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Response of Wine Grape Cultivars to Simulated Drift Rates of 2,4-D, Dicamba, and Glyphosate, and 2,4-D or Dicamba Plus Glyphosate

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Greenhouse experiments were conducted at Wooster, OH, during 2010 and 2011 growing seasons to evaluate the responses of five wine grape cultivars to sublethal doses of 2,4-D, dicamba, and glyphosate, and the 'Riesling' grape to mixtures of 2,4-D plus glyphosate and dicamba plus glyphosate. Treatments were made using a spray system calibrated to deliver 0.757 L min^{-1} at 276 kPa and 4.8 km h^{-1}. Herbicides were delivered through 8002 flat spray nozzles and applied at 1/30, 1/100, and 1/300 of the recommended field rate of 840, 560, and 840 g ae ha^{-1} for 2,4-D, dicamba, and glyphosate, respectively. Injury was observed in all treatments 7 d after treatment (DAT). However, injury symptoms greater than 10% were observed 42 DAT in plants treated with 2,4-D at all rates and plants treated with dicamba at the two highest rates. Injury (35%) at 357 DAT was noted only in plants treated with the highest rate of 2,4-D. French hybrids showed slightly less injury symptoms compared with wine grapes at 7 and 42 DAT. Shoot length reduction in plants treated with 2,4-D at the highest rate was 43, 84, and 16% at 7, 42, and 357 DAT, respectively. Glyphosate caused the fewest injury symptoms in Riesling compared with 2,4-D and dicamba when applied separately or tank mixed with glyphosate. Shoot length reduction in Riesling was observed 42 DAT with all rates of 2,4-D, with and without glyphosate and dicamba, and dicamba plus glyphosate at the highest rate; however, at 357 DAT, no effect was observed in shoot length. Spray drift of 2,4-D and dicamba can severely injure grapes, with injury increasing with increased exposure. The combination of 2,4-D plus glyphosate caused greater injury and shoot length reduction in grapes than glyphosate applied alone.
Nomenclature: 2,4-D; dicamba; glyphosate; wine grape, *Vitis vinifera* L. 'Riesling', 'Chardonnay', 'Chardonel', 'Traminette', 'Vidal blanc'.
Key words: Crop injury, herbicide drift.

Experimentos de invernadero fueron realizados en Wooster, Ohio, durante las temporadas de crecimiento 2010 y 2011, para evaluar la respuesta de cinco cultivares de uva para vino a dosis subletales de 2,4-D, dicamba, y glyphosate, y de la uva 'Riesling' a mezclas de 2,4-D más glyphosate y dicamba más glyphosate. Los tratamientos fueron realizados usando un sistema de aspersión calibrado para liberar 0.757 L min^{-1} a 276 kPa y 4.8 km h^{-1}. Los herbicidas fueron asperjados mediante una boquilla de abanico plana 8002 a 1/30, 1/100, y 1/300 de las dosis recomendadas de campo de 840, 560, y 840 g ae ha^{-1} para 2,4-D, dicamba, y glyphosate, respectivamente. Se observó daño en todos los tratamientos 7 d después del tratamiento (DAT). Sin embargo, los síntomas de daño superiores a 10% fueron observados 42 DAT en plantas tratadas con 2,4-D con todas las dosis y plantas tratadas con dicamba con las dos dosis más altas. El daño (35%) 357 DAT se notó solamente en plantas tratadas con la dosis más alta de 2,4-D. Los híbridos franceses mostraron síntomas de daño ligeramente menores al compararse con uvas para vino a 7 y 42 DAT. La reducción en la longitud de la parte aérea de plantas tratadas con 2,4-D a la dosis más alta fue 43, 84, y 16% a 7, 42, y 357 DAT. Glyphosate causó el menor número de síntomas de daño en Riesling al compararse con 2,4-D y dicamba cuando fueron aplicados separadamente o mezclados en tanque con glyphosate. La reducción en la longitud de la parte aérea en Riesling se observó 42 DAT con todas las dosis de 2,4-D, con y sin glyphosate y dicamba, y dicamba más glyphosate con la dosis más alta. Sin embargo, a 357 DAT, no se observó ningún efecto en la longitud de la parte aérea. Deriva de aspersión de 2,4-D y dicamba puede dañar severamente la vid, con daños aumentando al incrementarse la exposición. La combinación de 2,4-D más glyphosate causó mayor daño y mayor reducción en la longitud de la parte aérea de la vid que el glyphosate aplicado solo.

