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Response of Processing Tomato to Simulated Bromoxynil Drift Followed by In-Crop Metribuzin Application

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Simulated drift rates of bromoxynil followed by an in-crop application of metribuzin were applied to processing tomato in eight field studies conducted from 2008 to 2010 in Ridgetown, Ontario, Canada, to determine if a synergistic interaction occurred due to the cumulative herbicide application. A transient synergistic response was observed 7 d after treatment (DAT) when bromoxynil drift rates of 8.5, 17, and 34 g ai ha^{-1} were followed 3 to 5 d later by metribuzin at 250 g ai ha^{-1}. By 28 DAT, visible injury ratings were additive for 8.5, 17, and 34 g ha^{-1} bromoxynil followed by metribuzin treatments. However, when bromoxynil at 68 g ha^{-1} (20% of field rate) was followed by metribuzin, a synergistic interaction was evident and remained through harvest. Based on Colby's equation there was greater visible injury than expected at 7, 14, and 28 DAT when bromoxynil at 68 g ha^{-1} was followed by metribuzin. A corresponding synergistic reduction of plant dry weight and marketable tomato yield, compared with the nontreated control, was identified. Marketable yields were expected to be 65% of the control according to Colby's equation, but observed yield reductions were 49% when bromoxynil at 68 g ha^{-1} was followed by metribuzin. In general, tomato plants sprayed with metribuzin after bromoxynil drift had greater injury than treatments sprayed with bromoxynil alone.

Nomenclature: Bromoxynil; metribuzin; tomato, *Solanum lycopersicon* L.
Key words: Additive, synergistic, cumulative stress, herbicide drift, herbicide interaction.

Se aplicaron dosis de deriva simulada de bromoxynil seguidas de una aplicación de metribuzin dentro del cultivo de tomate para procesamiento en ocho estudios de campo realizados desde 2008 a 2010 en Ridgetown, Ontario, Canadá, para determinar si ocurrió una interacción sinérgica como consecuencia de la aplicación acumulada de herbicidas. A 7 d después del tratamiento (DAT) se observó una respuesta sinérgica transitoria cuando las dosis de bromoxynil 8.5, 17, y 34 g ai ha^{-1} fueron seguidas 3 a 5 d después por metribuzin a 250 g ai ha^{-1}. A 28 DAT, las evaluaciones de daño visual fueron aditivas para 8.5, 17, y 34 g ha^{-1} de bromoxynil seguidas de tratamientos de metribuzin. Sin embargo, cuando bromoxynil a 68 g ha^{-1} (20% de la dosis de campo) fue seguido de metribuzin, la interacción sinérgica fue evidente y esta se mantuvo hasta la cosecha. Con base en la ecuación Colby, hubo un daño visible mayor que el esperado a 7, 14, y 28 DAT cuando bromoxynil a 68 g ha^{-1} fue seguido de metribuzin. Se identificó una reducción sinérgica correspondiente de peso seco de planta y de rendimiento de tomate comercializable, al compararse con el testigo sin tratamiento. Según la ecuación Colby se esperaba que los rendimientos comercializables fueran 65% en comparación con el testigo, pero las reducciones de rendimiento observadas fueron 49% cuando bromoxynil a 68 g ha^{-1} fue seguido de metribuzin. En general, las plantas de tomate tratadas con metribuzin después de la deriva de bromoxynil tuvieron un daño mayor que los tratamientos aplicados con solamente bromoxynil.

Herbicide drift can be devastating, especially to vegetable producers. Aside from visible injury and potential yield decreases, buyers may reject a crop due to the application of an unregistered pesticide. Since 2008, 212 spray drift or overspray complaints have been registered with the Ontario Ministry of the Environment, 97 of which have occurred in southwestern Ontario (R. Sacilotto, personal communication). Within southwestern Ontario, vegetable and field crop producers are often closely situated and in some situations will incorporate both field and vegetable crops, such as tomato, in their rotation. The close proximity of processing tomato to field crops increases the probability that a spray drift event will occur. Processing tomatoes are a high-value crop. In 2011, gross returns ranged between $8,400 and $9,400 ha^{-1}, depending on individual contracts (OPVG 2012). Simulated drift rates of 2.5% or less of a glyphosate field dose have been shown to decrease red tomato yield by up to 25% (Kruger et al. 2012; McNaughton et al. 2012). Unfortunately, glyphosate is not the only herbicide applied to field crops that will harm processing tomatoes if a drift event occurs.

