Journal of Horticulture

Knezevic et al., J Hortic 2018, 5:1
DOI: 10.4172/2376-0354.1000229

Research Article Open Access

Sensitivity of Grape and Tomato to Micro-rates of Dicamba-based Herbicides

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Abstract

There is Agro-climatic concern that the widespread use of dicamba-based herbicides in Dicamba-Tolerant (DT) soybeans can result in un-intended drift onto non-DT crops in nearby field due to windy conditions and volatility. New dicamba-based products such as Engenia® and XtendiMax® with Vapor Grip technology were developed to reduce volatility, however, they are not completely volatile-free. A study was conducted to evaluate the sensitivity of pot-grown grape and tomato to six micro-rates of three dicamba-based products (Clarity®, Engenia® and XtendiMax®) in 2016 and 2017, at Haskell Ag Lab, Concord (42.37°N, 96.68°W), NE, USA. The tested dicamba formulations negatively impacted growth of grape and tomato as measured by vine length and plant height respectively, as well as by plant biomass. About 2% of the label rate was high enough to cause 50% injury and reduction in vine length or plant height. For example, a dose of 6.54 to 9.13 g ae ha-1 and 3.98 to 5.35 g ae ha-1 caused 50% injury in grape and tomato respectively, at 21 DAT. At 50% injury and vine reduction threshold, grape appeared more sensitive to XtendiMax® than Clarity® and Engenia®. For instance, a dose of 1.83 g ae ha-1 of XtendiMax® was required to cause 50% reduction in vine length (~49 cm) compared to significantly higher dose of 5.64 and 7.59 g ae ha-1 required for Clarity® and Engenia®, respectively. However, in tomato, there was no significant difference in sensitivity to all three products. In general, the present study showed that grape and tomato were very sensitive to micro-rates of all three dicamba products, irrespective of the of the new dicamba technology that reduces volatility. Hence, efforts should be made to avoid drift of dicamba onto these crops.

Keywords: Dicamba; Grape; Tomato; Injury

Introduction

Dicamba is a selective herbicide commonly used to control broadleaf weeds in fallow, pasture, rangeland and grassy type crops (e.g. corn, sugarcane, sorghum, wheat). With the commercialization of dicamba-tolerant (DT) broadleaf crops such as soybean and cotton, the adoption rate of dicamba for weed control is increasing, particularly for the control of "hard-to- manage", glyphosate-resistant broadleaf weeds [1]. However, there are increasing number of cases of un-intended drift of dicamba during application and this is of great concern to many landowners and land managers. Dicamba drift is known to cause various degree of injury [2], which are highly depended on the type of crop [3], growth stage of the crop [4], drift rate [5-7], dicamba formulation, and environmental conditions [8,9]. Dicamba as a growth-regulator herbicide that acts by stimulating abnormal cell growth in plant meristematic cells, which can lead to blockage of phloem vascular tissue, thereby starving plant the needed nutrients that could have been transported through the phloem.

Grapes and tomatoes, as well as other fruits and vegetables that are sensitive to dicamba, are regularly grown with close proximity to DT crops such as corn, cotton and soybean [1,10]. Grape is an important crop in the United States with over 400,000 ha grown in 2016, yielding 7.7 million tons of fruit [11]. Grapes are also commonly planted in small plots at local acreages and countrysides for local or home use. However, the off-target movement of dicamba from surrounding fields could be a potential threat to grape production. Dicamba injury in grape can cause reduction in growth, fruit yield and fruit quality. The injury symptoms caused by dicamba on grape include cupping of leaves, strapping, epinasty and poor fruit set [12].

United States is among the top five producers of tomato globally [11]. In 2016, tomatoes were grown on 147,629 ha with net worth of about $2.1 billion [11]. Similar to grape, tomato is very sensitive to dicamba drift [10].

Environmental conditions such as wind and temperature inversion during applications can move the spray droplets or volatilized dicamba off-target, thereby injuring nearby sensitive crops [13,6,8]. New dicamba-based products such as Engenia® and XtendiMax® with Vapor Grip technology were developed to reduce volatility. However, reports suggested that these new formulations of dicamba still can vaporize significantly [14], indicating the risk of off-target movement.

