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Impact of reduced rates of dicamba and glyphosate on sweetpotato growth and yield

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Research Article

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Abstract

A major concern of sweetpotato producers is the potential negative effects from herbicide drift or sprayer contamination events when dicamba is applied to nearby dicamba-resistant crops. A field study was initiated in 2014 and repeated in 2015 to assess the effects of reduced rates of N,N-Bis-(3-aminopropyl)methylamine (BAPMA) or diglycloamine (DGA) salt of dicamba, glyphosate, or a combination of these individually in separate trials with glyphosate on sweetpotato. Reduced rates of 1/10, 1/100, 1/250, 1/500, 1/750, and 1/1,000 of the 1× use rate of each dicamba formulation at 0.56 kg ha^{-1}, glyphosate at 1.12 kg ha^{-1}, and a combination of the two at aforementioned rates were applied to 'Beauregard' sweetpotato at storage root formation (10 d after transplanting) in one trial and storage root development (30 d after transplanting) in a separate trial. Injury with each salt of dicamba (BAPMA or DGA) applied alone or with glyphosate was generally equal to or greater than glyphosate applied alone at equivalent rates, indicating that injury is most attributable to the dicamba in the combination. There was a quadratic increase in crop injury and a quadratic decrease in crop yield (with respect to most yield grades) observed with an increased herbicide rate of dicamba applied alone or in combination with glyphosate applied at storage root development. However, with a few exceptions, neither this relationship nor the significance of herbicide rate was observed on crop injury or sweetpotato yield when herbicide application occurred at the storage root formation stage. In general, crop injury and yield reduction were greatest at the highest rate (1/10×) of either salt of dicamba applied alone or in combination with glyphosate, although injury observed at lower rates would be cause for concern after initial observation by sweetpotato producers. However, in some cases yield reduction of No.1 and marketable grades was observed following 1/250×, 1/100×, or 1/10× application rates of dicamba alone or with glyphosate when applied at storage root development.

Introduction

In 2018, North Carolina, Mississippi, California, and Louisiana were the four largest sweetpotato-producing states by acreage (Anonymous 2019). That year 3,109 hectares of sweetpotato were harvested in Louisiana with an estimated yield of 1,213 bu ha^{-1} (1 bu = 22.68 kg) resulting in \$94.5 million in total production value (Anonymous 2019). Production and packing costs were approximately \$9,884 to \$11,367 ha^{-1}, whereas production costs for the processing sector were approximately \$5,683 ha^{-1} prior to storage (Anonymous 2019). Given this high production cost, a small amount of crop injury from off-target herbicide application or sprayer contamination events can negatively impact yield and result in major economic consequences.

Maximum sweetpotato yield requires adventitious roots effectively producing lateral roots (Villordon et al. 2014). Villordon et al. (2014) indicated that in pot studies at approximately 5 to 15 d after transplanting (DAP), adventitious roots, which represented 80% of the final yield, progressively grew and produced lateral roots depending on internal auxin signaling. Villordon et al. (2009) differentiated storage root development into a three-stage phenology scheme, SR1, SR2, and SR3. SR1 consists of the presence of at least one adventitious root greater than 0.5 cm in length in at least 50% of transplanted slips. SR2 consists of the presence of anomalous cambium in at least one adventitious root on 50% of the plants. SR3 consists of at least one visible storage root and an adventitious root that is swollen 0.5 cm at its widest point in at least 50% of the plants. Storage root formation begins between 13 and 20 d in the field. Lateral root development is fundamentally dependent on auxin signaling and anything that interferes with this process interferes with storage root formation. This is the precise window for targeting negative impacts, such as herbicide injury, to determine maximum potential to reduce yield due to reduction in storage root number (A. Villordon, personal communication).

With increasing numbers of weeds becoming resistant to glyphosate, herbicide registrants have shifted their focus to developing new technologies with older herbicides to manage these weeds. One of these developments allows application of diglycolamine (DGA)/N,N-Bis-(3-aminopropyl)methylamine (BAPMA, or sodium methyl amine) salt of dicamba (3,6-dichloro-2-methoxybenzoic acid), alone or in combination with glyphosate, over the top of crops that were previously intolerant to these two herbicides. Commercialized soybean (*Glycine max*), cotton (*Gossypium hirsutum*), and corn (*Zea mays*) varieties are now available for purchase and use by producers. Dicamba controls most dicotyledonous plants, including major problem weeds such as Palmer amaranth (*Amaranthus palmeri* S. Watson; Norsworthy et al. 2008), morningglory (*Ipomoea* spp.; Siebert et al. 2004), and horseweed (*Conyza canadensis* L. Cronq; Bruce and Kells 1990). Therefore, this herbicide is more commonly used in monocotyledonous crops, such as pastures, turf, and in some instances, corn and small grains. This new technology utilizes modified plant genetic resistance to these products so that applications may be made directly to the transformed crops.

Merchant et al. (2013) found that morningglories, when exposed to dicamba at 280, 560, and 1,120 g ae ha^{-1}, were completely controlled. Glyphosate applied at 1,120 g ai/ha^{-1} controlled entireleaf morningglory (*Ipomoea hederacea* L.) and pitted morningglory (*I. lacunosa* L.) at 2 to 5 cm, whereas the same species at 8 to 10 cm were controlled 84% and 88%, respectively (Corbett et al. 2004). Because sweetpotato is also an *Ipomoea* species, off-target movement of dicamba and glyphosate is a major cause for concern to producers. Previous research has shown that 1/4 of the recommended rate of dicamba and triclopyr applied at 27 DAP will result in chlorosis and severe stunting (Clark and Braverman 1998). Dicamba, and triclopyr at 1/4 of the recommended use rate, resulted in almost nonexistent yield, whereas dicamba applied at 1/100 of the use rate resulted in intermediate yield reduction (Clark and Braverman 1998). Clark and Braverman (1998) also demonstrated that stored roots from plants treated with dicamba at 1/10 of the use rate produced shoots with epinastic symptomology 8 mo after application. In a separate study in 1998, Clark and Braverman also reported that glyphosate applied at 1/2, 1/4, and 1/10 of the use rate 27 DAP reduced ‘Beauregard’ U.S. No. 1 and total marketable yield. When applied at 41 DAP, yield reduction was observed only with the 1/2× and 1/4× rates. Meyers et al. (2017) also indicated injury and reduced yield when sweetpotato was exposed to simulated glyphosate drip rates encountered in wick weed control applications 4 to 8 wk after planting.