Spray drift is the movement of pesticide dust or droplets through the air beyond the intended area of application at the time of application or soon after (USEPA 2014). Studies have shown that off-target movement from an unshielded sprayer ranges from 1 to 16% of the target dose (Bode 1987; Maybank

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et al. 1978). Off-target movement of herbicides can cause extensive injury in susceptible crops. The severity of damage to the crop from a drift incident depends on factors such as the level of susceptibility and growth stage of the crop, environmental conditions, herbicide formulation, droplet size, and spray height above the target (Felix et al. 2011).

Simulated drift studies have documented the damaging effects of many herbicides on a variety of susceptible nontarget crops (Al-Khatib et al. 2003; Egan et al. 2014; Flessner et al. 2012; Kruger et al. 2012). Drift of 2,4-D or dicamba may damage leaves, growing points, flowers, or fruit by inducing abnormal growth (Teixeira et al. 2007). The Association of American Pesticide Control Officers (2005) reported that 2,4-D and dicamba ranked first and third, respectively, on the list of herbicide active ingredients in State Lead Agencies' confirmed drift occurrences. Both herbicides are commonly used POST to control emerged broadleaf weeds selectively in grass crops (corn [*Zea mays* L.], sorghum [*Sorghum bicolor* (L.) Moench]), fallow, pasture, and rangeland. Additionally, 2,4-D is used in tree fruit (Marple et al. 2007). They are also used preplant to kill weeds in fields to be planted to corn, cotton, and soybean (Everitt and Keeling 2007).

Grape is a broadleaf perennial crop grown worldwide for its fruit, which are consumed fresh, dried, or processed into juice, wine, and other products. Grape is an important crop in Ohio and other north-central and eastern states of the United States. In 2012, grapes were grown on 768 ha in Ohio, with a $786 million impact on the state economy (Anonymous 2014).

Vineyards are affected by spray drift every year (Bondada et al. 2006). Injury can cause a reduction in yield, poor fruit quality, and, in the most severe cases, grapevine death. Sometimes symptoms persist 2 to 3 yr after the drift incident, reducing vigor, increasing susceptibility to diseases, and shortening the life of the vineyard (Ball et al. 2014).

Several studies have documented the effects of 2,4-D and dicamba on grape (Bondada 2011; Castro et al. 2005; Dami et al. 2002; Volenberg 2009). Ogg et al. (1991) reported that grapes treated four times (between April and June) with 0.010 kg ai ha^{-1} of 2,4-D showed severe injury symptoms (more than 33%) and had an 85% yield reduction. Bhatti et al. (1996) reported injury symptoms and decreased grape shoot growth, leaf area, internode length, and dry cane weight with 2,4-D applications as low as 1/100 times the recommended field rate.

Use of 2,4-D and dicamba is likely to increase for POST treatment of hard-to-control, or glyphosate-resistant broadleaf weeds such as Palmer amaranth (*Amaranthus palmeri* S. Wats.) and horseweed [*Conyza canadensis* (L.) Cronq.], because resistance genes to these herbicides have already been introduced in corn and soybean and are likely to be commercialized soon. Specialty crop farmers and especially grape growers across the United States are concerned that increased use of 2,4-D and dicamba to control weeds in agronomic crops will result in more incidence of crop loss due to drift (Kruger et al. 2011). In Ohio, many vineyards are within close proximity of agronomic crop fields. Both herbicides will be applied to the respective genetically modified crops in combination with glyphosate; therefore, the potential for interactive effects on grape is of particular interest. Therefore the objectives of this study were (1) to evaluate the response of several economically important wine grape cultivars to simulated drift treatments of 2,4-D, dicamba, and glyphosate, and (2) to compare grape response to combinations of glyphosate with 2,4-D or dicamba with these herbicides applied alone.