Previous studies showed the effects of older dicamba formulations (e.g. Clarity®) on grape [15] and tomato [16,10]. However, with the introduction of new dicamba formulations, our objective was to evaluate the sensitivity of grape and tomato to micro-rates of three dicamba-based herbicides (Clarity®, Engenia® and XtendiMax®).

Materials and Methods

Studies were conducted during summers of 2016 and 2017 at Haskell Ag Lab, Concord, NE (42.37°N, 96.68°W). "Frontenac" grape (J.W. Jung Seed Company, 335 S. High St Randolph, WI 53956) and "better boy" tomato (W. Atlee Burpee & Co 300 Park Ave Warminster, PA 18974) were the varieties used for the experiment. A 2 year old bare rootstocks (about 70 cm) and tomato seedlings (about 20 cm) were planted into 20 by 25 cm pots filled with moisture control potting mix (Miracle Gro, Marysville, OH).

The pot-grown grape and tomato were separately placed on the field in a randomized complete block design with 4 replicates. The

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Received March 04, 2018; **Accepted** March 23, 2018; **Published** March 30, 2018

Citation: Knezevic SZ, Osipitan O A, Scott JE (2018) Sensitivity of Grape and Tomato to Micro-rates of Dicamba-based Herbicides. J Hortic 5: 229. doi: 10.4172/2376-0354.1000229

treatment combinations were 3 dicamba-based products, 6 micro-rates (0; 1/10; 1/50; 1/100; 1/500; 1/1000 of the label rate [560 g ae ha^{-1}]) of each product, and 2 application timings in respect to crop height or vine length. Tomato heights at time of application were 25 and 45 cm, while vine lengths were 75 and 115 cm. To help reader visualize the amount of product on a per acre (0.4 ha) basis, the 1/10th of the label rate is equivalent of a 3 tablespoons and 1/100th is a 1 teaspoon applied over a size of football field (1 acre; 0.4 ha). There were total of 20 plants for each treatment combination; 5 plants × 4 replicates. The 3 dicamba-based products were Clarity® (dicamba diglycolamine salt, 480 g l^{-1}), Engenia® (dicamba N,N- Bis-(3-aminopropyl)methylamine salt, 600 g l^{-1}) and XtendiMax® (dicamba diglycolamine salt, 350 g l^{-1}).

Herbicide applications were made using a CO_2-pressurized backpack boom sprayer calibrated to deliver 140 L ha^{-1} at 276 kPa through four 11004-VP flat spray nozzle tips (Turbo TeeJet Induction, Spraying systems Co., P.O. Box 7900, Wheaton, IL 60187). Wind speed at the time of application was below 4 km h^{-1} in both years. Air temperatures at time of herbicide application were 27 and 35 C in 2016 and 2017, respectively.

Visually rated injuries on the scale of 0 (no injury) to 100 (dead plant) were collected at 7, 14, 21 and 28 days after treatment (DAT). The injury symptoms included chlorosis, cupping of leaves, epinasty, stunting, and necrosis, depending on the crop and product rate. Maximum accumulated vine length of grape, plant height of tomato from plant base, and plant biomass were collected at 14 and 28 DAT.

Data for 2016 and 2017 were combined as there was no significant interaction between year and treatment. A four-parameter log-logistic regression model was used to analyze the relationship between dicamba micro-rates, and visual injury, vine length, plant height or biomass [17]. The regression analyses helped estimate the dicamba micro-rates (ED values) causing a range of injury levels (e.g. 10, 20 and 50% threshold) or growth reduction [18]. Regression analyses were conducted using R version 3.4.1 (R Core Team, 2017).

Results and Discussion

Sensitivity of grape to micro-rates of dicamba-based herbicides

All three products caused various degrees of injury and reduction in vine length as influenced by the micro-rate and application time.