No research has been conducted on the potential impacts on sweetpotato from dicamba herbicide formulations that are available for use in the Xtend® (dicamba-tolerant) cropping system. Sweetpotato injury from off-target movement or sprayer contamination of dicamba or glyphosate is a substantial concern, given the high cost of inputs required to produce the crop. With this concern in mind, research was conducted in Louisiana to evaluate the impact of reduced rates of two different formulations of dicamba and glyphosate applied during storage root formation and development on growth and yield of sweetpotato.

Materials and Methods

A field study was initiated in 2014 at the Sweet Potato Research Station near Chase, LA (32.098611°N, 91.705556°W) and repeated in 2015. The study was divided into two separate herbicide trials, hereafter referred to as DGA salt of dicamba trial and BAPMA salt of dicamba trial. Furthermore, each trial was subdivided into two trials based on the timing of herbicide application: those made at storage root formation (SR1, 10 DAP) or storage root development (SR3, 30 DAP). Therefore, a total of four trials were conducted each year. In each trial, ‘Beauregard’ sweetpotato, a prominent Louisiana variety, was mechanically transplanted at a population of 32,292 plants per hectare into a 5.8 pH Gigger silt loam (fine-silty, mixed, active, thermic Typic Fragiudalfs) with an organic matter content of 1.5% to 1.8%. Each trial was conducted in a randomized complete block experimental design with treatments placed in a three-by-six factorial arrangement with four replications. Factor one consisted of herbicide [glyphosate alone (Roundup PowerMax®; Monsanto Company, 700 Chesterfield Parkway North, St. Louis, MO), dicamba alone (DGA, Clarity®; BAPMA, Engenia®; BASF, 26 Davis Drive, Research Triangle Park, NC) or dicamba in combination with glyphosate [DGA (Xtendimax® with VaporGrip® Technology; Monsanto Company), BAPMA (Engenia®, BASF), and Roundup PowerMax® (Monsanto Company)] and factor two consisted of herbicide rate (1/10, 1/100, 1/250, 1/500, 1/750, and 1/1,000 of the 1× use rate of each product). Within all studies, the 1× rates of herbicides used for fractional rate calculations were as follows: DGA/BAPMA salt of dicamba at 0.56 kg ha^{-1}, glyphosate at 1.12 kg ha^{-1}, and DGA/BAPMA salt of dicamba in combination with glyphosate at aforementioned rates. Plots consisted of three rows, and plot dimensions were 3 m wide by 7.62 m long. Two rows were treated (one for root measurements and the other for yield) leaving the third as a border row. Each trial included a nontreated control for comparison. Herbicide treatments were applied at a constant 187 L ha^{-1} carrier volume using a compressed air tractor mounted 2-row sprayer, with 4 Teejet (TeeJet Technologies, Glendale Heights, IL) AI 11003 nozzles at 138 kPa.

To eliminate weed interference, flumioxazin (Valor SX®; Valent USA, Walnut Creek, CA) at 71.4 g ai ha^{-1} pretransplant followed by S-metolachlor at 1.4 kg ai ha^{-1} immediately posttransplant was applied to all plots. Subsequent applications of clethodim (Select Max®; Valent USA) at 170 g ai ha^{-1}, tank-mixed with nonionic surfactant (0.25% vol/vol) were made throughout the growing season as needed for grass control in addition to hand weeding for broadleaf weed control. Plants were monitored during the growing season, and insect control and irrigation were scheduled as needed.

In all trials where application occurred at the SR1 stage, five plants were sampled, excavated from the nonyield record row, and roots were examined for storage root development at 10 d and 30 d after treatment (DAT). This evaluation included determining storage root number, diameter, and fresh weight. From all trials, visual rating of plant injury based on a scale of 0 = no effect to 100 = plant death was recorded at 7, 14, and 28 DAT. A single row from all plots was mechanically harvested and sweetpotatoes were separated into U.S. No.1, canner, or jumbo categories to determine yield, based on fresh weights. Marketable yield was the sum of No.1, canner, and jumbo. These grades are determined based on USDA standards (USDA 2005).

Data were subjected to ANOVA using the PROC GLIMMIX procedure in SAS 9.3 (SAS Institute Inc., Cary, NC) considering the factorial treatment arrangement. Data from each trial were