Materials and Methods

Greenhouse experiments were conducted at the Ohio Agricultural Research and Development Center (OARDC), Wooster, OH, during the 2010 and 2011 growing seasons. Five wine grape cultivars were selected from those most commonly planted in Ohio (Dami et al. 2005), including two *vinifera* ('Chardonnay' and 'Riesling') and three interspecific French hybrids (*Vitis* spp., 'Chardonel', 'Traminette', and 'Vidal blanc'). These cultivars enabled a comparison between the response of French hybrids and *vinifera* because previous work conducted at OARDC indicated that *vinifera* were more sensitive to 2,4-D and dicamba (L Jiang, personal communication). Dormant vines were obtained from Double A Vineyards (10277 Christy Road, Fredonia, NY) and were planted in May 2, 2011, in 7.57-L pots using a general-purpose peat-based growing medium (ProMix® BX, 200 Kelly Rd., Unit E-1, Quakertown, PA). The split plot arrangement of treatments, with rate as the main

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plot and herbicide as the subplot, was a randomized complete block with five replications. Each replication was placed on one bench. Replication was by bench because a temperature gradient spanned the length of the greenhouse (benches were perpendicular to the gradient).

Herbicide treatments included 1/30, 1/100, and 1/300 of the recommended field rate of 840, 560, and 840 g ha^{-1} for 2,4-D dimethylamine salt (Weedar® 64, Nufarm Inc. 150 Harvester Drive, Burr Ridge, IL 60527), dicamba diglycolamine salt (Clarity®, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709), and glyphosate dimethylamine salt (Durango® DMA®, Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268), respectively. Additionally, mixes of 2,4-D plus glyphosate and of dicamba plus glyphosate were also applied to Riesling. Riesling was selected because it is one of the most important white cultivars planted in Ohio (Anonymous 2014).

Treatments were applied using a track-suspended laboratory spray system calibrated to deliver 0.757 L min^{-1} at 276 kPa with a speed of 4.8 km h^{-1} through 8002 flat spray nozzles (TeeJet Technologies, Wheaton, IL 60187). A nontreated control was also included. Herbicides were applied on May 23, 2010 (room temperature and relative humidity were 26 C and 40%, respectively), when the vines had new leaf growth on approximately four to six nodes. Shoot lengths of vines at the time of treatment were on average 36, 43, 41, 38, and 39 cm for Chardonel, Chardonnay, Riesling, Traminette, and Vidal blanc, respectively. Potted vines were placed on the floor under the spray track and treated in a single pass. Ten minutes after spraying, when spray droplets were no longer visible on the foliage, each vine was moved to the greenhouse. All plants received slow-release fertilizer (Osmocote 14–14–14, The Scotts Company, 14199 Industrial Parkway, Marysville, OH 43040) and were watered daily as needed. Conditions in the greenhouse were maintained at approximately 27 C during the day and 18 C at night. Throughout the experiment, vines were maintained as a single shoot. Flower clusters were removed as they appeared.

Vine injury and shoot length were recorded 3, 7, 14, 21, 28, and 42 DAT (7 and 42 DAT data are reported). Vine injury, based on chlorosis, epinasty, leaf deformation, and overall growth stunting, was assessed visually on a scale of 0% (no visible crop injury) to 100% (death of the crop). Shoot length was measured from the base of the shoot (i.e., from the soil line) to the tip of the terminal leaf. At the end of September 2011, vines were removed from the greenhouse and placed in storage at 2.2 C. Vines were watered once every 2 wk while in storage. In March 15, 2012, they were returned to the greenhouse. Identical measurements and ratings as those described above were performed 70 d later (357 DAT) to assess any residual damage from herbicides applied the previous year.

