{-1}. Soil flats were treated in a separate location and transported to the greenhouse.

Following application, soil flats were placed within their assigned humidomes and sealed using heavy duty duct tape to mitigate vapor escape. Humidomes were then transported to a greenhouse where attachment of the PUF occurred and air sampling was initiated. Air sampling initiated the start of the 24-hour treatment period.

At the conclusion of the treatment period, PUFs were collected and analyzed by the Mississippi State Chemical Lab using liquid chromatography/ mass spectrometry to provide concentrations of dicamba vapor molecules present in each PUF. Dicamba concentration was quantified using the same methodology described for field PUF analysis. Data were subjected to ANOVA to evaluate significance of main effects and interactions of factors. Data were analyzed using PROC GLIMMIX and means were separated by LSMEANS using an alpha level of 0.05.

Results

No interaction of tank-mixed chloroacetamide herbicide and tank-mixed with glyphosate was detected. Differences among effects within each factor were observed. No site year effects were observed for plant injury, pH, percent of injured plants, and PUF concentration; therefore, data were pooled over site year. Plant height was unaffected.

Injury 14 DAT from treatments containing EC acetochlor expressed increased volatility injury when compared to all other treatments at 49 to roughly 304 cm from treated soil flats, with injury ranging from 20 to below 4% (Figure 2.5). Treatments of the pre-mix of dicamba plus CS *S*-metolachlor showed less dicamba injury than all other treatments at 72 cm and continued to 258 cm from treated flats, with injury from 13% to slightly above 2% (Figure 2.5). Dicamba treatments containing EC *S*-metolachlor, no chloroacetamide, and ME acetochlor expressed no differences in vapor injury with respect to distance (Figure 2.5, Table 2.1). Dicamba vapor injury was observable to 488 cm from the treated soil 14 DAT (Table 2.1). Five percent or greater vapor injury was observed at further distances 14 DAT from treatments containing EC acetochlor (304 cm) when compared to treatments containing ME acetochlor (217 cm) (Figure

2.5). Five percent or greater vapor injury was observed at shorter distances 14 DAT from treatments of the CS premix (168 cm) when compared to treatments containing EC *S*-metolachlor (217 cm) (Figure 2.5).

Averaged over all chloroacetamide treatments, glyphosate increased dicamba phytotoxicity to non-tolerant soybean 14 DAT from distances of 0 to 328 cm when injury was regressed over distance (Figure 2.6). When glyphosate was present, injury ranged from a high of 26% at 0 cm to a low of 3% at 328 cm (Figure 2.6). In the absence of glyphosate, dicamba treatments expressed vapor injury levels below 20% at 0 cm and fell below 1.5% at 328 cm (Figure 2.6) Five percent or greater visual injury was observed to 266 cm with glyphosate present, compared to 164 cm in the absence of glyphosate (Figure 2.6). When each rating distance was analyzed individually averaged over chloroacetamide, glyphosate increased volatility injury at each distance from 0 to 488 cm (Table 2.2).

Dicamba injury regressed over distance did not differ among chloroacetamide additions averaged over glyphosate 28 DAT (Figure 2.7). At 28 DAT, mean dicamba vapor injury greater than 5% was observed out to between 177 and 253 cm from treated soil flat regardless of chloroacetamide addition (Figure 2.7). At 28 DAT, glyphosate increased dicamba vapor injury when averaged over chloroacetamide (Figure 2.8, Table 2.3). Mean dicamba injury resulting from treatments containing glyphosate was greater than non-glyphosate treatments from 0 to 329 cm 28 DAT (Figure 2.8). In the presence of glyphosate, injury ranged from a high of 24% at 0 cm and decreased to a level of 5% at 246 cm 28 DAT (Figures 2.8). Dicamba treatments lacking tank-mixed glyphosate expressed vapor injury levels below 20% at 0 cm and decreased to 5% at 159 cm from the treated soil 28 DAT (Figures 2.8). When each rating point was analyzed individually averaged over chloroacetamide 28 DAT, glyphosate increased dicamba vapor injury from distances of 0 to 457 cm (Table 2.3).

Under field conditions, dicamba treatments containing EC acetochlor were more volatile than dicamba treatments containing ME acetochlor (Table 2.4). Mean dicamba concentration of PUF samples was 42 ng when an EC formulation of acetochlor was applied, compared to 25 ng from treatments containing ME acetochlor (Table 2.4). Similar formulation effects were observed with *S*-metolachlor. Additions of an EC formulation of *S*-metolachlor resulted in a higher mean dicamba concentration of 42 ng when compared to 27 ng in PUFs from treatments of the CS premix containing *S*-metolachlor (Table 2.4). Treatments lacking chloroacetamide expressed no separation in PUF concentration from any other treatments (Table 2.4). The addition of a chloroacetamide formulated as an EC increased quantifiable volatility when compared to both encapsulated formulations (Table 2.4). In humidome experiments, chloroacetamide addition had no effect on dicamba concentration in PUF samples (Table 2.4). Tank-mixing glyphosate increased PUF concentration from 25 to 42 ng in field experiments (Table 2.4). The effect of tank-mixed glyphosate in humidome experiments agreed with field data by increasing concentration of dicamba in PUFs from 4.37 to 7.29 ng when present in the herbicide solution (Table 2.4).