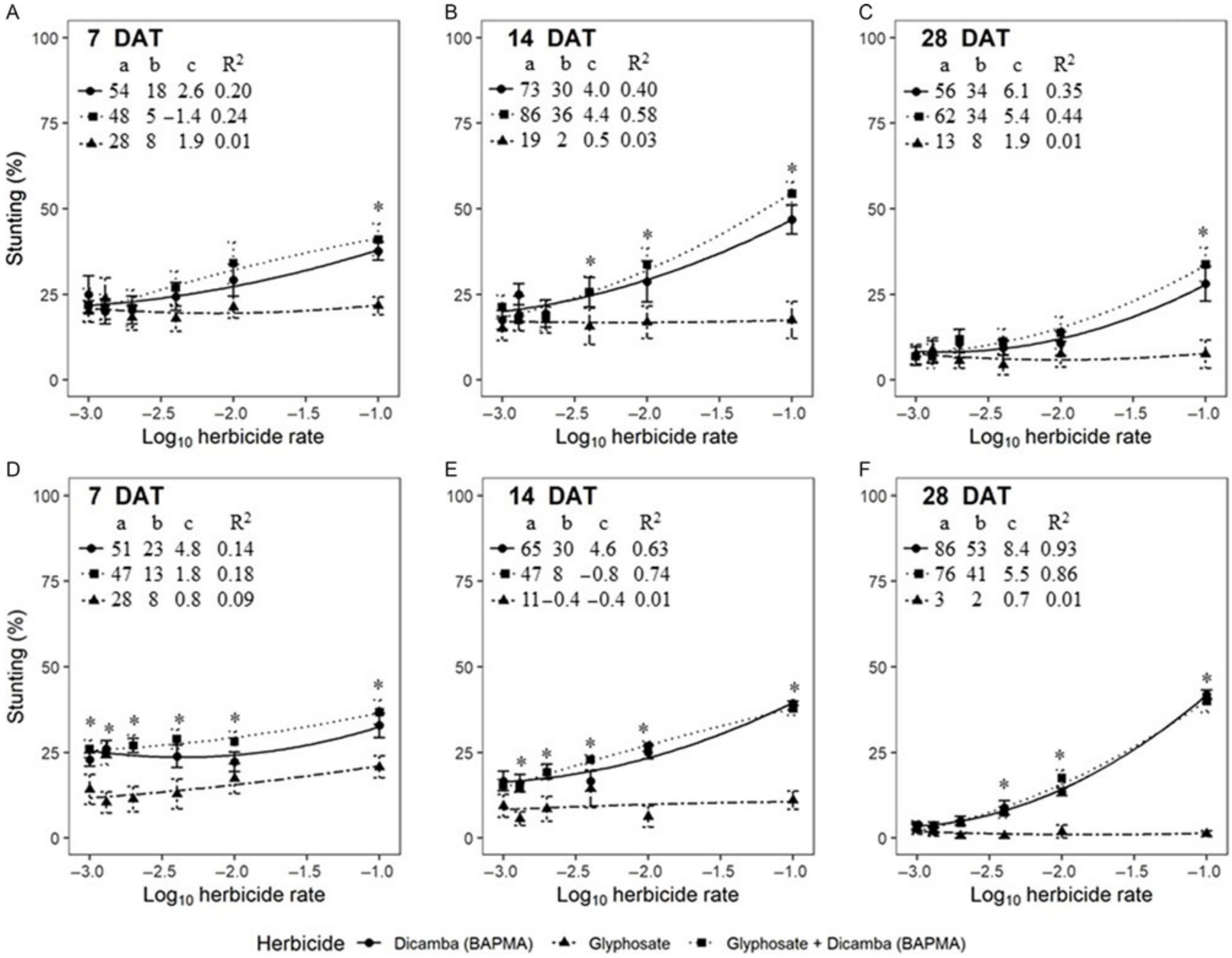

Figure 1. Effect of reduced rate application of glyphosate and/or BAPMA salt of dicamba on sweetpotato injury when herbicide application made at storage root formation (A to C) and storage root development (D to F) stages at Chase, LA, in 2014 and 2015. *Indicates statistically significant difference between herbicide type within an application rate based on Fisher's protected LSD test at $\alpha = 0.05$. Equation represents as $Y = a + bX + cX^2$; where Y = crop injury; a, b, and c are constants; and X = herbicide application rates transformed as $\log_{10}$.

analyzed separately due to the limitations of experimental design as separate field trials were conducted for each herbicide and herbicide application timing. All data were checked for homogeneity of variance before statistical analysis by plotting residuals. Fixed effects included herbicide, herbicide rate, and their interaction. Year and replications within year were included as random effects. Treatment means were separated by *F*-protected LSD at a significance level of $\alpha = 0.05$. When significant main effects were determined, the LINES option of the LSMEANS statement was used to perform Fisher's protected LSD means separation. When significant interactions were determined, the SLICEBY and LINES options of the SLICE statement were used to perform Fisher's protected LSD means separation of effects within the interaction. Furthermore, crop injury and yield data were subjected to regression analysis using the quadratic model in R (v.3.2.1, R Foundation for Statistical Computing, Vienna, Austria). The relative goodness of fit was determined using Akaike information criterion (AIC). The model with lower AIC was selected.

$$Y = a + bX(\text{linear}) \text{ or } Y = a + bX + cX^2(\text{quadratic}),$$

where Y = crop injury or sweetpotato yields by grades; a, b, and c are constants; and X = herbicide rates transformed as $\log_{10}$. The nontreated check was not included in sweetpotato injury analysis as crop injury was 0% and had a variance of zero but was included in root measurement and yield analysis.

Results and Discussion

Due to a lack of treatment-by-year interaction, data were combined across years for each trial. Further analysis indicated that the two-way interaction among herbicide and herbicide rate was significant ($P < 0.05$) except for the root measurements data; therefore, results are presented with respect to significance of either main effects or their interaction. Also, for either salt of dicamba, there were no significant effects with canner yield and therefore, those data are not presented.

BAPMA Salt of Dicamba Study

For both storage root formation and development stage application, the effect of herbicide rate was not significant for glyphosate ($P > 0.05$) and resulted in 1% to 24% crop injury regardless of evaluation interval (Figure 1 A to F). However, a quadratic increase in crop injury was observed with increase in herbicide rate of dicamba alone or dicamba in combination with glyphosate at most

Table 1. Effect of reduced rate application of glyphosate and/or BAPMA salt of dicamba on sweetpotato storage root measurements taken at 10 and 30 DAT when herbicide application made at storage root formation stage at Chase, LA, in 2014 and 2015.[a]

	10 DAT			30 DAT		
Dependent variable	Number	Weight	Diameter	Number	Weight	Diameter
		—g—	—mm—		—g—	—mm—
Herbicide type						
Glyphosate	5.2 a	2.0	2.0	7.4	38.6	7.5
BAPMA dicamba	4.3 b	1.6	1.9	7.1	39.1	7.2
Glyphosate plus BAPMA dicamba	4.8 ab	2.0	2.0	7.2	39.1	7.3
H (P-value)	0.0233	0.2804	0.8857	0.8502	0.9916	0.8290
Application rate						
1/10×	4.3	1.8	2.1	6.6	29.5	6.2 c
1/100×	4.3	1.5	1.8	6.8	35.0	7.2 bc
1/250×	4.8	2.3	2.2	7.6	45.7	7.8 ab
1/500×	5.2	1.9	2.0	8.3	40.3	7.1 bc
1/750×	4.6	1.7	1.9	7.2	38.8	6.8 bc
1/1,000×	4.6	1.9	2.0	6.9	40.4	7.7 ab
Nontreated	5.5	1.7	1.9	7.3	42.9	8.7 a
AR (P-value)	0.1253	0.7063	0.4737	0.1982	0.2239	0.0101
H × AR (P-value)	0.7430	0.3396	0.2589	0.0332	0.0543	0.3159

[a] Data were combined over years.