Visual ratings: The observed dicamba injury symptoms in the grape plants were epinasty (downward bending and twisting of leaves and stem), cupping of leaves, and chlorosis (Figure 1). Injury caused by the dicamba herbicides increased with increase in micro-rate from 1/1000 to 1/10 of the label rate (560 g ae ha^{-1}) (Figure 2). A dose range of 0.95 to 1.07 g ae ha^{-1} and 6.54 to 9.13 g ae ha^{-1} caused 10% and 50% injury respectively, at 21 DAT, depending on the dicamba product (Table 1). For example, a dose of 6.54 g ae ha^{-1} of XtendiMax® compared to higher dose of Clarity® (9.13 g ae ha^{-1}) and Engenia® (8.34 g ae ha^{-1}) was required to cause 50% injury. However, the range of dose was not significantly different among products for 10% injury. The dicamba rates that caused 10% injury to the grape plant were equivalent to 1/622- 1/523 of the label rate. While those rates that caused 50% injury was equivalent to 1/86-1/61 of the label rate, which was equivalent to 1 teaspoon amount of the product per acre (Table 1). The injury caused by the micro-rates of dicamba increased gradually with time of observation after treatment, and peaked injury was recorded at 21 and 28 DAT. This was similar to a study by Mohseni-Moghadam et al. [15] in which observed injury in grape increased with time of observation. However, there was a possibility that the grape plant may recover from injury over time [15] depending on the dicamba rates.

Figure 1: Grape injury with 1/10 of label rate (560 g ae ha^{-1}) at 21 DAT.

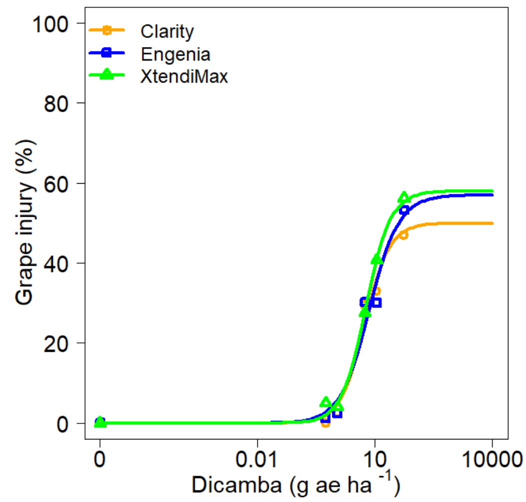

Figure 2: Grape injury caused by increasing micro-rates of dicamba products.

Measurement	Dicamba	ED10 (SE)	1/X[a]	ED20 (SE) g ae ha^{-1}	1/X	ED50 (SE)	1/X
Injury	Clarity®	0.95 (0.28)	1/622	2.19 (0.45)	1/255	9.13 (1.32)	1/61
	Engenia®	1.07 (0.46)	1/523	2.29 (1.02)	1/245	8.24 (1.32)	1/67
	XtendiMax®	0.96 (0.31)	1/583	1.98 (0.47)	1/283	6.54 (0.81)	1/86
Vine length	Clarity®	0.93 (0.85)	1/603	2.02 (1.30)	1/277	7.59 (2.51)	1/73
	Engenia®	0.49 (0.21)	1/1142	1.21 (0.53)	1/463	5.64 (2.47)	1/99
	XtendiMax®	0.52 (0.29)	1/1076	0.82 (0.33)	1/682	1.83 (0.56)	1/306

1/X[a] was the diluted fraction of the label rate.

Table 1: Dose of Clarity®, Engenia® and XtendiMax® that resulted in 10%, 20% and 50% injury and vine length reduction of grape at 21 DAT.

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The impact of injury caused by dicamba or similar growth-regulator herbicide on grape fruit yield were rarely reported, hence, study should be conducted to evaluate impact of dicamba rates on grape yield.