Bromoxynil is a broadleaf herbicide that inhibits photosynthesis at photosystem II by binding to the Q_B-binding niche on the D1 protein (Abendroth et al. 2006; Devine et al. 1993). In Ontario, bromoxynil is used primarily in field, seed, or sweet corn (*Zea mays* L.) and cereals, accounting for almost 3% of the herbicide use in the province (McGee et al. 2010). In corn, particularly for seed and sweet corn, bromoxynil is applied POST, and its application can coincide with the first POST in-crop metribuzin application in processing tomato. Low doses of bromoxynil on potato (*Solanum tuberosum* L.) have been reported to cause anywhere from no visible injury or yield reduction (10% field dose) (Pfleeger et al. 2008) to extensive leaf necrosis, where injury was rate dependent and resulted in a 25% yield reduction (66% field dose) (Haderlie and Petersen 1986; Leino and Haderlie 1985).

Because bromoxynil applications to corn can correspond with the first metribuzin application in processing tomato, it

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Table 1. Soil specifications of tomato trial site-years for cumulative herbicide stress in tomato, Ridgetown, Ontario, Canada, 2008 to 2010.

Year	Location	Planting date	Sand	Silt	Clay	Organic matter	pH	CEC
			%					
2008	1	May 22	49.3	29.5	21.2	5.8	5.8	14
	2	May 23	51.0	28.5	20.5	5.1	7.1	12
2009	3	May 21	49.5	26.1	24.4	3.8	6.9	17
	4	May 21	49.5	26.1	24.4	3.8	6.9	17
	7	May 21	49.5	26.1	24.4	3.8	6.9	17
2010	5	May 27	49.5	28.1	22.3	5.7	6.0	21
	6	May 27	49.5	28.1	22.3	5.7	6.0	21
	8	May 27	49.5	28.1	22.3	5.7	6.0	21

is reasonable to assume that the combination of a bromoxynil spray drift event followed by an in-crop metribuzin application could lead to cumulative herbicide damage. Metribuzin is also a photosynthetic inhibitor affecting photosystem II (Devine et al. 1993), which although registered for use in tomato can cause injury under certain environmental conditions. Injury to susceptible plants generally consists of marginal chlorosis to necrosis beginning on older plant tissue. The unintentional drift of bromoxynil followed by an in-crop application of metribuzin could cause a synergistic response in processing tomato. Bromoxynil tank-mixes have previously been found to cause synergistic interactions; for instance, the combination of bromoxynil and mesotrione may enhance the control of certain weed species (Abendroth et al. 2006; Hugie et al. 2008). Synergism occurs when the herbicidal effect of two or more compounds is greater than the expected effect of each compounds applied individually (Gressel 1990). Additive responses are those where the effect of the herbicide mixture is equal to the sum of the mixture's components individually (Green 1989), whereas antagonistic responses occur when the mixture results in less injury or control than expected (Lich et al. 1997). Earlier research has indicated that various herbicide drift events followed by an in-crop herbicide application can result in transient synergistic effects but that the cumulative effect of the herbicides at yield is additive (Brown et al. 2009; McNaughton et al. 2012).

The purpose of this research was to determine if simulated bromoxynil drift followed by a POST metribuzin application caused synergistic, antagonistic, or additive herbicide injury in processing tomato. Additionally, the degree of injury caused by bromoxynil drift either alone or followed by metribuzin was examined.

Materials and Methods

Study Sites. Eight field trials were conducted from 2008 to 2010 at the University of Guelph, Ridgetown Campus, in Ridgetown, Ontario (42°26′N, 81°53′W). A RJV600 plug planter (RJ Equipment, 75 Industrial Ave., P.O. Box 1180, Blenheim, ON, Canada, N0P 1A0) was used to transplant 'H9909′ tomato plugs (H. J. Heinz Company of Canada Ltd., Erie St. S., Leamington, ON, Canada, N8H 3W8) to a depth of 5 cm in twin rows. Twin row centers were 1.5 m apart, and plugs were transplanted at 45-cm spacing within each row. Plot size was 1.5 m by 8 m, and there were approximately 29,167 plants ha^{-1}. Based on soil tests, the recommended fertilizer rate, as outlined by the Ontario Ministry of Agriculture and Rural Affairs (OMAFRA 2009), was applied. All trials were treated with a preplant tank-mix application of *S*-metolachlor plus metribuzin (1200 + 700 g ai $ha^{-1)}$. Trial planting dates mirrored those of local producers. Planting dates and soil specifications are listed in Table 1. The soil was a Watford/Brady series sandy clay loam for all years of the trial. Using a combination of hand-weeding and cultivation, plots were maintained weed-free for the duration of the trial.