[b] Abbreviations: AR, application rate; BAPMA, N,N-Bis-(3-aminopropyl)methylamine; DAT, days after treatment; H, herbicide type.

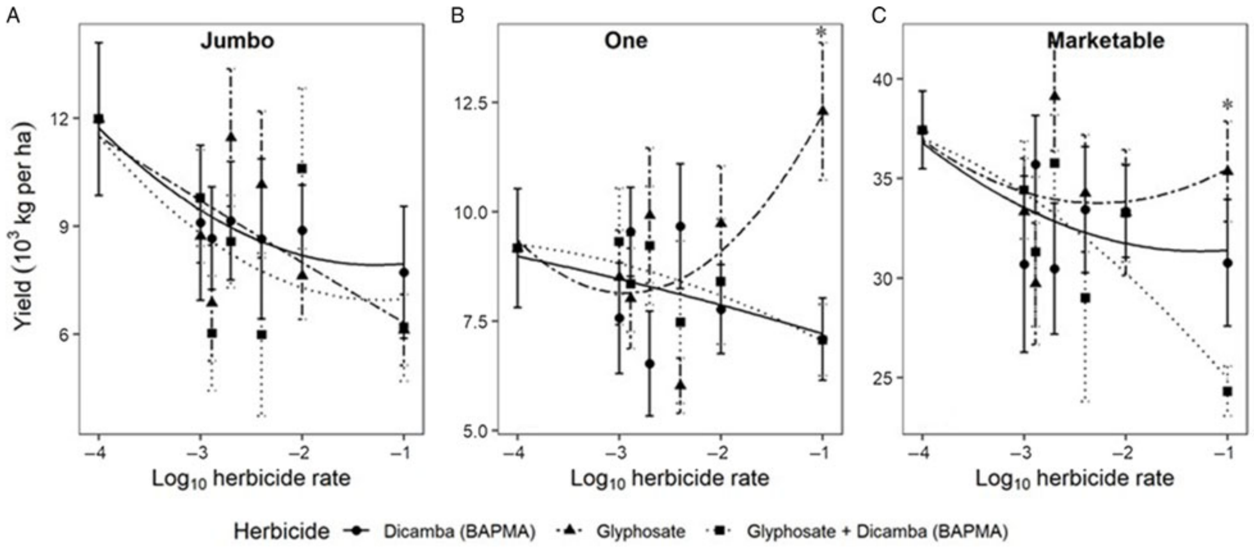

Figure 2. Effect of reduced rate application of glyphosate and/or BAPMA salt of dicamba on sweetpotato yields at storage root formation at Chase, LA, in 2014 and 2015. *Indicates statistically significant difference between herbicide type within an application rate based on Fisher's protected LSD test at $\alpha = 0.05$. (A) ● $Y = 8.7 + 1.3X - 0.5X^2$ ($R^2 = 0.05$), ▲ $Y = 4.7 - 1.6X + 0.01X^2$ ($R^2 = 0.1$), ■ $Y = 7.8 + 1.5X + 0.6X^2$ ($R^2 = 0.02$); (B) ● $Y = 6.5 - 0.8X + 0.01X^2$ ($R^2 = 0.02$), ▲ $Y = 17.5 + 6.4X - 1.1X^2$ ($R^2 = 0.13$), ■ $Y = 5.7 - 1.5X - 0.2X^2$ ($R^2 = 0.03$); (C) ● $Y = 32.5 + 1.8X - 0.7X^2$ ($R^2 = 0.04$), ▲ $Y = 39.2 + 4.8X + 1.1X^2$ ($R^2 = 0.02$), ■ $Y = 18.4 - 7.2X - 0.6X^2$ ($R^2 = 0.15$).

of the evaluation intervals. At SR1, the only significant difference in crop injury with regard to herbicide was observed at the 1/10× rate, with the exception of 1/100× and 1/250× rates at 14 DAT (Figure 1 A to C). At the 1/10× rate, higher injury of 28% to 47% and 34% to 54% was observed with dicamba alone and dicamba in combination with glyphosate, respectively, compared with glyphosate alone (8% to 22%) regardless of evaluation interval. At 7 DAT and 14 DAT, sweetpotatoes treated at SR3 had significantly higher injury from dicamba alone (16% to 39%) or in combination with glyphosate (15% to 38%) compared with glyphosate alone (6% to 11%) across all herbicide rates (Figure 1 D and E). However, at 28 DAT, dicamba and dicamba plus glyphosate resulted in greater injury than glyphosate alone only at rates ≥1/250× (Figure 1F).

At both 10 DAT and 30 DAT, storage root weight and diameter were not influenced by herbicide, whereas storage root number at 10 DAT was reduced when exposed to dicamba or dicamba plus glyphosate compared with glyphosate alone, when applied at SR1 (Table 1). The effect of herbicide rate was observed for storage root diameter, which was reduced 17% to 29% from 1/10×, 1/100×, 1/500×, and 1/750× compared with the nontreated control.

For herbicide application at SR1, reduction in No.1 and marketable sweetpotato yield was observed with the 1/10× rate of dicamba alone and dicamba plus glyphosate, respectively, compared with glyphosate alone (Figure 2 A to C). At all other herbicide rates, grade yields were similar between herbicide treatments.