At 14 DAT, an increase in percentage of injured soybean plants in selected quadrants was observed in treatments containing EC *S*-metolachlor (30%) compared to treatments containing the CS *S*-metolachlor premix (23%) (Table 2.5). Similar observations occurred between formulations of acetochlor 14 DAT. Treatments containing EC formulated acetochlor increased percent of soybean plants injured (37%) when compared to treatments containing ME acetochlor (27%) (Table 2.5). At 28 DAT, no difference in percent injured plants was observed between chloroacetamide addition by formulation (Table 2.5). Both treatments containing *S*-metolachlor lowered percent of injured soybean plants when compared to EC acetochlor 28 DAT (Table 2.5). The EC acetochlor had an increasing effect on percent injured plants in selected quadrants when compared to treatments without a tank mixed chloroacetamide (Table 2.5). Tank mixing glyphosate increased soybean injury by 9 percent both 14 and 28 DAT (Table 2.5).

Chloroacetamide addition impacted spray solution pH when averaged over levels of glyphosate. Treatments containing ME acetochlor were most alkaline with a mean pH value of 5.17 (Table 2.5). Treatments containing EC *S*-metolachlor and EC acetochlor lacked separation of pH, with mean values of 4.95 and 4.96 respectively (Table 2.5). Treatments lacking tank mixed chloroacetamide had a mean pH value of 4.92 (Table 2.5). The CS *S*-metolachlor and DGA dicamba premix was the most acidic solution with mean pH value of 4.88 (Table 2.5). All chloroacetamide tank mixes increased solution pH except treatments of the CS premix of DGA plus *S*-metolachlor (Table 2.5). Glyphosate had acidifying effects, decreasing mean solution pH from 5.23 to 4.74 when tank mixed (Table 2.5). Glyphosate's acidifying properties on dicamba solution has been observed in previous research (Mueller and Steckel 2019).

These data suggest that chloroacetamide and glyphosate tank-mix decisions can impact severity of dicamba vapor movement. Current label restrictions regarding the tank mixing of *S*-metolachlor and acetochlor support safe application regarding volatility. These tank mixes have little to no effect on volatility when applied with DGA salt of dicamba plus VaporGrip®. Data suggests that the pre-mix containing DGA plus CS *S*-metolachlor is less volatile than mixing *S*-metolachlor and dicamba in the tank. Tank-mixing ME acetochlor with dicamba created less volatility than mixing EC acetochlor. Regardless of tank-mix partner, dicamba volatility was clearly increased when glyphosate was included.

Table 2.1 Effect of chloroacetamide tank mix on dicamba vapor injury of non-DR soybean fourteen days after treatment averaged over glyphosate addition under field conditions[a]

Distance from treated soil[b]	Chloroacetamide[c]				
	Harness®	Dual Magnum®	No Chloroacetamide	Warrant®	Tavium®
(cm)	%				
0	26 a	24 a	22 a	22 a	22 a
30	24 a	22 ab	19 b	20 b	18 b
61	20 a	18 ab	16 ab	14 bc	12 c
91	17 a	12 b	13 ab	11 bc	8 c
122	14 a	11 ab	10 ab	9 b	6 b
152	12 a	9 ab	8 ab	7 b	6 b
183	9 a	7 ab	6 ab	5 b	4 b
213	9 a	5 b	5 b	4 b	3 b
244	8 a	4 b	4 b	4 b	2 b
274	6 a	4 ab	3 b	4 ab	1 b
305	5 a	3 ab	3 bc	3 abc	1 c
335	5 a	3 ab	1 bc	3 ab	0 c
366	4 a	2 bc	1 bc	2 ab	0 c
396	2 a	1 abc	1 bc	1 ab	0 c
427	2 a	1 a	1 a	1 a	0 a
457	1 a	1 a	1 a	1 a	0 a
488	1 a	1 a	0 a	1 a	0 a
518	0 a	0 a	0 a	0 a	0 a
549	0 a	0 a	0 a	0 a	0 a
579	0 a	0 a	0 a	0 a	0 a
610	0 a	0 a	0 a	0 a	0 a
640	0 a	0 a	0 a	0 a	0 a
671	0 a	0 a	0 a	0 a	0 a
701	0 a	0 a	0 a	0 a	0 a
732	0 a	0 a	0 a	0 a	0 a
762	0 a	0 a	0 a	0 a	0 a

[a]Means averaged over locations separated by LSMEANS (α=0.05). Letters represent significance differences between dicamba soybean injury at each individual rating distance represented in table rows.