Experimental Design. Trials had four replicates and were designed as a randomized complete block. Four simulated bromoxynil (Pardner® 280 EC, Bayer CropScience Inc., 5–160 Research Lane, Guelph, ON, Canada, N1G 5B2) drift rates of 8.5, 17, 34, and 68 g ha^{-1}, corresponding respectively to 2.5, 5, 10, and 20% of the recommended bromoxynil field rate in Ontario, were applied. Simulated drift rates were chosen based on work conducted by Wolf et al. (1993) who found that drift could range from 2 to 16% of a field dose. All drift rates were applied 28 d after transplanting, which typically corresponded to tomato flower initiation. All in-crop applications of metribuzin (Sencor® 75 DF, Bayer CropScience) were applied 3 to 5 d after the simulated bromoxynil drift application at 250 g ha^{-1}. Treatments included a nontreated control, metribuzin at 250 g ha^{-1}, the four rates of simulated bromoxynil drift alone, and the four drift rates followed by (fb) metribuzin at 250 g ha^{-1}. A back-pack CO_2-pressurized sprayer (R&D CO_2 pressurized sprayer, 419 Hwy. 104, Opelousas, LA 70570) with Hypro Ultra-Lo Drift 120-02 nozzles (Hypro® ULD 120-02 nozzle, 375 5th Ave. N.W., New Brighton, MN 55112) was used to apply herbicides at 207 kPa and an output of 200 L ha^{-1}.

Data Collection. Visible symptoms of tomato injury were rated 7, 14, and 28 d after metribuzin application (DAT-B) on a 0 to 100% scale where 0% represented no injury and 100% represented complete plant death. Plant dry weights of four tomato plants from each plot were recorded at 14 DAT-B. Flower and fruit counts from one earlier-flagged tomato plant per plot were taken 14 and 28 DAT-B in 2009 and 2010. The plant was selected randomly, from near the center of the plot, prior to herbicide application. Tomato fruit were hand-harvested from a 1.5- by 2.0-m area and were sorted into marketable and green fruit. Marketable fruit had at least some red color while green fruit had no red color.

Statistical Analysis. The PROC MIXED procedure in SAS (SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513) was used to compare individual treatment means for each dependent variable. Differences among treatments were compared using a Fisher's protected LSD test ($P \leq 0.05$). An arcsine square root transformation was required to normalize all injury data. A logarithmic transformation was required to normalize flower count at 28 DAT-B, fruit count at 14 DAT-B, and green tomato yield data, whereas a square root transformation was used to normalize the flower count at 14 DAT-B, fruit count at 28 DAT-B, and marketable and marketable + green yield data. Lack of a significant year or

Table 2. Tomato injury with simulated bromoxynil spray drift alone and followed by an in-crop metribuzin application at Ridgetown, Ontario, Canada, 2008 to 2010.

Treatment	Rate	Injury[a,b]					
		7 DAT-B[c]		14 DAT-B		28 DAT-B	
		Observed	Expected[d]	Observed	Expected	Observed	Expected
	g ai ha^{-1}	%					
Nontreated control		0 h		0 g		0 g	
Bromoxynil	8.5	2 g		2 f		1 f	
Bromoxynil	17	6 f		6 e		3 ef	
Bromoxynil	34	15 d		16 c		10 c	
Bromoxynil	68	29 b		29 b		18 b	
Metribuzin	250	1 g		1 f		1 f	
Bromoxynil fb metribuzin	8.5 fb 250	**5 f**	**3**	5 e	4	3 de	3
Bromoxynil fb metribuzin	17 fb 250	**11 e**	**7**	10 d	8	5 d	4
Bromoxynil fb metribuzin	34 fb 250	**24 c**	**17**	**24 b**	**18**	14 bc	12
Bromoxynil fb metribuzin	68 fb 250	**43 a**	**30**	**42 a**	**31**	**26 a**	**20**

[a] Injury data, observed and expected, required an arcsine square root transformation; the data reported in table were back-transformed.

