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Response of 'Russet Burbank' Seed Tubers Containing Dicamba and Glyphosate

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Research Article

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Abstract

Increased use of dicamba and/or glyphosate in dicamba/glyphosate-tolerant soybean might affect many sensitive crops, including potato. The objective of this study was to determine the growth and yield of 'Russet Burbank' potato grown from seed tubers (generation 2) from mother plants (generation 1) treated with dicamba (4, 20, and 99 g ae ha^{-1}), glyphosate (8, 40, and 197 g ae ha^{-1}), or a combination of dicamba and glyphosate during tuber initiation. Generation 2 tubers were planted near Oakes and Inkster, ND, in 2016 and 2017, at the same research farm where the generation 1 tubers were grown the previous year. Treatment with 99 g ha^{-1} dicamba, 197 g ha^{-1} glyphosate, or 99 g ha^{-1} dicamba + 197 g ha^{-1} glyphosate caused emergence of generation 2 plants to be reduced by up to 84%, 86%, and 87%, respectively, at 5 wk after planting. Total tuber yield of generation 2 was reduced up to 67%, 55%, and 68% when 99 g ha^{-1} dicamba, 197 g ha^{-1} glyphosate, or 99 g ha^{-1} dicamba + 197 g ha^{-1} glyphosate was applied to generation 1 plants, respectively. At each site year, 197 g ha^{-1} glyphosate reduced total yield and marketable yield, while 99 g ha^{-1} dicamba reduced total yield and marketable yield in some site-years. This study confirms that exposure to glyphosate and dicamba of potato grown for potato seed tubers can negatively affect the growth and yield potential of the subsequently grown daughter generation.

Introduction

Glyphosate and dicamba caused a decrease in germination and emergence of potato, soybean, dry bean (*Phaseolus vulgaris* L.), and wheat (*Triticum aestivum* L.) when the parent generation was exposed to the herbicide in the prior season (Auch and Arnold 1978; Blackburn and Boutin 2003; Colquhoun et al. 2017; Hatterman-Valenti 2014; Hutchinson et al. 2014; Lyon and Wilson 1986; Norsworthy 2004; Wall 1994; Seefeldt et al. 2014; Yenish and Young 2000). Dicamba/glyphosate-tolerant cultivars of soybean and cotton (*Gossypium hirsutum* L.) will allow dicamba and glyphosate to be applied during the cropping season to control hard to kill broadleaf weeds and glyphosate-resistant weeds. The potential exposure of susceptible crops to these chemicals increases as applications have been allowed through the R1 soybean growth stage (Barber et al. 2017; Bradley 2017). Minor crop producers and the USDA have expressed concern that off-target movement through volatility, particle drift, or spray-tank contamination could result in crop injury, yield reduction, and pesticide residue issues (USDA-ARS 2015).

U.S. potato production in 2015 totaled 22.4 million Megagrams valued at US$3.7 billion on about 404,000 ha (USDA-NASS 2017). North Dakota ranked fourth in overall potato production, which totaled 1.1 million Megagrams and a crop valued at US$222 million (National Potato Council 2017). Successful commercial potato production begins with the availability of high-quality seed tubers. North Dakota has the second largest seed potato tuber production program in the United States, certifying and inspecting an average of 6,100 ha of seed potato tubers annually (NDSSD 2008). 'Russet Burbank' is the most widely grown potato cultivar for seed tubers in the United States (National Potato Council 2017).

A number of studies have reported the effects of glyphosate on potato when treated during the growing season (Colquhoun et al. 2017; Hatterman-Valenti 2014; Hatterman-Valenti et al. 2017; Hutchinson et al. 2014; Wall 1994; Worthington 1985). Worthington (1985) reported that glyphosate treatments applied to a growing crop of potatoes adversely affected the sprout growth of the harvested tubers planted the following season. Hatterman-Valenti (2014) reported that sprouting of 'Red LaSoda' was reduced more than 80% when mother plants were exposed to 71 to 282 g ha^{-1} glyphosate during the late bulking growth stage. Hutchinson et al. (2014) evaluated the effect of glyphosate treatments (8.5, 54, 107, 215, and 423 g ha^{-1}) applied to 'Ranger Russet' at 10- to 15-cm plant height, stolon hooking, tuber initiation, and mid-bulking potato growth stages. Glyphosate treatments at mid-bulking caused the least foliar injury, but reduced daughter plant emergence the most among the exposure timings. Ranger Russet treated with to 107 to 423 g ha^{-1} glyphosate at tuber initiation had a 40% to 55% decrease in yield when compared with untreated plants. However, Colquhoun et al. (2017) found that treatments of 9 to 38 g ha^{-1} glyphosate at tuber initiation to Russet Burbank mother plants caused up to 30% foliar injury to daughter plants, but did not reduce total tuber yield of either the mother or daughter crop.