[b]Distances rounded to nearest cm

[c]Dual Magnum – 2.24 kg ae ha^{-1} diglycolamine (DGA) salt of dicamba + 4.4 kg ai ha^{-1} *S*-metolachlor as EC formulation; Harness – 2.24 kg a ha^{-1} DGA salt of dicamba + 5.04 ka ai ha^{-1} of acetochlor as EC formulation; No Chloroacetamide – 2.24 kg ae ha^{-1} DGA salt of dicamba; Tavium – 6.69 kg ai ha^{-1} (DGA salt of dicamba + *S*-metolachlor premix) as CS formulation; Warrant – 2.24 kg ae ha^{-1} DGA salt of dicamba + 5.06 kg ai ha^{-1} acetochlor as ME formulation

Table 2.2 Effect of glyphosate tank mix on dicamba vapor injury of non-DR soybean fourteen days after treatment averaged over chloroacetamide addition under field conditions[a]

Distance from treated soil[b]	Glyphosate[c]	
	Glyphosate Tank Mix	No Glyphosate
(cm)	------------------------ %	---------------------
0	27 a	20 b
30	23 a	17 b
61	19 a	13 b
91	15 a	9 b
122	13 a	7 b
152	11 a	5 b
183	9 a	4 b
213	7 a	4 b
244	6 a	3 b
274	5 a	2 b
305	4 a	2 b
335	3 a	1 b
366	2 a	1 b
396	2 a	1 b
427	1 a	1 b
457	1 a	0 b
488	1 a	0 b
518	0 a	0 a
549	0 a	0 a
579	0 a	0 a
610	0 a	0 a
640	0 a	0 a
671	0 a	0 a
701	0 a	0 a
732	0 a	0 a
762	0 a	0 a

[a]Means averaged over locations separated by LSMEANS (α=0.05). Rounded to nearest percent. Letters represent differences between dicamba soybean injury at each individual rating distance represented in table row

[b]Distances rounded to nearest cm

[c]Glyphosate Tank Mix - K-Salt of glyphosate applied at 3.48 kg ae ha^{-1} with diglycolamine (DGA) salt of dicamba and various chloroacetamide herbicides; No Glyphosate – no glyphosate mixed with DGA salt of dicamba and various chloroacetamide herbicides

Table 2.3 Effect of glyphosate tank mix on dicamba vapor injury of non-DR soybean twenty-eight days after treatment averaged over chloroacetamide addition under field conditions[a]

Distance from treated soil[b]	Glyphosate[c]	
	Glyphosate Tank Mix	No Glyphosate
(cm)	------------------------ %	---------------------
0	24 a	20 b
30	21 a	17 b
61	17 a	12 b
91	14 a	9 b
122	11 a	7 b
152	9 a	6 b
183	7 a	4 b
213	6 a	3 b
244	6 a	3 b
274	4 a	2 b
305	3 a	1 b
335	2 a	1 b
366	2 a	0 b
396	2 a	1 b
427	1 a	0 b
457	1 a	0 b
488	1 a	0 a
518	0 a	0 a
549	0 a	0 a
579	0 a	0 a
610	0 a	0 a
640	0 a	0 a
671	0 a	0 a
701	0 a	0 a
732	0 a	0 a
762	0 a	0 a

[a]Means averaged over locations separated by LSMEANS (α=0.05). Rounded to nearest percent. Letters represent differences between dicamba soybean injury at each individual rating distance represented in table rows.

[b]Distances rounded to nearest cm

[c]Glyphosate Tank Mix - K-Salt of glyphosate applied at 3.48 kg ae ha^{-1} with diglycolamine (DGA) salt of dicamba and various chloroacetamide herbicides; No Glyphosate – no glyphosate mixed with DGA salt of dicamba and various chloroacetamide herbicides

Table 2.4 Effect of tank mixes on dicamba vapor concentration in PUF samples in field and humidome methodology[a]

Factor	Tank Mix[b]	Concentration of Dicamba in PUF[a]	
		Experiment Method	
		Field Conditions[g]	Humidome[h]
Chloroacetamide[cd]		-------------------- ng --------------------	
	Dual Magnum®	42 a	6.09 a
	Harness®	42 a	6.50 a
	No Chloroacetamide	33 ab	5.35 a
	Tavium®	27 b	4.92 a
	Warrant®	25 b	6.32 a
Glyphosate[ef]			
	Glyphosate Tank Mix	42 a	7.29 a
	No Glyphosate	25 b	4.37 b

[a]Means averaged over locations separated by LSMEANS (α=0.05). Letters show differences of dicamba concentration in columns within factor and experiment method

[b]Tank mixes containing DGA salt of dicamba + VaporGrip™

[c]Effect of chloroacetamide addition averaged over glyphosate effects

[d]Dual Magnum – 2.24 kg ae ha^{-1} diglycolamine (DGA) salt of dicamba + 4.4 kg ai ha^{-1} *S*-metolachlor as EC formulation; Harness – 2.24 kg a ha^{-1} DGA salt of dicamba + 5.04 ka ai ha^{-1} of acetochlor as EC formulation; No Chloroacetamide – 2.24 kg ae ha^{-1} DGA salt of dicamba; Tavium – 6.69 kg ai ha^{-1} (DGA salt of dicamba + *S*-metolachlor premix) as CS formulation; Warrant – 2.24 kg ae ha^{-1} DGA salt of dicamba + 5.06 kg ai ha^{-1} acetochlor as ME formulation