[b] Means followed by the same letter in each column are not significantly different according to Fisher's protected LSD test, $P < 0.05$.

[c] Abbreviations: DAT-B, days after metribuzin application; fb, followed by.

[d] Expected responses based on Colby's equation: $E = A \times B/100$. Significant differences based on a paired *t* test between observed and expected values are in bold.

location effect enabled pooling data across all trials. All data were back-transformed for the purpose of reporting. Flower and fruit counts and yield data are reported as a percentage of the nontreated control. Expected values were calculated using Colby's model (Colby 1967)

$$E = A \times B/100 \qquad [1]$$

where E = percentage of expected response with respect to the nontreated control, A = percentage of response of bromoxynil at rate x, and B = percentage of response of metribuzin at 250 g ha^{-1}. A Student's paired *t* test was used to identify herbicide interactions by comparing the calculated expected value of a rating parameter to the observed value. If the observed rating value was greater than the calculated expected value, based on the Student's paired *t* test, the herbicide interaction was defined as synergistic. Additive responses were identified as those where the observed value was equal to the expected value and antagonistic responses were those where the observed value was less than the expected value. Flower counts at 28 DAT-B from location 6 and green yield data from location 2 were removed from analysis because several nontreated plots had values of zero. Therefore, percentage of control and Colby's expected values could not be generated. The Pearson product-moment correlation (*r*) (PROC CORR in SAS) was used to identify a possible linear relationship between marketable tomato yield and plant dry weight. For the analysis, plant dry weight was transformed with the natural logarithm to linearize the data. Significance was set using a probability level of $P \leq 0.05$.

Results and Discussion

Crop Injury. Tomato injury at all rating dates was consistent with expected bromoxynil injury; leaf chlorosis, slight leaf cupping, and necrotic spots on leaves. Generally injury symptoms were located along the length of the leaf blade and were not limited to leaf margins as might be expected with metribuzin injury to tomato. As bromoxynil drift rates increased, so did tomato injury at 7, 14, and 28 DAT-B (Table 2). However, by 28 DAT-B, only tomato sprayed with bromoxynil at 34 and 68 g ha^{-1} had injury greater than or equal to 10%. Drift rates of bromoxynil at 64 g ha^{-1} caused 18 and 26% tomato injury at 28 DAT-B when applied alone or fb metribuzin, respectively. Regardless of herbicide interaction, if bromoxynil was fb metribuzin there was an increase in injury compared with the corresponding bromoxynil treatment, across all rating dates, with the exception of bromoxynil at 34 g ha^{-1} at 28 DAT-B (Table 2). Based on Colby's model a transient synergistic interaction was identified at 7 DAT-B when bromoxynil at 8.5 or 17 g ha^{-1} was fb metribuzin; the interaction was additive by 14 DAT-B. At 7 DAT-B injury ratings of 3 and 7% were expected when bromoxynil at 8.5 and 17 g ha^{-1} fb metribuzin respectively, were applied; however, 5 and 11% injury respectively, were observed (Table 2). As bromoxynil drift rates increased so did the persistence of the synergistic interaction. Tomato plants sprayed with bromoxynil at 34 g ha^{-1} fb metribuzin maintained the synergistic interaction until 14 DAT-B, whereas the highest drift rate, 20% of a bromoxynil field dose fb metribuzin, still showed a synergistic interaction at 28 DAT-B.

Tomato Dry Weight. Generally, as bromoxynil drift rates increased, tomato plant dry weight decreased, corresponding with the observed injury symptom trend. However, only treatments with drift rates of 10 to 20% of bromoxynil field rates had lower plant dry weights than the nontreated control (data not shown). Dry weights ranged from 48 to 100% of the control, depending on treatment (Table 3). The synergistic interaction identified with the injury ratings for bromoxynil at 68 g ha^{-1} fb metribuzin treatment was mirrored by the 14 DAT-B dry weight rating. Based on Colby's equation, the dry weight was expected to be reduced by 43% compared with the control; however, average dry weights were reduced by 52%, indicating a synergistic reduction. The effect of the herbicide interaction on plant dry weight was additive in those

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Table 3. Tomato yield with simulated bromoxynil spray drift alone and followed by an in-crop metribuzin application at Ridgetown, Ontario, Canada, 2008 to 2010 expressed as a percentage of the nontreated control.