The effects of dicamba on mother plants and subsequent tuber seed pieces has shown dicamba can persist in seed potato tubers. Wall (1994) reported that treatments of 2.8, 5.6, and 11.1 g ha^{-1} dicamba applied to 'Norland' mother plants caused 6% visible foliar injury 2 wk after daughter tuber emergence, but this injury did not affect yield. Similarly, Colquhoun et al. (2017) found that a treatment of 6 g ha^{-1} dicamba to mother plants did not reduce emergence density or yield of daughter tubers planted the following year.

Differing results from herbicide injury studies on potato could be explained by environmental conditions. Masiunas and Weller (1988) reported that potatoes grown at a 25/13 C temperature regime were injured more by glyphosate treatments than plants grown at 13/4 C. Smid and Hiller (1981) observed similar symptoms when potato plants were exposed to glyphosate and reported that translocation patterns were symplastic. Multiple low-dose herbicide studies suggest that environmental conditions at the time of treatment may cause differences in susceptibility to sublethal doses applied to non-target crops (Al-Khatib and Tamhane 1999; Hatterman-Valenti 2014; Hatterman-Valenti et al. 2017).

Glyphosate residue within seed tubers has been shown to decrease emergence and crop quality for russet-skinned potato cultivars grown in irrigated and nonirrigated conditions (Hatterman-Valenti 2014; Hutchinson et al. 2014). However, there is no information on the effects of dicamba plus glyphosate on Russet Burbank seed tubers from mother plants exposed to these herbicides. Because glyphosate and dicamba are increasingly used in tank mixtures, the objective of this study was to determine the effects of dicamba, glyphosate, and the combination of dicamba and glyphosate on emergence and yield of potato seed tubers.

Materials and Methods

Field experiments were conducted at the North Dakota State University Oakes Irrigation Research Site near Oakes, ND (46.07°N, 98.09°W; elevation 392 m), and at the Northern Plains Potato Growers Association Irrigation site near Inkster, ND (48.16°N, 97.43°W; elevation 314 m). Soil type at Oakes was an Embden coarse-loamy, mixed, superactive, frigid Pachic Hapludolls (14% clay, 70% sand, 16% silt). Soil at Inkster was an Inkster coarse-loamy, mixed, superactive, frigid Pachic Hapludolls (15% clay, 66% sand, 19% silt) (USDA-NRCS 2017). Studies were conducted from 2015 to 2016 and from 2016 to 2017 (Hatterman-Valenti et al. 2017). In the first year of each experiment, mother plants (experimental generation 1) were treated at tuber initiation to simulate the latest timing dicamba and glyphosate would be applied for weed control in soybean.

Experimental Generation 1

In each year, the experiment was set up as a randomized complete block design with four replications. Ten treatments consisting of a nontreated control; 4, 20, and 99 g ha^{-1} dicamba (Clarity®, BASF, Research Triangle Park, NC 27709); 8, 40, and 197 g ha^{-1} glyphosate (Roundup PowerMax®, Monsanto, St Louis, MO 63167); and 4 g ha^{-1} dicamba + 8 g ha^{-1} glyphosate, 20 g ha^{-1} dicamba + 40 g ha^{-1} glyphosate, and 99 g ha^{-1} dicamba + 197 g ha^{-1} glyphosate. The maximum single application allowed in soybean is 1,680 g ha^{-1} glyphosate and 560 g ha^{-1} dicamba. Seed tubers averaging 57 g were planted 12-cm deep at 30-cm spacing within row and 91-cm spacing between rows with a 2-row potato planter on May 22, 2015, and May 5, 2016, at Oakes, and on June 10, 2015, and May 18, 2016, at Inkster. Plots were 7.6-m long by 3.7-m wide and included 4 rows. Treatments were applied at the tuber initiation stage of growth to the center 2 rows of the mother plant plots on July 7, 2015, and June 28, 2016, at Oakes, and on July 30, 2015, and July 6, 2016, at Inkster. All treatments were applied in 140 L ha^{-1} carrier volume using a CO_2-pressurized backpack sprayer with a 1.8-m-wide boom and XR11002 flat-fan nozzles (Teejet® Spraying Systems Company, Wheaton, IL 60189) at 138 kPa. Tubers were harvested from the center 2 rows of each plot on September 14, 2015, and September 13, 2016, at Oakes, and on October 5, 2015, and September 30, 2016, at Inkster. After harvest, tubers from each experimental plot were suberized at 12 C for 3 wk and then stored at 2.2 C with 90% to 95% relative humidity.