Vine length reduction: Similarly, reduction in vine length caused by the dicamba products at 28 DAT increased with increase in dicamba micro-rates from 1/1000 to 1/10 of the label rate (560 g ae ha^{-1}) (Figure 3). A dose range of 0.49 to 0.93 g ae ha^{-1} and 1.83 to 7.59 g ae ha^{-1} caused 10% (~20 cm) and 50% (~49 cm) reduction in vine length, respectively, at 28 DAT, depending on the dicamba product. A dose of 0.49 g ae ha^{-1} of Engenia® compared to higher dose of Clarity® (0.93 g ae ha^{-1}) and XtendiMax® (0.52 g ae ha^{-1}) was required to cause 10% reduction in vine length. Similar to our result, Mohseni- Moghadam et al. [15] also reported that a Clarity® dose of 1.9 g ha^{-1} caused 25% reduction in grape shoot length averaged across five grape cultivars at 42 DAT. In our study, the differences in vine length reduction among the three products were significant at 50% threshold; in this case, lower dose (1.83 g ae ha^{-1}) of XtendiMax® compared to significantly higher dose (7.59 g ae ha^{-1}) of Clarity® was required to cause 50% reduction in vine length at 28 DAT (Table 1). The dicamba rates that caused 10% reduction in vine length were equivalent to 1/1142-1/603 of the label rate, while those rates that caused 50% reduction in vine length were equivalent to 1/306-1/73 of the label rate, depending on the dicamba product (Table 1). The results indicate that growth of grape vine as measured by accumulated vine length could be impaired by micro-rates of dicamba, irrespective of the dicamba formulation. Further studies are needed to determine the negative impact of dicamba micro-rates on fruit yield and quality.

Sensitivity of tomato to micro-rates of dicamba-based herbicides

All three dicamba products equally injured and reduced height of tomato plant, and the level of injury was significantly influenced by dicamba rates and the two application times.

Visual ratings: The severity of injury on the tomato plants increased with increase in dicamba micro-rates (Figure 4). The observed injury symptoms in the tomato plants were stunting, chlorosis, callus-like formation on main-stem, epinasty, cupping and curling of leaves, and necrosis (Figure 5). A dose range of 0.82 to 0.91 g ae ha^{-1} caused 10% injury, at 21 DAT, across all three dicamba products. These rates were equivalent to 1/683-1/615 of the label rate. Equal amount of dose (0.82 g ae ha^{-1}) of Engenia and XtendiMax caused the 10% injury, whereas 0.91 g ae ha^{-1} of Clarity® was needed to cause the 10% injury (Table 2). At the same time of observation, a dose range of 3.98 to 5.35 g ae ha^{-1} caused 50% injury. These rates were equivalent to 1/141-/105 of the label rate. Engenia® dose of 3.98 g ae ha^{-1} compared to statistically similar dose of Clarity® (5.35 g ae ha^{-1}) and XtendiMax® (4.49 g ae ha^{-1}) was required to cause 50% injury. Application of 1/10 of the label rate caused up to 80% injury across the three products (Figure 4), which was equivalent to 3 tablespoons of the product per acre.

Tomato height reduction: The growth of tomato, measured by plant height, was equally sensitive to micro-rates of all dicamba products. Reduction in tomato height caused by the dicamba products at 28 DAT increased with increase in herbicide micro-rates from 1/1000 to 1/10 of the label rate (Figure 6). A dose range of 0.32 to 1.10 g ae ha^{-1} and 5.01 to 9.76 g ae ha^{-1} caused 10% (~10 cm) and 50% (~24 cm) reduction in plant height respectively, at 28 DAT, across the three dicamba products (Table 2).

The injury and growth reduction caused by the micro-rates of these dicamba products could result to yield loss in tomato. A study by Kruger et al. [10] showed that 11.5 g ae ha^{-1} of dicamba caused 25% reduction in tomato yield when applied at early vegetative stage, and a

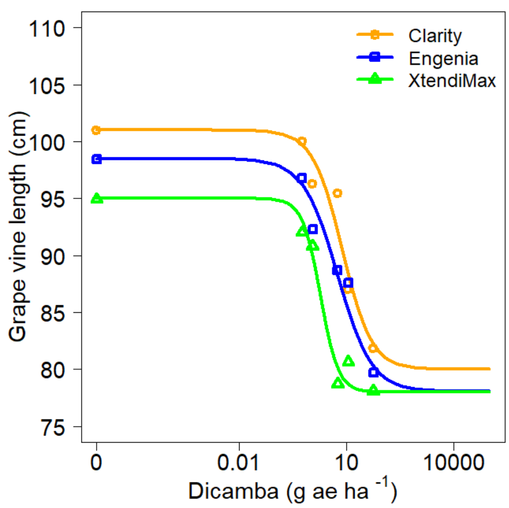

Figure 3: Grape vine length as reduced by increasing micro-rates of dicamba products.