		Plant dry weight		Yield[a,b]					
		14 DAT-B[c]		Marketable		Green		Marketable + green	
Treatment	Rate	Observed	Expected[d]	Observed	Expected	Observed	Expected	Observed	Expected
	g ai ha^{-1}	% of nontreated control[e]							
Bromoxynil	8.5	100 a		102 a		104 c		101 a	
Bromoxynil	17	86 bc		95 a		112 bc		96 ab	
Bromoxynil	34	81 cd		90 ab		101 c		92 b	
Bromoxynil	68	61 e		70 c		140 abc		83 c	
Metribuzin	250	93 ab		90 ab		95 c		92 b	
Bromoxynil fb metribuzin	8.5 fb 250	91 abc	95	88 ab	92	117 bc	100	94 ab	94
Bromoxynil fb metribuzin	17 fb 250	82 bc	82	86 ab	87	124 bc	107	93 b	90
Bromoxynil fb metribuzin	34 fb 250	70 de	76	79 bc	83	**157 ab**	**99**	92 b	86
Bromoxynil fb metribuzin	68 fb 250	**48 e**	**57**	**49 d**	**65**	**198 a**	**133**	76 c	78

[a] Dry weight, marketable and marketable + green yield data, observed and expected, required a (square root + 0.05) transformation whereas the green yield, observed and expected, required a (log + 1) transformation; the data reported in table were back-transformed.

[b] Means followed by the same letter in each column are not significantly different according to Fisher's protected LSD test, $P < 0.05$.

[c] Abbreviation: DAT-B, days after metribuzin application; fb, followed by.

[d] Expected responses based on Colby's equation: $E = A \times B/100$. Significant differences based on a paired *t* test between observed and expected values are in bold.

[e] Average dry weight of nontreated control at 14 DAT-B was 326.7 g and the average yields were 71, 8, and 79 t ha^{-1} for the marketable, green and marketable + green yields, respectively.

treatments where less than 68 g ha^{-1} of bromoxynil fb metribuzin was applied.

Flower and Fruit Counts. Bromoxynil applied at 34 and 68 g ha^{-1} caused a decrease in average flower number per plant (26 and 12 flowers $plant^{-1}$, respectively) compared with the nontreated control (35 flowers $plant^{-1}$) at 14 DAT-B (data not shown). However, when bromoxynil was fb metribuzin there was a decrease in flower number, compared with the nontreated control, even at the lowest simulated bromoxynil drift rate of 8.5 g ha^{-1}, 2.5% of a field rate (24 flowers $plant^{-1}$). The percentage of reduction of average flower numbers compared with the control ranged from 19 to 35% when a bromoxynil drift rate of 68 g ha^{-1} was applied either alone or fb metribuzin, respectively (Table 4). Generally, the percentage of reduction of flowers at 14 DAT-B was greater in treatments where bromoxynil drift rates were fb metribuzin compared with treatments that received the corresponding bromoxynil rate alone. Additionally, a synergistic response was identified when 8.5, 34, and 68 g ha^{-1} bromoxynil drift rates were fb metribuzin, which corresponds to the synergistic dry weight reduction and injury interactions identified. Respectively, flower counts were expected to be 115, 73, and 36% of the control when tomato was treated with bromoxynil at 8.5, 34, and 64 g ha^{-1} fb metribuzin; however, flower count reductions of 67, 48, and 19% of the control,

Table 4. Tomato flower and fruit counts with simulated bromoxynil spray drift alone and followed by an in-crop metribuzin application at Ridgetown, Ontario, Canada, 2009 to 2010 expressed as a percentage of the nontreated control.