[e]Effect of glyphosate addition averaged over chloroacetamide effects

[f]Glyphosate Tank Mix - K-Salt of glyphosate applied at 3.48 kg ae ha^{-1} with diglycolamine (DGA) salt of dicamba and various chloroacetamide herbicides; No Glyphosate – noglyphosate mixed with DGA salt of dicamba and various chloroacetamide herbicides

[g]Herbicides applied at 4x rate using this methodology

[h]Herbicides applied at labeled rate using this methodology

Table 2.5 Effect of tank mixed herbicides on percentage of non-DR soybean injured fourteen and twenty-eight days after treatment and solution pH[a]

Factor	Tank Mix[b]	Percentage of Injured Soybean[g]		pH[h]
		14 DAT	28 DAT	
Chloroacetamide[cd]		-------- % --------		
	Harness®	37 a	34 a	4.95 b
	Dual Magnum®	30 ab	25 b	4.96 b
	No Chloroacetamide	27 bc	26 b	4.92 c
	Warrant®	27 bc	29 ab	5.17 a
	Tavium®	23 c	24 b	4.88 d
Glyphosate[ef]				
	Tank Mixed Glyphosate	33 a	32 a	4.74 a
	No Glyphosate	24 b	23 b	5.23 b

[a]Means averaged over locations separated by LSMEANS (α=0.05). Letters show differences in percent of injured soybean and solution pH of columns within factor

[b]Tank mixes with DGA salt of dicamba + VaporGrip®

[c]Effect of chloroacetamide addition averaged over glyphosate effects

[d]Dual Magnum – 2.24 kg ae ha^{-1} diglycolamine (DGA) salt of dicamba + 4.4 kg ai ha^{-1} *S*-metolachlor as EC formulation; Harness – 2.24 kg a ha^{-1} DGA salt of dicamba + 5.04 ka ai ha^{-1} of acetochlor as EC formulation; No Chloroacetamide – 2.24 kg ae ha^{-1} DGA salt of dicamba; Tavium – 6.69 kg ai ha^{-1} (DGA salt of dicamba + *S*-metolachlor premix) as CS formulation; Warrant – 2.24 kg ae ha^{-1} DGA salt of dicamba + 5.06 kg ai ha^{-1} acetochlor as ME formulation

[e]Effect of glyphosate addition averaged over chloroacetamide effects

[f]Glyphosate Tank Mix - K-Salt of glyphosate applied at 3.48 kg ae ha^{-1} with diglycolamine (DGA) salt of dicamba and various chloroacetamide herbicides; No Glyphosate – no glyphosate mixed with DGA salt of dicamba and various chloroacetamide herbicides

[g]Percentage of injured soybean plants within selected quadrants in field experiments