Statistical analyses were conducted using PROC GLM in SAS 9.2 (SAS Institute Inc., SAS Campus Drive, Cary, NC 27513). Data were subjected to ANOVA, and means for each variable measured were separated with the use of Fisher's protected LSD test at the 5% level of probability. Because there were no interactions between herbicides and/or herbicide rates for each variable measured, results are presented as herbicide and herbicide rates in their respective tables.

Results and Discussion

Effect of 2,4-D, Dicamba, and Glyphosate on Five Cultivars of Wine Grape. Herbicide treatments injured each variety. Averaging across grape cultivars, the response to the simulated drift rate of herbicides was different (Table 1). Symptoms were visible 3 DAT (data not reported) and were sufficiently developed to rate at 7 DAT. Simulated drift rates of glyphosate caused leaf chlorosis, mainly on mature leaves that had been exposed directly to the herbicide (Figure 1a). Symptoms caused by simulated drift rates of glyphosate 7 DAT ranged from 2 to 4% for 2.8 and 28 g ha^{-1} rates, respectively (Table 1). Injury peaked in glyphosate-treated vines 14 DAT (7 to 8% injury, data not reported). Partial recovery was noted in glyphosate-treated vines 42 DAT, when injury ranged between 3 and 6% (Table 1). The effect of simulated drift rates of glyphosate on grape was minimal and similar to data reported by Dami et al.(2002), confirming the relative tolerance of the crop to sublethal doses of this herbicide.

Injury symptoms from simulated drift rates of 2,4-D included parallel venation, fan-shaped leaves, shortened internodes, epinasty, and reduction of new growth (Figure 1b). Effects were mostly observed in the youngest growth with the highest

Table 1. The effect of simulated drift rates of 2,4-D, dicamba, or glyphosate on injury determined visually and shoot length of Riesling, Chardonnay, Chardonel, Vidal blanc, and Traminette grapevines in greenhouse trial,[a] averaged over grape cultivars.

Herbicide	Rate	Injury[b] 7 DAT[c]	Injury[b] 42 DAT	Injury[b] 357 DAT	Shoot length[b] 7 DAT	Shoot length[b] 42 DAT	Shoot length[b] 357 DAT
	$g\ ha^{-1}$	%			cm		
2,4-D	2.8	6 d	37 c	4 b	59 a	124 ab	74 a
2,4-D	8.4	13 c	29 d	0 b	50 ab	88 d	69 a
2,4-D	28	31 a	66 a	35 a	33 c	22 e	50 b
Dicamba	1.9	2 e	10 e	0 b	51 ab	118 bc	77 a
Dicamba	5.6	6 d	36 c	0 b	51 ab	110 c	70 a
Dicamba	19	15 b	47 b	0 b	46 b	87 d	75 a
Glyphosate	2.8	2 e	6 ef	0 b	56 a	138 a	76 a
Glyphosate	8.4	4 e	3 f	0 b	53 ab	117 bc	73 a
Glyphosate	28	4 e	3 ef	0 b	56 a	120 bc	69 a
Untreated control	—	0 f	0 f	0 b	58 a	136 a	71 a
LSD (0.05%)		2	7	9	9	14	10

[a] By 42 DAT, two Chardonel, one Chardonnay, two Riesling, and three Vidal blanc vines, all treated with 2,4-D at 28 g ha^{-1}, were recorded as 100% injury.

[b] Means with the same letter are not significantly different according to Fisher's protected LSD test ($\alpha = 0.05$).

[c] Abbreviation: DAT, days after treatment.

rates (28 g ha^{-1} of 2,4-D); however, lower leaves were also affected with the passage of time. These symptoms ranged from 6% for the 2.8 g ha^{-1} rate to 31% for the 28 g ha^{-1} rate at 7 DAT. Symptoms of injury increased progressively over the course of the experiment and by 42 DAT were 37, 29 and 66% for 2,4-D at 2.8, 8.4, and 28 g ha^{-1}, respectively (Table 1). Injury data reported here corresponded with those described by Dami et al. (2002).