		Flower count[a,b]				Fruit count			
		14 DAT-B[c]		28 DAT-B		14 DAT-B		28 DAT-B	
Treatment	Rate	Observed	Expected[d]	Observed	Expected	Observed	Expected	Observed	Expected
	g ai ha^{-1}	% of nontreated control[e]							
Bromoxynil	8.5	117 a		114 abc		114 a		114 a	
Bromoxynil	17	95 ab		117 abc		97 ab		99 a	
Bromoxynil	34	77 bc		77 abc		103 ab		94 ab	
Bromoxynil	68	35 e		122 ab		69 ab		69 bc	
Metribuzin	250	88 bc		96 abc		78 ab		96 a	
Bromoxynil fb metribuzin	8.5 fb 250	**67 cd**	**115**	74 bc	111	118 a	88	91 abc	111
Bromoxynil fb metribuzin	17 fb 250	77 bc	94	68 c	113	**115 a**	**75**	96 a	98
Bromoxynil fb metribuzin	34 fb 250	**48 de**	**73**	122 ab	75	59 bc	80	66 c	94
Bromoxynil fb metribuzin	68 fb 250	**19 f**	**36**	134 a	118	35 c	55	**44 d**	**68**

[a] Flower counts at 14 DAT-B and fruit counts at 28 DAT-B, observed and expected, required a (square root + 0.05) transformation whereas the flower counts at 28 DAT-B and fruit counts at 14 DAT-B, observed and expected, required a (log + 1) transformation; the data reported in table were back-transformed.

[b] Means followed by the same letter in each column are not significantly different according to Fisher's protected LSD test, $P < 0.05$.

[c] Abbreviation: DAT-B, days after metribuzin application; fb, followed by.

[d] Expected responses based on Colby's equation: $E = A \times B/100$. Significant differences based on a paired *t*-test between observed and expected values are in bold.

[e] Average flower counts for nontreated control were 35 and 22 whereas average fruit counts were 14 and 50 at 14 DAT-B and 28 DAT-B, respectively.

respectively, were observed (Table 4). There was little difference between treatments of average flower loss compared with the nontreated control at 28 DAT-B. This finding was not unexpected because bromoxynil is primarily a contact herbicide and typically only causes damage to tissue coming in contact with the herbicide. Bromoxynil application in this study, occurred either just prior to, or at, flower initiation. Therefore, any injury resulting in flower loss or abortion would likely be observed at 14 DAT-B. By 28 DAT-B, new flowers would have developed on plants, and therefore were not affected.

When bromoxynil was applied alone, only the highest drift rate treatment, at 28 DAT-B, had fewer fruit per plant compared with the nontreated control (data not shown). At the same rating, bromoxynil at 34 and 68 g ha^{-1} fb metribuzin had fewer fruit per plant vs. the control. A 20% bromoxynil field rate application, either alone or fb metribuzin, decreased fruit production to 69 or 44% of the nontreated control, respectively (Table 4). Treatments sprayed with bromoxynil at 34 or 68 g ha^{-1} fb metribuzin had fewer tomato fruit per plant than the corresponding bromoxynil-alone treatments. Similar to the 14 DAT-B average flower count rating, a synergistic interaction occurred when metribuzin was applied following bromoxynil at 68 g ha^{-1}. Using Colby's model, fruit counts were expected to be reduced to 68% of the nontreated control, but a reduction of 44% was observed at 28 DAT-B (Table 4), further corroborating the interactions identified from the injury and dry weight rating parameters. Additionally, similar to the previous rating parameters, the interaction between simulated bromoxynil drift at 8.5, 17, and 34 g ha^{-1} fb metribuzin was additive for the 28 DAT-B average fruit count rating.

Yield. Similar to tomato plant dry weight, only bromoxynil at 68 g ha^{-1} fb metribuzin had a lower marketable tomato yield than the corresponding bromoxynil-alone treatment. Treatments sprayed with bromoxynil alone at 8.5, 17, or 34 g ha^{-1} had similar marketable yields than the corresponding rate fb metribuzin. Bromoxynil alone at 68 g ha^{-1} reduced marketable yields compared with the nontreated control or metribuzin alone treatments; marketable yield was 70% of the control (Table 3). However, when metribuzin followed bromoxynil drift rates of 34 and 68 g ha^{-1}, marketable yield was only 79 and 49% of the control, respectively. The increased yield loss observed when an in-crop metribuzin application followed the higher bromoxynil drift rates was consistent with effects on the dry weight, 14 DAT-B flower counts, and 28 DAT-B fruit counts. An additive interaction was identified when bromoxynil at 8.5, 17, or 34 g ha^{-1} was fb metribuzin. However, at the highest simulated drift rate, 20% of a bromoxynil field rate, a synergistic yield reduction was identified when bromoxynil was fb metribuzin; marketable yield was expected to be reduced by 35% compared with the control but the average marketable yield was observed to be reduced by 51% (Table 3).