[h]Solution pH measurements following application at room temperature

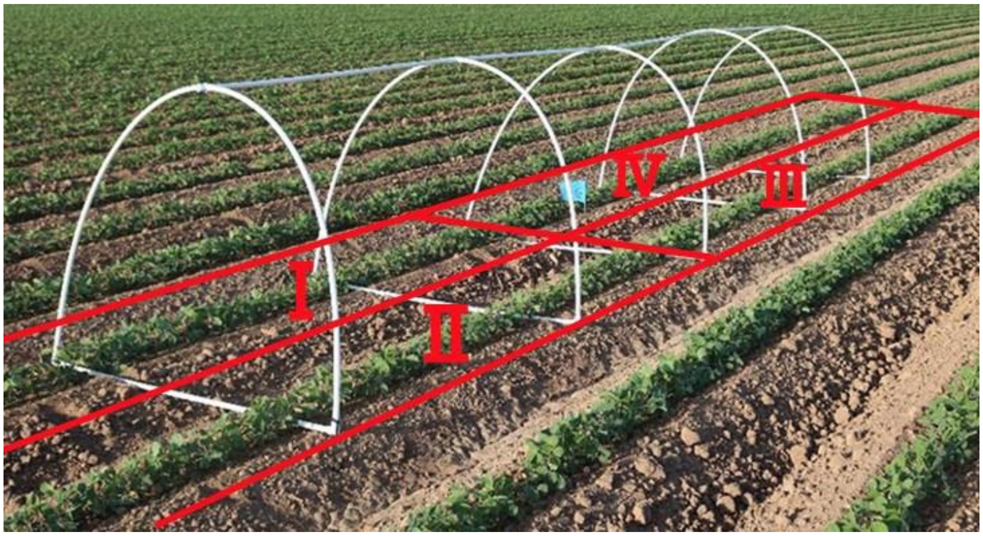

Figure 2.1 PVC frame of low-tunnel tent with quadrant diagram

Figure 2.2 Completed low-tunnel tent frame with contractor’s plastic covering

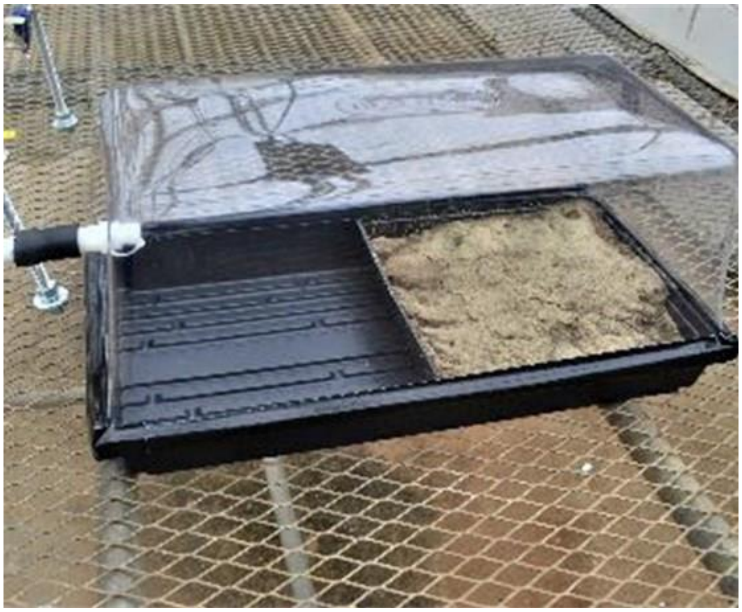

Figure 2.3 Humidome design with 1010 soil flat and sealed humidity dome

Figure 2.4 Humidome experiment design

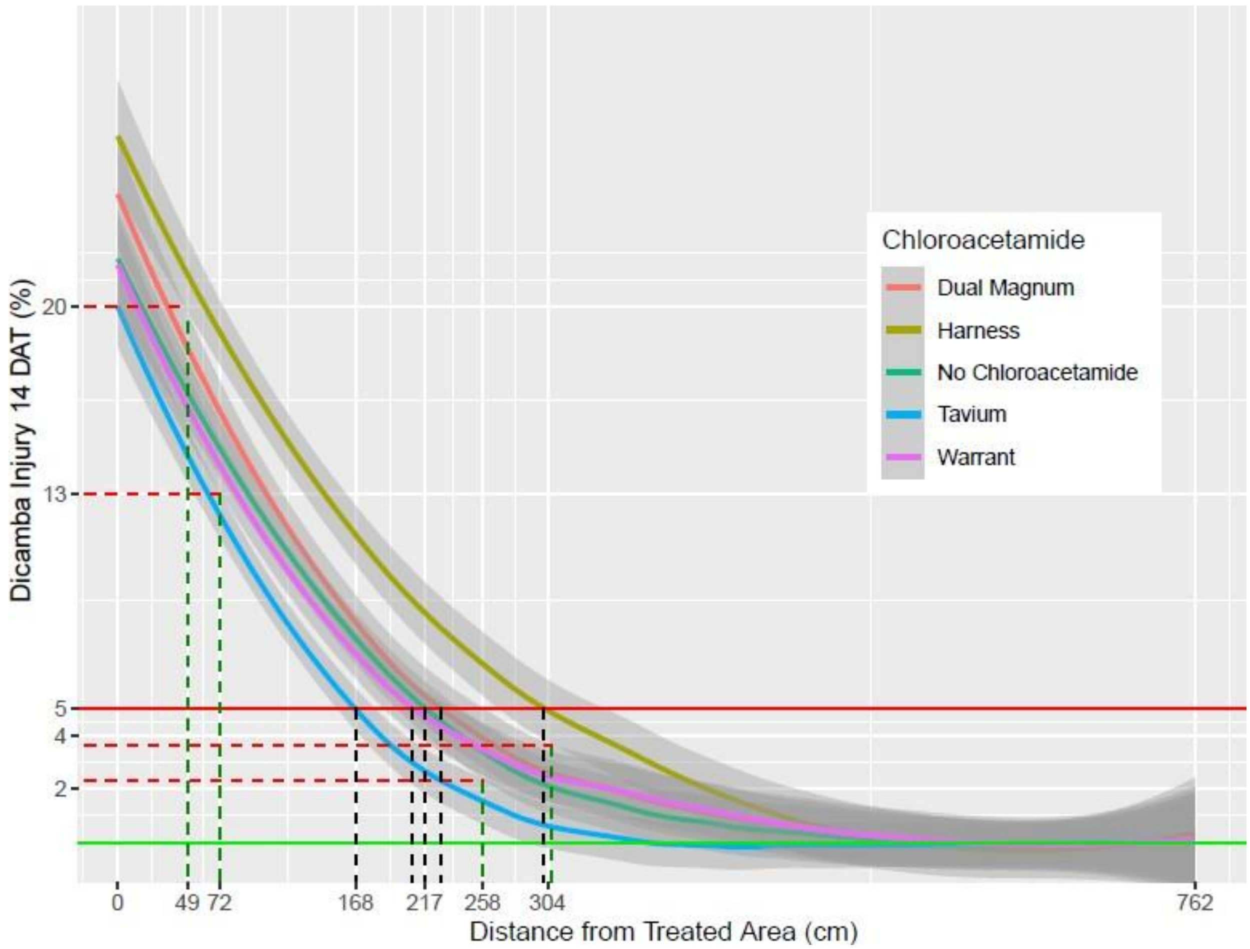

Figure 2.5 Effect of chloroacetamide averaged over glyphosate on dicamba vapor injury of non-DR soybean regressed over distance fourteen days after treatment[abc]