Injury of vines treated with simulated drift rates of dicamba included upward cupping of the younger leaves and a distinct marginal band of restricted growth (Figure 1c) and ranged from 2 to 15% at 7 DAT. Similar to the effect of simulated drift rates of 2,4-D, the injury caused by simulated drift rates of dicamba increased gradually throughout the experiment and at 42 DAT was 10, 36 and 47% for dicamba at 1.9, 5.6, and 19 g ha^{-1}, respectively (Table 1).

The only residual effect observed the year after (357 DAT) sublethal dose treatments was injury (35%) in vines treated with the 28 g ha^{-1} rate of 2,4-D compared with that of the control (Table 1). Other vines, even those displaying significant injury the year of treatment, showed little or no damage 1 yr after treatment (average 4% injury for vines treated with 2,4-D at 2.8 g ha^{-1}). This result indicates that damaged vines are likely to recover from herbicide injury that does not completely kill the vine (Table 1).

The severity of injury symptoms observed because of 2,4-D, dicamba, and glyphosate differed among grape cultivars. This effect was apparent at 3 DAT in all cultivars (data not reported), progressed throughout the time course of the experiment, and was most pronounced 42 DAT (Table 2). Averaged across herbicide treatments, Traminette was least sensitive (19% injury 42 DAT), whereas *vinifera* cultivars Chardonnay and Riesling (28 and 27% injury 42 DAT, respectively) exhibited the greatest intensity of symptoms (Table 2).

Across cultivars, simulated drift rates of 2,4-D caused more injury than those of dicamba or glyphosate, with a maximum mean response of 66% injury 42 DAT (Table 1). By 42 DAT, two Chardonel, one Chardonnay, two Riesling, and three Vidal Blanc vines, all treated with 2,4-D at 28 g ha^{-1}, were recorded as 100% injury. Simulated drift rates of dicamba caused less severe injury than those of 2,4-D, but greater than those caused by glyphosate. Averaged across all treatments, v*inifera* cultivars were more sensitive to simulated drift rates of 2,4-D and dicamba than were French hybrids. These results concur with those of Dami et al. (2002) who also reported that *vinifera* cultivars were more sensitive to sublethal doses of 2,4-D and dicamba than French hybrids.