For herbicide application at SR3, glyphosate rate had no impact on any sweetpotato grade yield; however, a quadratic decrease in all

Table 2. Effect of reduced rate application of glyphosate and/or DGA salt of dicamba on sweetpotato storage root measurements taken at 10 and 30 DAT when herbicide application made at storage root formation stage at Chase, LA, in 2014 and 2015.[a]

Dependent variable	10 DAT			30 DAT		
	Average number	Average weight	Average diameter	Average number	Average weight	Average diameter
		——g——	——mm——		——g——	——mm——
Herbicide						
Glyphosate	3.9	0.4	1.3	7.8	24.3	5.6
DGA dicamba	3.2	0.4	1.3	7.8	18.5	5.0
Glyphosate plus DGA dicamba	3.5	0.4	1.4	7.8	16.6	4.9
H (P-value)	0.0708	0.6897	0.5909	0.9996	0.0778	0.0962
Application rate						
1/10×	3.2	0.4	1.5	6.3	17.2	4.5
1/100×	3.8	0.4	1.4	7.9	20.9	5.3
1/250×	4.2	0.6	1.3	8.6	23.9	5.4
1/500×	3.4	0.4	1.3	7.7	15.8	4.8
1/750×	3.6	0.4	1.4	8.5	22.5	5.6
1/1,000×	3.4	0.3	1.3	8.1	23.5	5.8
Nontreated	3.1	0.3	1.2	7.8	14.9	4.7
AR (P-value)	0.2463	0.1728	0.1150	0.1350	0.4193	0.1244
H × AR (P-value)	0.8849	0.7666	0.2728	0.0579	0.5263	0.6510

[a] Data were combined over years.

[b] Abbreviations: AR, application rate; DAT, days after treatment; DGA, diglycloamine; H, herbicide type.

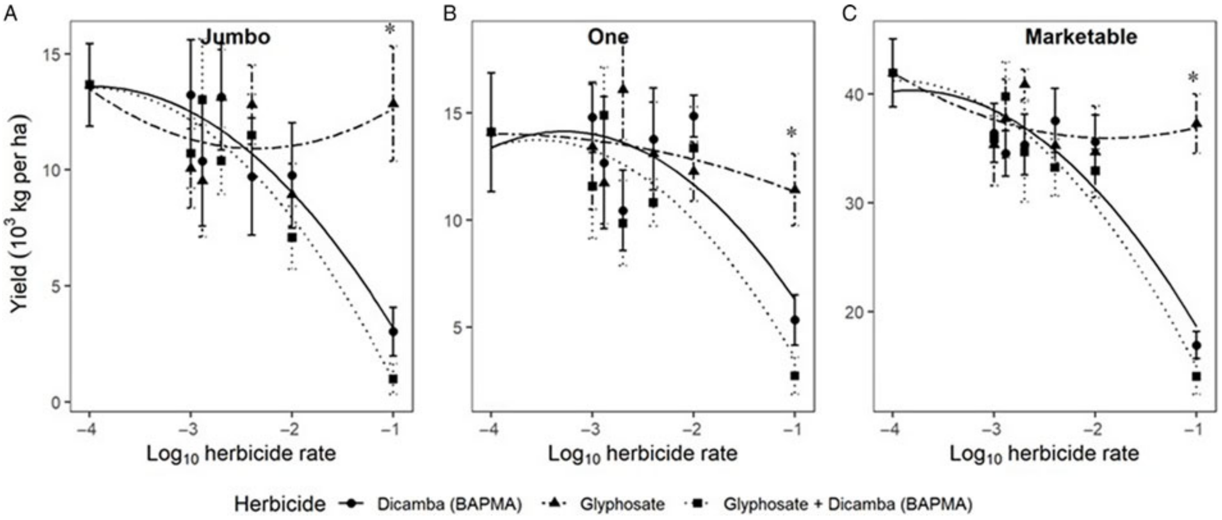

Figure 3. Effect of reduced rate application of glyphosate and/or BAPMA salt of dicamba on sweetpotato yields at storage root development (A to C) at Chase, LA, in 2014 and 2015. *Indicates statistically significant difference between herbicide type within an application rate based on Fisher's protected LSD test at $\alpha = 0.05$. (A) -●- $Y = -5.1 - 9.4X - 1.2X^2$ ($R^2 = 0.23$), -▲- $Y = 16.1 + 4.4X - 0.9X^2$ ($R^2 = 0.03$), ·■· $Y = -8.9 - 11.2X - 1.4X^2$ ($R^2 = 0.43$); (B) -●- $Y = -2.1 - 9.9X - 1.5X^2$ ($R^2 = 0.17$), -▲- $Y = 9.2 - 2.4X - 0.3X^2$ ($R^2 = 0.02$), ·■· $Y = -5.9 - 11.1X - 1.6X^2$ ($R^2 = 0.26$); (C) -●- $Y = 0.5 - 20.9X - 2.7X^2$ ($R^2 = 0.47$), -▲- $Y = 40.6 + 4.9X + 1.3X^2$ ($R^2 = 0.05$), ·■· $Y = -5.9 - 23.8X - 3.0X^2$ ($R^2 = 0.52$).

grade yields was observed with increasing rates of dicamba alone or dicamba plus glyphosate (Figure 3 A to C). At the highest rate, dicamba alone or in combination with glyphosate resulted in 76% to 92%, 53% to 76%, and 55% to 62% yield reductions in jumbo, U.S. No.1, and marketable grades compared with glyphosate, respectively.

DGA Salt of Dicamba Study

In both SR1 and SR3 stage application trials, the effect of application rate was not significant for glyphosate ($P > 0.5$) and resulted in 1% to 18% crop injury regardless of evaluation interval (Figure 4 A to F). However, a quadratic increase in crop injury was observed with increase in rate of dicamba alone or in combination with glyphosate at most of the evaluation intervals. At 14 DAT and 28 DAT, significantly higher injury resulted from dicamba alone (13% to 62%) or in combination with glyphosate (14% to 63%) compared with glyphosate alone (4% to 14%) at 1/100× and 1/10× rates when applied at SR1 (Figure 4 A to C). However, when applied at SR3, significantly higher injury from dicamba alone (7% to 42%) or in combination with glyphosate (8% to 46%) compared with glyphosate alone (1% to 7%) was reported at all the rates ≥1/500× at 14 DAT and 28 DAT (Figure 4 D to F).