[a]Vapor injury (%) non-linearly regressed over distance (cm)

[b]Grey shaded area represents 95% confidence interval; Horizontal solid green line represents no injury; Horizontal solid red line represents 5% injury; Horizontal dashed red lines represent injury % at separation; Vertical dashed green lines represent distance at separation; Vertical dashed black lines represent distance of 5% injury observation

[c]Dual Magnum – 2.24 kg ae ha^{-1} diglycolamine (DGA) salt of dicamba + 4.4 kg ai ha^{-1} *S*-metolachlor in EC formulation; Harness – 2.24 kg a ha^{-1} DGA salt of dicamba + 5.04 ka ai ha^{-1} in EC formulation; No Chloroacetamide – 2.24 kg ae ha^{-1} DGA salt of dicamba; Tavium plus VaporGrip – 6.69 kg ai ha^{-1} (DGA salt of dicamba + *S*-metolachlor premix) in CS formulation; Warrant – 2.24 kg ae ha^{-1} DGA salt of dicamba + 5.06 kg ai ha^{-1} acetochlor in ME formulation

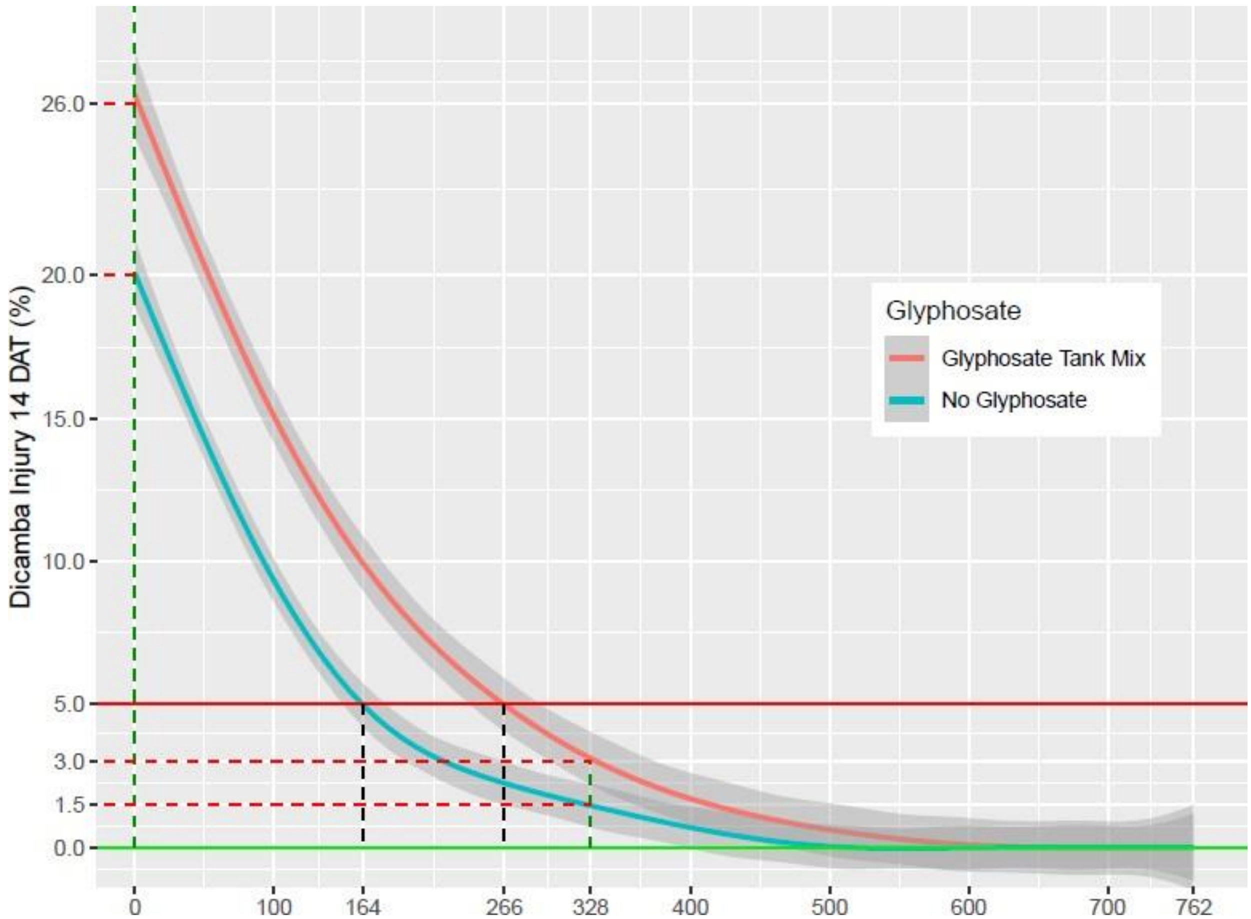

Figure 2.6 Effect of glyphosate averaged over chloroacetamide on dicamba vapor injury of non-DR soybean regressed over distance fourteen days after treatment[abc]