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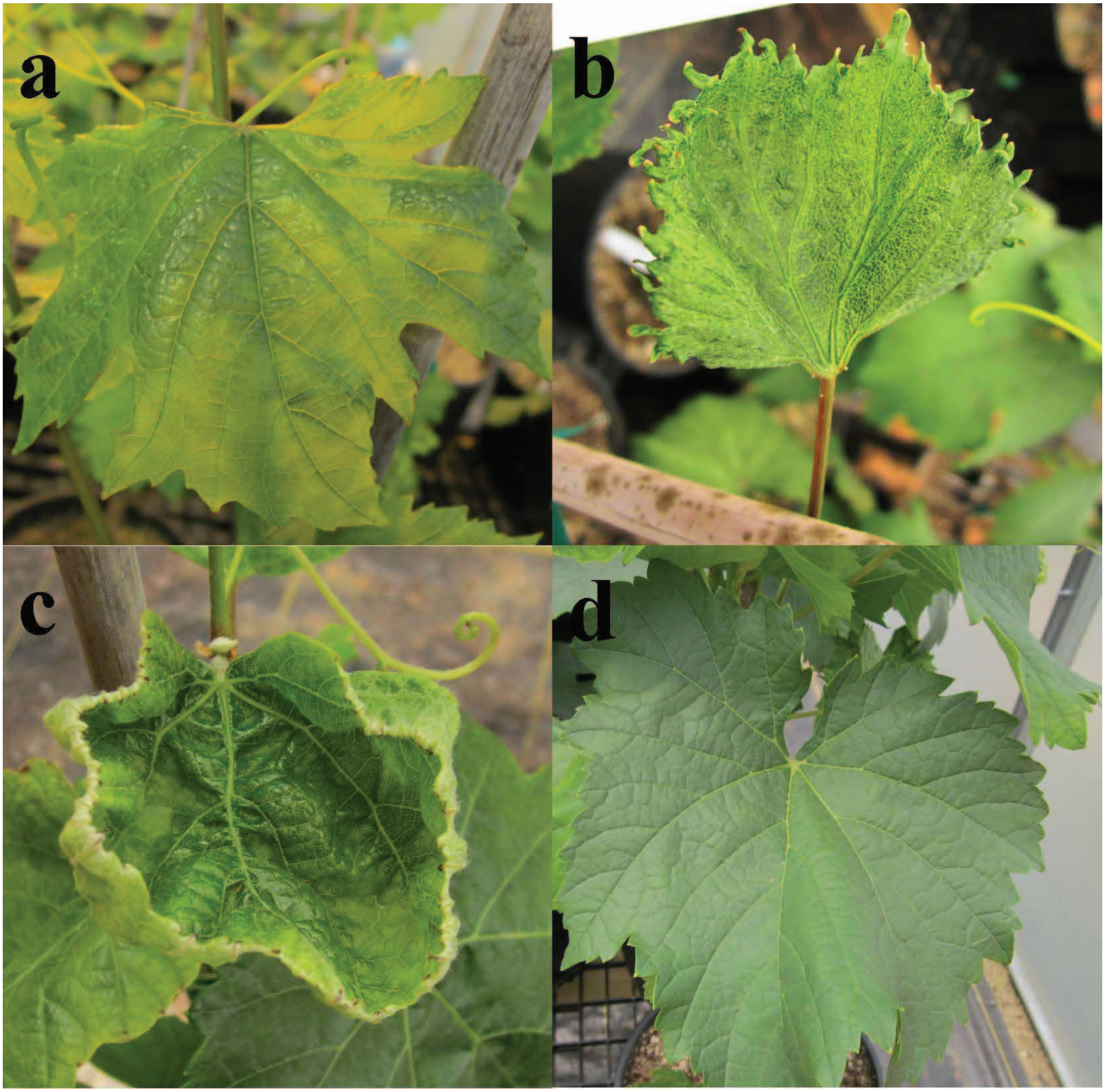

Figure 1. Common leaf injury symptoms observed in vines 42 d after being treated with (a) glyphosate at 8.4 g ha^{-1}, (b) 2,4-D at 8.4 g ha^{-1}, (c) dicamba at 5.6 g ha^{-1}, and (d) nontreated control. (Color for this figure is available in the online version of this article.)

Growth, as measured by shoot length, was affected by herbicides. Treatments that caused the greatest injury symptoms also resulted in the shortest shoots (42 DAT). Vines treated with 2,4-D at 28 kg ha^{-1} were 30% shorter than nontreated vines (357 DAT), whereas no other treatment affected shoot length at that interval. In contrast, glyphosate had little effect on visual injury or growth, except a reduction of shoot length was noted 42 DAT.

Vine shoot length 7 DAT was 43 and 21% shorter for vines treated with 2,4-D at 28 g ha^{-1} and dicamba at 19 g ha^{-1}, respectively, compared with that of the control vines. Similarly, at 42 DAT,

Table 2. The effect of simulated drift rates[a] of 2,4-D, dicamba, and glyphosate on injury determined visually and shoot length of Riesling, Chardonnay, Chardonel, Vidal blanc, and Traminette grapevines. Means reported for "Type of grape" are averaged across all treatments within the three hybrid and two *vinifera* varieties.