At both 10 DAT and 30 DAT, all root measurements including storage root number, weight, and diameter were not influenced by herbicide or herbicide rate when applications were made at SR1 (Table 2). For herbicide application at SR1, reduction in U.S. No.1 and marketable sweetpotato yield was observed with the highest rate of dicamba alone or in combination with glyphosate, compared with glyphosate alone (Figure 5 A to C). At all other rates, grade yields were similar between herbicide treatments.

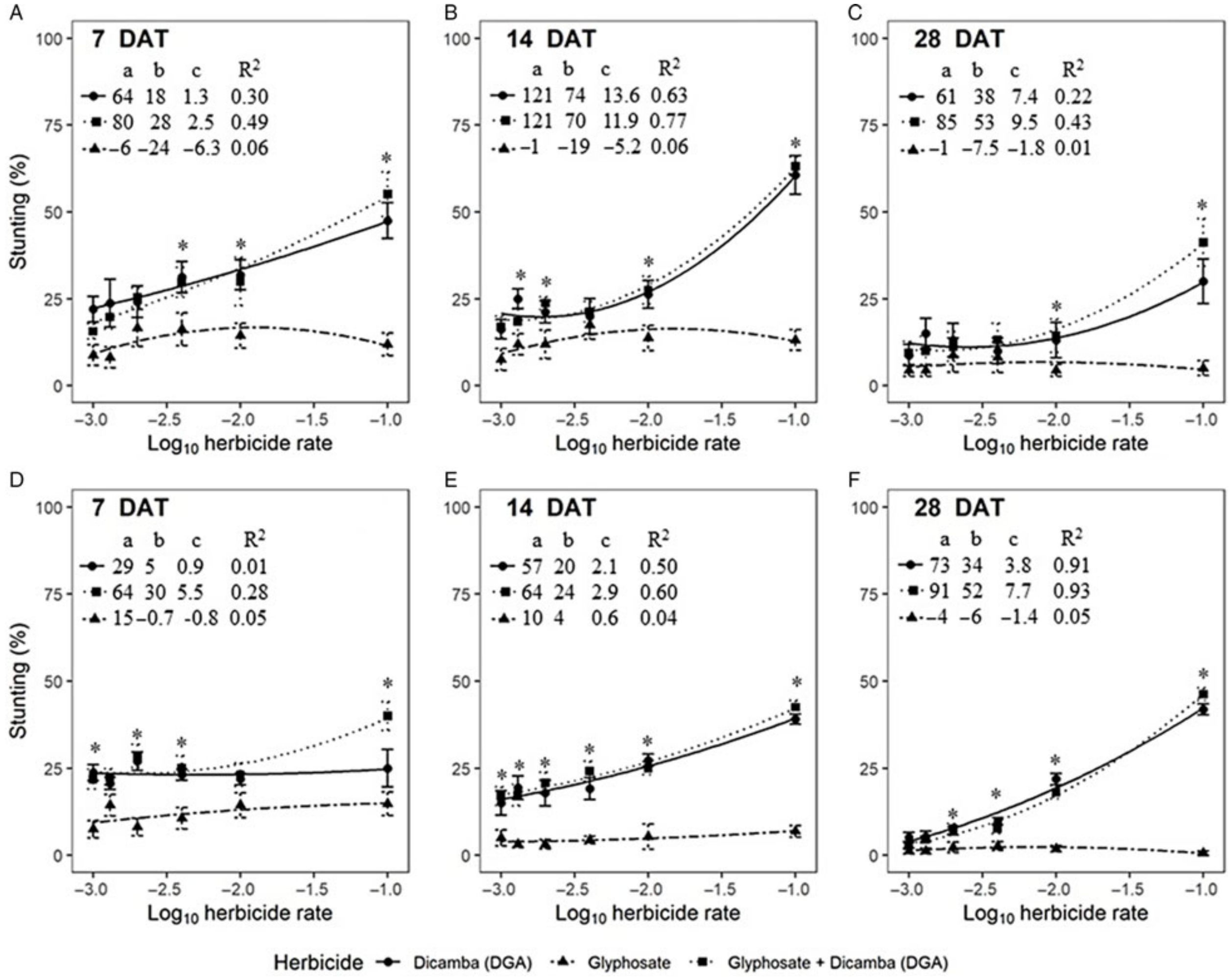

Figure 4. Effect of reduced rate application of glyphosate and/or DGA salt of dicamba on sweetpotato injury when applied at storage root formation (A to C) or storage root development (D to F) at Chase, LA, in 2014 and 2015. *Indicates statistically significant difference between herbicide type within an application rate based on Fisher's protected LSD test at $\alpha = 0.05$. Equation represents as $Y = a + bX + cX^2$; where Y = crop injury; a, b, and c are constants; and X = herbicide application rates transformed as $\log_{10}$.