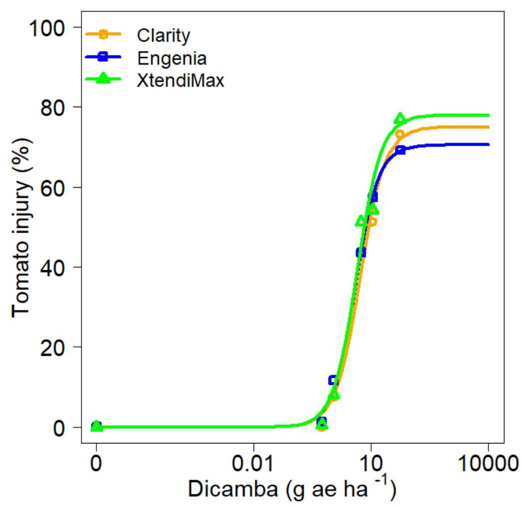

Figure 4: Tomato injury caused by increasing micro-rates of dicamba products.

Figure 5: Tomato injury with 1/10 of label rate (560 g ae ha^{-1}) at 21 DAT.

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Measurement	Dicamba	ED10 (SE)	1/X[a]	ED20 (SE) g ae ha^{-1}	1/X	ED50 (SE)	1/X
Injury	Clarity®	0.91 (0.32)	1/615	1.73 (0.44)	1/324	5.35 (0.94)	1/105
	Engenia®	0.82 (0.32)	1/683	1.45 (0.43)	1/386	3.98 (0.35)	1/141
	XtendiMax®	0.82 (0.29)	1/683	1.48 (0.39)	1/378	4.49 (0.52)	1/125
Plant height	Clarity®	0.42 (01.6)	1/1333	1.34 (0.54)	1/418	9.76 (3.01)	1/57
	Engenia®	1.10 (1.01)	1/509	1.92 (1.35)	1/292	5.01 (1.42)	1/112
	XtendiMax®	0.32 (0.19)	1/1750	0.93 (0.40)	1/602	5.77 (1.51)	1/97

1/X[a] was the diluted fraction of the label rate

Table 2: Dose of Clarity®, Engenia® and XtendiMax® that resulted in 10%, 20% and 50% injury and plant height reduction of Tomato at 28 DAT.

Crop	Measure	Stage	ED10 (SE)	ED20 (SE)$^{-1}$ g ae ha	ED50 (SE)
Grape	Injury	75 cm	1.93 (0.28)	2.03 (0.72)	9.02 (4.21)
		115 cm	7.91 (4.40)	21.41 (1.21)	60.18 (7.56)
	Biomass	75 cm	1.00 (0.21)	2.76 (1.01)	15.62 (5.73)
		115 cm	0.94 (0.41)	2.13 (0.92)	8.51 (3.64)
Tomato	Injury	25 cm	0.92 (0.15)	1.64 (0.17)	5.44 (2.62)
		45 cm	1.07 (0.06)	3.15 (1.22)	20.77 (9.51)
	Biomass	25 cm	1.39 (0.84)	8.82 (2.32)	14.44 (4.17)
		45 cm	0.33 (0.19)	1.04 (0.63)	7.53 (3.59)

Table 3: Dose of dicamba that resulted in 10%, 20% and 50% injury and biomass reduction of grape and tomato at 28 DAT for each time of application.

lower amount of dicamba was required to cause the same amount of yield reduction when applied at early bloom stage of tomato. Similarly, Lovelace et al. [19] predicted tomato yield losses of 2, 15 and 50% from 10, 20 and 50% visual injury on tomato, respectively, by a growth-regulator herbicide, quinclorac.

Influence of dicamba application time on grape and tomato injury

In general, grape and tomato were both sensitive to low rates of dicamba applied at early and later vegetative stages.