Tomato fruit were separated at harvest into marketable and green categories to determine if treatments caused a physiological delay (i.e., increased green yield), or an overall decrease in fruit production (i.e., decreased total marketable plus green yield) (Table 3). When bromoxynil at 34 or 68 g ha^{-1} was fb metribuzin there was an increase in green tomato yield compared with the control. Green tomato yield increased by almost two times compared with the control when the highest bromoxynil rate fb metribuzin was sprayed. Additionally, a synergistic interaction was identified in treatments where the two highest bromoxynil drift rates were fb metribuzin. Despite the increased green yield when bromoxynil at 34 g ha^{-1} was fb metribuzin, the combined marketable plus green yield was equivalent to the control, indicating this treatment only caused a delay in maturity (data not shown). However, there was decreased total fruit production and developmental delay caused by the application of bromoxynil alone at 64 g ha^{-1} or fb metribuzin (Table 3). Although the combined marketable and green yield was similar between the control and several treatments, the marketable yield reductions could pose a problem for producers, because some tomato processors pay based on marketable yield and not total yield.

The Pearson product-moment correlation (*r*) was examined to determine the existence of a linear relationship between plant dry weight at 14 DAT-B and marketable tomato yield. The Pearson coefficient was 0.74 ($P < 0.001$) for the nontreated control and bromoxynil-only treatments, $r = 0.78$ ($P < 0.001$) for the nontreated control and bromoxynil fb metribuzin treatments and when all treatments were compared with the nontreated control $r = 0.76$ ($P < 0.001$), indicating a strong linear correlation. Potentially, tomato producers could use plant dry weights at 14 DAT-B to estimate their marketable tomato yield following a bromoxynil spray drift incident, either alone or if the producer unintentionally compounded the damage by applying metribuzin following the drift incident.

Although injury was initially greater when bromoxynil was fb metribuzin, compared with the corresponding bromoxynil-alone treatment, this trend did not persist across remaining rating evaluations, except for bromoxynil at 68 g ha^{-1} treatments. However, when metribuzin was applied following bromoxynil drift there tended to be increased injury compared with bromoxynil-only treatments. For instance, tomato plants sprayed with the three lowest drift rates of bromoxynil alone had similar marketable yields to the control. In contrast, only the two lowest bromoxynil rates fb metribuzin had marketable yields comparable to the control, whereas tomato marketable yields were reduced with the two higher rates of bromoxynil. Producers could expect up to a 51% yield reduction when a 20% field dose of bromoxynil is fb an in-crop metribuzin application but only a 30% reduction if the drift rate alone occurred (Table 3). The application of metribuzin 3 to 5 d following a 20% bromoxynil field dose not only increases tomato damage but caused a synergistic interaction that persisted until harvest. The synergistic interactions of visible injury ratings and flower counts at 14 DAT-B, fruit counts at 28 DAT-B, dry weight, and marketable yield reductions compared with the nontreated control indicate the possibility of herbicide interactions even when mixture components are applied separately, up to 5 d apart. This finding could increase the complexity of determining projected damage caused by a spray drift incident. Although cumulative herbicide injury was identified with bromoxynil at 68 g ha^{-1} fb metribuzin, a primarily additive interaction was associated with the lower bromoxynil drift rates of 8.5, 17, and 34 g ha^{-1} fb metribuzin, despite transient synergistic interactions for some visible injury ratings.

Aside from the cumulative herbicide interaction identified, damage resulting from bromoxynil spray drift appears to be less insidious than that of glyphosate in processing tomato. Kruger et al. (2012) and McNaughton et al. (2012) both documented at least a 23% yield reduction when a 2.5% field dose, or lower, of glyphosate was applied, even though little injury was observed. Conversely, in this study only tomato plants sprayed with bromoxynil alone at 68 g ha^{-1}, 20% of a field dose, reduced marketable tomato fruit yields compared with the control. Bromoxynil doses of 2.5, 5, and 10% of a field rate did not reduce marketable yields, a finding mirrored by relatively low 28 DAT-B injury ratings.

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