Variety[b]	Injury[c] 7 DAT[d]	Injury[c] 42 DAT	Injury[c] 357 DAT	Shoot length[c] 7 DAT	Shoot length[c] 42 DAT	Shoot length[c] 357 DAT
	%			% of control		
Chardonel	8 b	24 ab	6	69	79	117
Chardonnay	10 a	28 a	2	89	77	96
Riesling	9 a	27 a	3	80	66	106
Traminette	7 b	19 c	2	98	80	104
Vidal blanc	9 ab	22 bc	6	79	79	96
LSD (5%)	2	5	NS	—	—	—
Type of grape						
French hybrids	8 b	22 b	5	84	79	105
Vinifera	9 a	27 a	3	84	71	101
LSD (5%)	1	3	NS	—	—	—

[a] Herbicide treatments included 1/30, 1/100, and 1/300 of the recommended field rate of 840, 560, and 840 kg ha^{-1} for 2,4-D, dicamba, and glyphosate, respectively.

[b] The average shoot length for untreated control vines at 7 DAT were 63, 65, 65, 52, and 61 cm, at 42 DAT were 113, 150, 154, 125, and 136 cm, and at 357 DAT were 117, 96, 106, 104, and 96 cm for Chardonel, Chardonnay, Riesling, Traminette, and Vidal blanc, respectively.

[c] Means with the same letter are not significantly different according to Fisher's protected LSD test ($\alpha = 0.05$).

[d] Abbreviations: DAT, days after treatment; NS, not significant ($P = 0.05$).

shoot length was 84 and 36% shorter when treated with 2,4-D at 28 g ha^{-1} and dicamba at 19 g ha^{-1}, respectively, compared with that of the untreated control. At 42 DAT, shoot length of vines treated with 2,4-D at 8.4 g ha^{-1}, dicamba at 1.9 and 5.6 g ha^{-1}, and glyphosate at 8.4 and 28 g ha^{-1} was 35, 13, 19, 14, and 12% shorter, respectively, than the shoot length of the control vines (Table 1).

Although the crop injury response of varieties 7 DAT did not differ by more than 3%, shoot length as an indication of growth ranged between 69% (Chardonel) to 98% (Traminette) of the control when the shoot length was averaged across all herbicide rates (Table 2). At 42 DAT, shoot length for all varieties was not more than 80% of the control for each variety. However at 357 DAT, shoot length was at least 96% of the control averaged across all herbicide treatments for each variety (Table 2). These data also indicated that *vinifera* vines were more sensitive to injury from herbicide drift rates at 7 and 42 DAT compared with French hybrids; however, shoot length of the two types did not differ at any rating interval (Table 2). These observations correspond with work by OARDC viticultural staff (David Scurlock, personal communication), who have observed that sensitivity to 2,4-D and glyphosate is *vinifera* > French hybrids > American grape cultivars.

Effect of 2,4-D, Dicamba, Glyphosate, and Combinations of Glyphosate with 2,4-D or Dicamba on Riesling Grape. Different simulated drift rates of 2,4-D, dicamba, and glyphosate caused injury on Riesling 7 DAT, ranging between 1% with glyphosate at 2.8 g ha^{-1} to 36% with 2,4-D at 28 g ha^{-1}. At 7 DAT, Riesling vines treated with different rates of 2,4-D plus glyphosate (2.8 + 2.8, 8.4 + 8.4, and 28 + 28 g ha^{-1}) or dicamba plus glyphosate (1.9 + 2.8, 5.6 + 8.4, 19 + 28 g ha^{-1}) were injured 4 to 16% and 6 to 25%, respectively (Table 3). Injury symptoms increased over the course of the experiment and, by 42 DAT, ranged between 3% for vines treated with glyphosate (all rates) and 69% for vines treated with 28 g ha^{-1} of 2,4-D (Table 3). Residual damage in Riesling observed 357 DAT after the sublethal dose treatments was caused by 2,4-D at 28 g ha^{-1} (34% injury) and by 2,4-D plus glyphosate mix at 28 plus 28 g ha^{-1} (20% injury). No injury was observed with other treatments at this interval (Table 3). Shoot length was severely affected by herbicides 42 DAT. For example 2,4-D at 28 g ha^{-1} caused a 91% reduction in shoot length. Similarly,

Table 3. The effect of simulated drift rates of 2,4-D, dicamba, and glyphosate, and 2,4-D or dicamba plus glyphosate on injury determined visually and shoot length of Riesling grape.