Dicamba application at later growth stage of grape (vine length of 115 cm) resulted in the need for higher dose of 7.91 and 60.18 g ae ha^{-1} to cause 10 and 50% injury respectively, compared to earlier application (vine length of 75 cm) (Figure 7 and Table 3). However, there was no statistical difference in dicamba dose required to cause 10 to 50% reduction in grape biomass between the two application times.

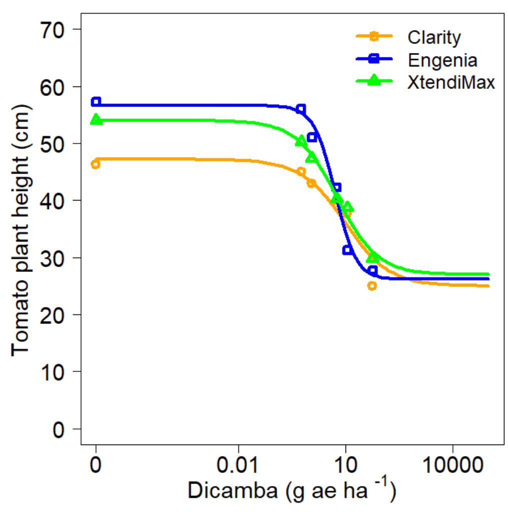

Figure 6: Tomato plant height as reduced by increasing micro-rates of dicamba products.

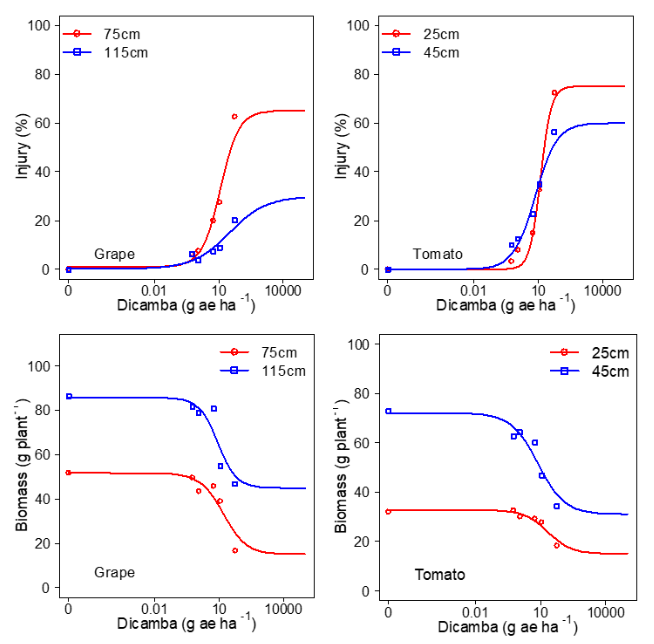

Figure 7: Crop injury and biomass reduction caused by increasing micro-rates of dicamba at different time of application.

A significantly higher dicamba dose of 1.07 and 20.77 g ae ha^{-1} was required to cause 10 and 50% injury, respectively in taller tomato plant (45 cm) compared to earlier application on shorter plants (25 cm). However, tomato biomass appeared more sensitive to dicamba applied on taller plant (45 cm) than when applied on a shorter plant (25 cm). For example, a dose of 0.33 to 7.53 g ae ha^{-1} was needed to reduce tomato biomass by 10 to 50% when plant height was 45 cm, whereas a dose of 1.39 to 14.44 g ae ha^{-1} was needed for the same biomass reduction when plant height was 25 cm. More injury observed in earlier application was similar to the findings of Kruger et al. [10], in which application of dicamba at early vegetative stage (plant height was 15 cm) had more observable injury than later application at early boom stage (plant height was 25 cm); meanwhile there were more yield losses in the later than the former. Compared to grape, tomato largely appeared to be more injured by the dicamba micro-rates.

Conclusion

All the dicamba formulations negatively impacted growth of grape and tomato. These results clearly showed that both crops were equally sensitive to micro-rates of older product (Clarity®) and the new products (Engenia® and XtendiMax®). The micro-rates tested in this study were potentially what could be found in off-target movement from dicamba applications in DT-soybean and DT-cotton; therefore, efforts must be made to avoid drift of dicamba onto neighboring fields.

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