[a]Vapor injury (%) non-linearly regressed over distance (cm)

[b]Grey shaded area represents 95% confidence interval; Horizontal solid green line represents no injury; Horizontal solid red line represents 5% injury; Horizontal dashed red lines represent injury % at separation; Vertical dashed green lines represent distance at separation; Vertical dashed black lines represent distance of 5% injury observation

[c]K salt of glyphosate tank mixed at rate of 3.47 kg ae ha $^{-1}$ with DGA salt of dicamba and various chloroacetamides

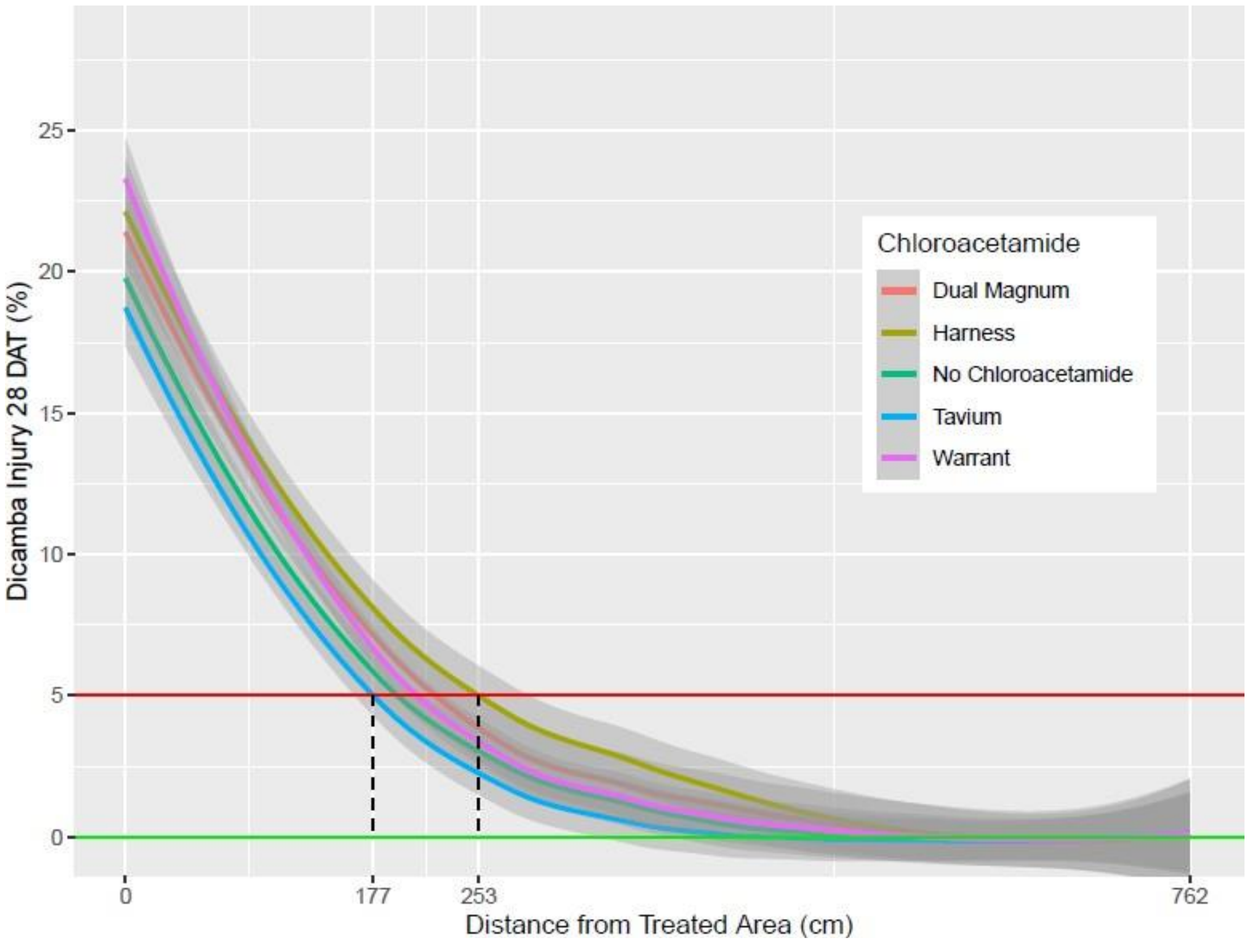

Figure 2.7 Effect of chloroacetamide averaged over glyphosate on dicamba vapor injury of non-DR soybean regressed over distance twenty-eight days after treatment[abc]

[a]Vapor injury (%) non-linearly regressed over distance (cm)

[b]Grey shaded area represents 95% confidence interval; Green line represents no injury. Red line represents 5% injury observation; Vertical black lines represent mean distances of 5% injury observation by tank mix