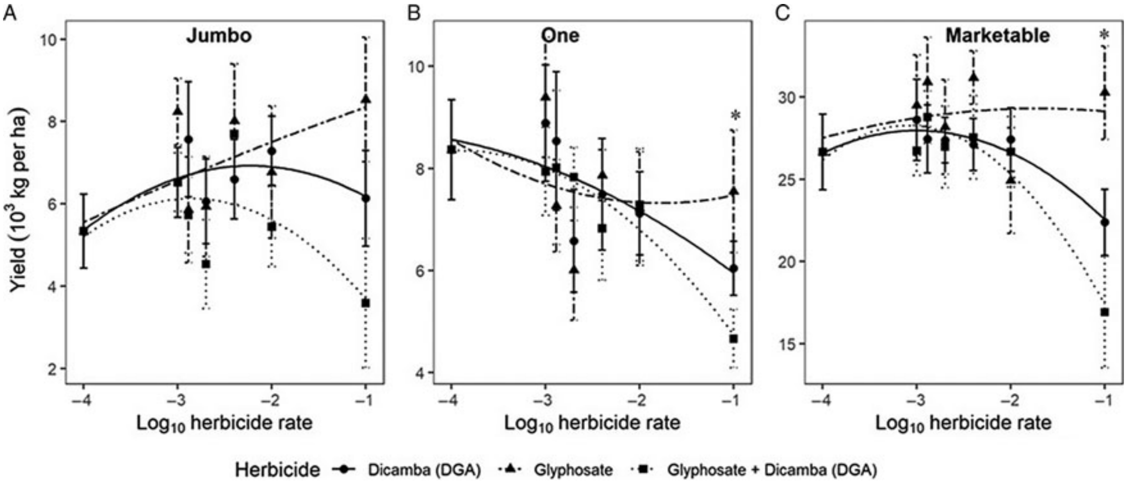

Figure 5. Effect of reduced rate application of glyphosate and/or DGA salt of dicamba on sweetpotato yields applied at storage root formation (A to C) at Chase, LA, in 2014 and 2015. *Indicates statistically significant difference between herbicide type within an application rate based on Fisher's protected LSD test at $\alpha = 0.05$. (A) —●— $Y = 4.5 - 2.2X - 0.5X^2$ ($R^2 = 0.03$), -▲- $Y = 9.1 + 0.7X + 0.01X^2$ ($R^2 = 0.05$), ·■· $Y = 0.4 - 4.0X - 0.7X^2$ ($R^2 = 0.06$); (B) —●— $Y = 4.4 - 1.7X - 0.2X^2$ ($R^2 = 0.07$), -▲- $Y = 8.1 + 0.9X + 0.3X^2$ ($R^2 = 0.02$), ·■· $Y = 1.8 - 3.4X - 0.4X^2$ ($R^2 = 0.15$); (C) —●— $Y = 15.8 - 8.1X - 1.4X^2$ ($R^2 = 0.1$), -▲- $Y = 28.3 - 1.2X - 0.3X^2$ ($R^2 = 0.01$), ·■· $Y = 4.5 - 15.4X - 2.5X^2$ ($R^2 = 0.24$).

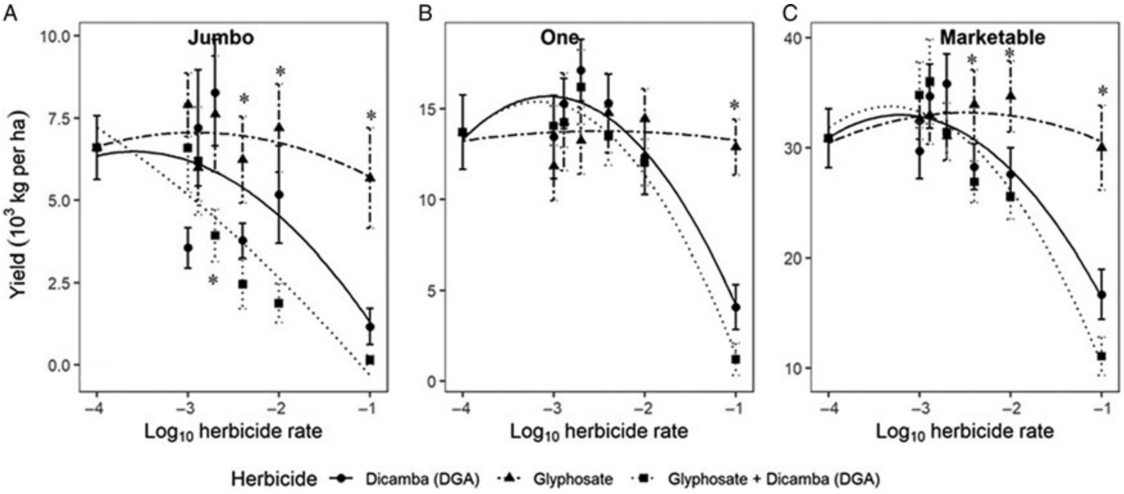

Figure 6. Effect of reduced rate application of glyphosate and/or DGA salt of dicamba on sweetpotato yields applied at storage root development (A to C) at Chase, LA, in 2014 and 2015. *Indicates statistically significant difference between herbicide type within an application rate based on Fisher's protected LSD test at $\alpha = 0.05$. (A) ● $Y = -3.5 - 5.5X - 0.8X^2$ ($R^2 = 0.18$), ▲ $Y = 4.0 - 2.1X - 0.4X^2$ ($R^2 = 0.02$), ■ $Y = -3.8 - 3.7X - 0.2X^2$ ($R^2 = 0.37$); (B) ● $Y = -9.6 - 16.6X - 2.7X^2$ ($R^2 = 0.37$), ▲ $Y = 12.4 - 1.1X - 0.2X^2$ ($R^2 = 0.01$), ■ $Y = -14.4 - 18.8X - 3.0X^2$ ($R^2 = 0.55$); (C) ● $Y = -1.9 - 21.7X - 3.4X^2$ ($R^2 = 0.37$), ▲ $Y = 25.8 - 5.9X - 1.2X^2$ ($R^2 = 0.02$), ■ $Y = -14.0 - 28.7X - 4.3X^2$ ($R^2 = 0.52$).

For herbicide application timing at SR3, application rate had no impact on any sweetpotato grade yield for glyphosate but a quadratic decrease in all grade yields was reported with an increased rate of dicamba alone or in combination with glyphosate (Figure 6 A to C). At 1/250× to 1/10× rates, significantly lower yield of jumbo and marketable grades was observed with dicamba alone or in combination with glyphosate as compared with glyphosate only. Yield of U.S. No.1 grade sweetpotato was reduced by 68% and 90% following application of dicamba alone or in combination with glyphosate, respectively, compared with glyphosate at the 1/10× herbicide rate (Figure 6B).

An abundance of research has been conducted to determine the effects of reduced rates of hormonal-type herbicides that simulate rates encountered in off-target applications in crops other than sweetpotato. When exposed to 1/50 of the normal use rate of 2,4-D, pepper (*Capsicum* spp. L.), tomato (*Solanum lycopersicum* L.), and squash (*Cucurbita pepo* L.) were injured 35%, 41%, and 49%, respectively (Merchant et al. 2012). Similar injury responses were observed with sweetpotato in the current research. Greater injury at the later application timing could simply be due to the plants being larger and having greater leaf/stem surface area to intercept more of the herbicide spray solution.