		DAT[a]					
		Injury[b]			Shoot length[b]		
Herbicide	Rate	7	42	357	7	42	357
	g ha^{-1}	%			cm		
2,4-D	2.8	7 e	45 bc	0 b	59	100 cd	86
2,4-D	8.4	12 d	39 cd	0 b	58	76 de	69
2,4-D	28	36 a	69 a	34 a	33	14 f	56
Dicamba	1.9	2 fgh	8 ef	0 b	43	115 bc	89
Dicamba	5.6	6 ef	49 bc	0 b	61	132 abc	84
Dicamba	19	18 c	53 abc	0 b	47	69 de	76
Glyphosate	2.8	1 gh	3 f	0 b	60	155 a	86
Glyphosate	8.4	5 efg	3 f	0 b	47	126 abc	82
Glyphosate	28	5 efg	3 f	0 b	63	129 abc	76
2,4-D + glyphosate	2.8 + 2.8	6 ef	41 bcd	0 b	50	119 bc	88
2,4-D + glyphosate	8.4 + 8.4	6 ef	46 bc	0 b	54	100 cd	76
2,4-D + glyphosate	28 + 28	25 b	57 ab	20 a	51	51 e	66
Dicamba + glyphosate	1.9 + 2.8	4 efgh	25 de	0 b	61	143 ab	97
Dicamba + glyphosate	5.6 + 8.4	4 efgh	47 bc	0 b	53	128 abc	89
Dicamba + glyphosate	19 + 28	16 cd	51 bc	0 b	49	53 e	83
Untreated control	—	0 h	0 f	0 b	60	154 a	75
LSD (5%)		5	18	20	NS	34	NS

[a] Abbreviations: DAT, days after treatment; NS, not significant ($P = 0.05$).

[b] Means with the same letter are not significantly different according to Fisher's protected LSD test ($\alpha = 0.05$).

shoot length was reduced by 67 and 66% when vines were treated with 2,4-D plus glyphosate and dicamba plus glyphosate, respectively, at the highest rate. However, no effect of any herbicide on shoot length was detected 357 DAT (Table 3).

These results define the response of five wine grape cultivars that are important to the wine industry in the southern Great Lakes Region and beyond. The elevated sensitivity of *vinifera* cultivars relative to French hybrids reported by other investigators has been confirmed. Both *vinifera* grapes and French hybrids are highly sensitive to simulated drift rates of 2,4-D and slightly less so to dicamba in the year of application but are likely to recover from a single drift event. Thus the predicted increase in use of both herbicides to control glyphosate-resistant weeds in new genetically modified soybean and corn crops is worrisome for the future of the grape and wine industry in the north-central United States. Only slight vine injury resulted from simulated drift of glyphosate.

These data show that the potential for injury to Riesling from herbicide drift is usually greatest with 2,4-D plus glyphosate, dicamba plus glyphosate, 2,4-D alone, or dicamba alone than from glyphosate applied alone. This corresponds well to the observations of experiments done by Bhatti et al. (1996); however, it contrasts with findings from other crops (Mohseni-Moghadam and Doohan 2015), in which injury from 2,4-D alone caused more injury than 2,4-D herbicide mixes. This finding indicates that the risk to grape production in the north-central region of the United States will be elevated beyond what would occur simply as a result of expansion of 2,4-D and dicamba use. Future field studies should be conducted to characterize the effect of injury to vines and leaves on crop yield and quality. Furthermore, research should also address other cultivars, especially cold-tolerant French Hybrids that are popular outside of the southern Great Lakes region, as well as the effect of new herbicide formulations, additives, and application techniques.

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