[c]Dual Magnum – 2.24 kg ae ha^{-1} diglycolamine (DGA) salt of dicamba + 4.4 kg ai ha^{-1} *S*-metolachlor as EC formulation; Harness – 2.24 kg a ha^{-1} DGA salt of dicamba + 5.04 ka ai ha^{-1} as EC formulation; No Chloroacetamide – 2.24 kg ae ha^{-1} DGA salt of dicamba; Tavium – 6.69 kg ai ha^{-1} (DGA salt of dicamba + *S*-metolachlor premix) as CS formulation; Warrant – 2.24 kg ae ha^{-1} DGA salt of dicamba + 5.06 kg ai ha^{-1} acetochlor as ME formulation

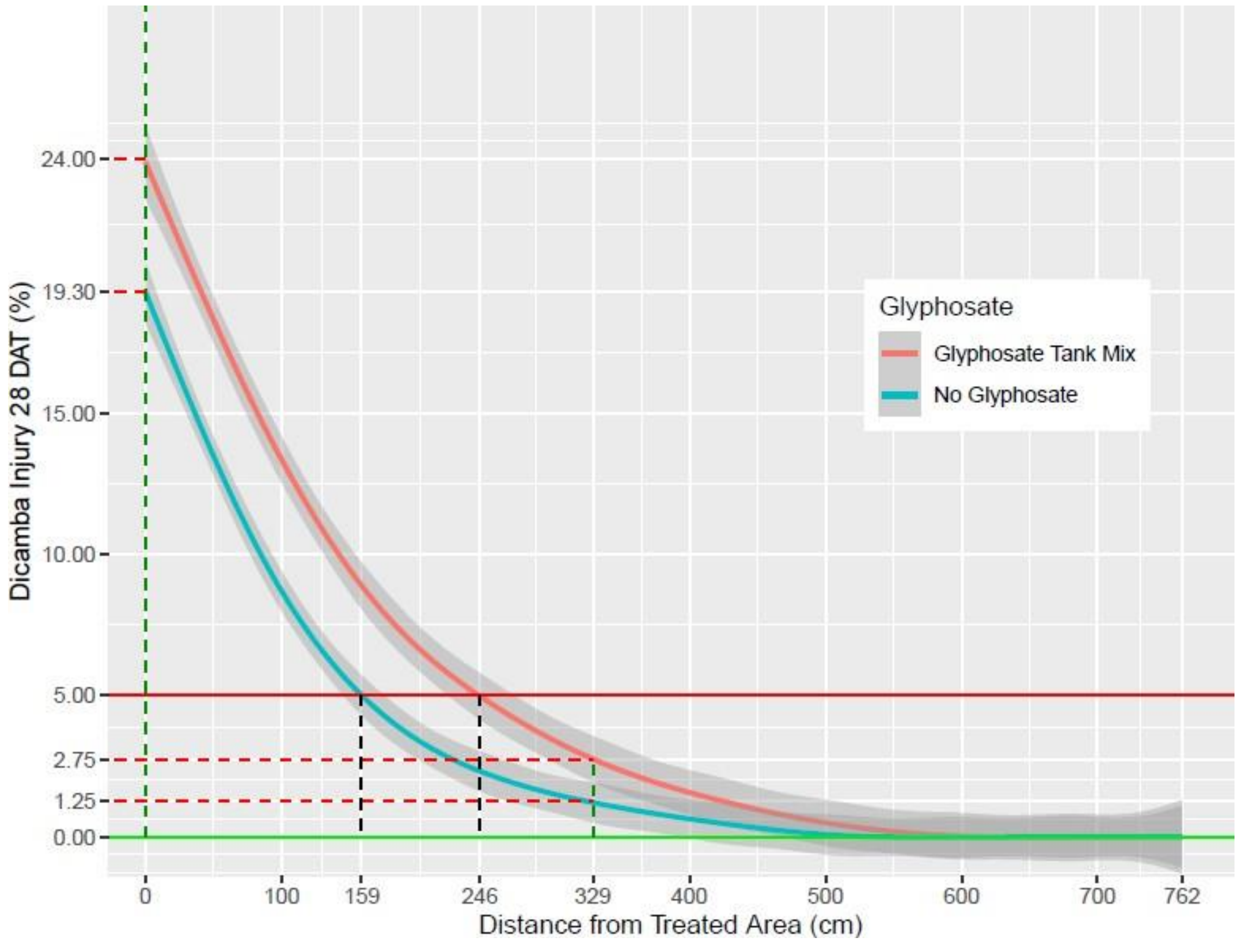

Figure 2.8 Effect of glyphosate averaged over chloroacetamide on dicamba vapor injury of non-DR soybean regressed over distance twenty-eight days after treatment[abc]

[a]Vapor injury (%) non-linearly regressed over distance (cm)

[b]Grey shaded area represents 95% confidence interval; Horizontal solid green line represents no injury; Horizontal solid red line represents 5% injury; Horizontal dashed red lines represent injury % at separation; Vertical dashed green lines represent distance at separation; Vertical dashed black lines represent distance of 5% injury observation

[c]Glyphosate tank mixed at rate of 3.47 kg ae ha $^{-1}$ with DGA salt of dicamba and various chloroacetamides

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