Negative yield impacts with hormonal-type herbicides have also been observed in other crops. In Louisiana, when exposed to 1/2× the labeled rate of dicamba at the 2- to 3-trifoliate stage, a yield reduction of 85%, as well as height reduction of 72% was observed in soybean (Griffin et al. 2013). Potato (*Solanum tuberosum* L. 'Norland') has been observed to exhibit phytotoxic symptomology following application of dicamba ranging from 2.8 g ai/ha to 22.2 g ai/ha (Wall 1994). Wall (1994) also found that at 22.2 g ai/ha, marketable yield loss equaled 70% to 75%. When exposed to 1/50× of the normal use rate of 2,4-D, pepper, tomato, and squash, yield was reduced by 51%, 23%, and 27% respectively (Merchant et al. 2012). In addition, rates as low as 1/400× of the use rate resulted in a 14.5% yield reduction of pepper.

Injury with each salt of dicamba (BAPMA or DGA) applied alone or with glyphosate in the current research was generally equal to or greater than glyphosate applied alone at equivalent rates, indicating that injury is most attributable to the dicamba in the combination. Similarly, Clark and Braverman (1998) reported that the effects of glyphosate at low rates on 'Beauregard' sweetpotato were not as pronounced as those observed with hormone herbicides 2,4-D, dicamba, and triclopyr. Even though the statistical analysis was not conducted to directly compare herbicide application timings because of limitation of experimental design, the impact of dicamba on crop injury and yield was generally greater when application was made at SR3 than SR1. The authors are led to believe that this is due to the increased leaf area at SR3 versus SR1. There was a quadratic increase in crop injury and quadratic decrease in crop yield (with respect to most yield grades) observed with increasing rates of dicamba alone or in combination with glyphosate applied at storage root development. However, with a few exceptions, neither this relationship nor the significance of herbicide rate was observed on crop injury or sweetpotato yield when herbicide application occurred at the SR1 stage.

In general, crop injury and yield reduction were greatest at the highest rate (1/10×) of either salt of dicamba applied alone or in combination with glyphosate, although injury observed at lower rates would be cause for concern after initial observation by sweetpotato producers. However, in some cases yield reduction of No.1 and marketable grades was observed following 1/250×, 1/100×, or 1/10× application rate of dicamba alone or with glyphosate when applied at storage root development. Clark and Braverman (1998) reported that the 1/10× and 1/100× rates of dicamba, and the 1/10× rate of glyphosate resulted in intermediate yield reduction when herbicides were applied at 27 DAP. These data suggest that injury and subsequent total yield reduction concerns from the herbicide combinations evaluated are valid with sublethal rates as low as 1/10× that may be encountered in sprayer contamination events and off-target spray applications during SR1 or SR3. Therefore, producers with multicrop farming operations are cautioned to thoroughly follow all sprayer cleanout procedures when previously spraying the combination herbicides evaluated or to devote different equipment to spraying Xtend® crops. In addition, proper consideration should be given to planting these crops in close proximity to sweetpotato production fields and making herbicide applications under environmental conditions that are not conducive to off-target spray movement.

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References

Anonymous (2019) Sweet potatoes, Louisiana Summary. https://www.lsuagcenter.com/~/media/system/7/9/6/7/796773af58d4c3e610063c7a8f7985f1/pub2382%20ag%20summary%202018_fullpdf.pdf. Accessed: December 10, 2019

Bruce JA, Kells JJ (1990) Horseweed (*Conyza canadensis*) control in no-tillage soybeans (*Glycine max*) with preplant and preemergence herbicides. Weed Technol 4:642–647

Clark CA, Braverman MP (May 1998) Herbicide damage on Beauregard. Tater Talk 4

Corbett JL, Askew SD, Thomas WE, Wilcut JW (2004) Weed efficacy evaluations for bromoxynil, glufosinate, glyphosate, pyrithiobac and sulfosate. Weed Technol 18:443–453

Griffin JL, Bauerle MJ, Stephenson DO 4th, Miller DK, Boudreaux JM (2013) Soybean response to dicamba applied at vegetative and reproductive stages. Weed Technol 27:696–703

Merchant RM, Culpepper AS, Sosnoskie LM, Prostko EP, Richburg JS, Webster TM (2012) Fruiting vegetable and cucurbit response to simulated drift rates of 2,4-D. Proc South Weed Sci Soc 65:10

Merchant RM, Sosnoskie LM, Culpepper AS, Steckel LE, York AC, Braxton LB, Ford JC (2013) Weed response to 2,4-D, 2,4-DB, and dicamba applied alone or with glufosinate. J Cotton Sci 17:212–218

Meyers SL, Jennings KM, Monks DW (2017) Sweetpotato response to simulated glyphosate wick drip. Weed Technol 31:130–135

Norsworthy JK, Griffith GM, Scott RC, Smith KL, Oliver LR (2008) Confirmation and control of glyphosate-resistant palmer amaranth (*Amaranthus palmeri*) in Arkansas. Weed Technol 22:108–113

Siebert JD, Griffin JL, Jones CA (2004) Red Morningglory (*Ipomoea coccinea*) control with 2,4-D and alternative herbicides. Weed Technol 18:38–44

[USDA-AMS] US Department of Agriculture–Agricultural Marketing Service (2005) United States Standards for Grades of Sweetpotatoes. Washington DC: US Department of Agriculture. http://www.ams.usda.gov/sites/default/files/media/Sweetpotato_Standard%5B1%5D.pdf

Villordon AQ, Ginzberg I, Firon N (2014) Root architecture and root and tuber crop productivity. Trends Plant Science 19:419–425

Villordon A, LaBonte DR, Firon N (2009) Development of a simple thermal time method for describing the onset of morpho-anatomical features related to sweetpotato storage root formation. Sci Hort 121: 374–377

Wall DA (1994) Potato (*Solanum tuberosum*) response to simulated drift of dicamba, clopyralid, and tribenuron. Weed Sci 42:110–114