Experimental Generation 2

Stored tubers from experimental generation 1 were warmed to 10 C at 90% to 95% relative humidity 1wk before planting. Fifty seed tubers were arbitrarily selected from each stored plot sample and cut into 70 ± 5 g seed pieces 1 d before planting. Each seed piece was cut from a different tuber to expand variability among seed pieces. Seed pieces were planted in a randomized complete block design with four replications. Seed pieces were planted 12-cm deep at 30-cm spacing within row and 91-cm spacing between rows with a 2-row Harriston belt-fed potato planter. Plots were 7.6-m long by 3.7-m wide and included 4 rows. Experimental generation 2 tubers were planted at the same research farm as experimental generation 1, but in a different field to reduce potential problems with soilborne diseases. Seed pieces were planted May 5, 2016, and May 12, 2017, in Oakes, and May 18, 2016, and June 2, 2017, in Inkster. The plots were maintained according to North Dakota State University recommended potato production standards (Bissonnette et al. 1993).

Potato plant emergence and height data were collected at 5 and 8 wk after planting (WAP). Plant height was measured from the top of the hill to the youngest leaf on the first 10 plants in each of the 2 middle rows. Visible injury data were not collected, because previous work has indicated that visual injury does not correlate well to yield loss (Colquhoun et al. 2017). All plots were desiccated twice with 30 g ae ha^{-1} diquat (Reglone®, Syngenta Crop Protection, Greensboro, NC 27419) at 3 and 2 wk before harvest. The Oakes site was harvested on September 13, 2016, and September 13, 2017, and the Inkster site was harvested on September 30, 2016, and October 6, 2017. The 2 center rows of each experimental plot were harvested with a single-row mechanical harvester, and tuber yield and quality were determined according to USDA grading standards (USDA 2011). Tubers were graded for size and quality and separated into <113, 113 to 170, 171 to

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Table 1. 'Russet Burbank' potato emergence and plant height at 5 and 8 wk after planting (WAP) when grown from seed tubers derived from mother plants that were treated with glyphosate and dicamba the previous growing season at Inkster, ND, 2016.

			Plant emergence[a]		Plant height[a]	
Treatment	Glyphosate	Dicamba	5 WAP	8 WAP	5 WAP	8 WAP
	———— g ae ha^{-1} ————		———————— % ————————		———————— cm ————————	
1	0	0	87 a	96 a	20 a	53 ab
2	8	0	86 a	89 a	20 ab	51 ab
3	40	0	77 ab	87 ab	16 ab	51 ab
4	197	0	12 c	72 bc	3 c	27 c
5	0	4	93 a	92 a	18 ab	51 ab
6	0	20	64 b	84 abc	13 b	48 ab
7	0	99	14 c	73 bc	4 c	45 ab
8	8	4	93 a	94 a	20 a	58 a
9	40	20	61 b	90 a	14 ab	49 ab
10	197	99	11 c	69 c	3 c	39 bc

[a]Numbers followedby the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05.

283, 284 to 397, >397 g tuber categories. Total marketable yield was calculated as a summation of all tubers >113 g.

The data collected met the assumptions of normally and equally distributed data by the Shapiro-Wilk test. Data were subjected to ANOVA to determine whether there was a year by location interaction using PROC MIXED in Statistical Analysis Software (SAS v. 9.4, SAS Institute, 100 SAS Campus Drive, Cary, NC 27513). An interaction was observed; therefore, data were analyzed and presented separately by site and year. Tukey's pairwise comparisons (P = 0.05) were used to separate treatment means.

Results and Discussion

Glyphosate and dicamba treatments on generation 1 plants had a negative effect on generation 2 plant emergence and plant height. This was most evident at the treatments of 99 g ha^{-1} dicamba and/or 197 g ha^{-1} glyphosate, for which plant emergence and plant height were reduced at most site-years (Tables 1–4). In general, 197 g ha^{-1} glyphosate caused more potato seed tubers to have reduced plant emergence and height at 5 and 8 WAP compared with the nontreated control. Similarly, treatment with 99 g ha^{-1} dicamba caused a decrease in plant emergence at 5 and

Table 2. 'Russet Burbank' potato emergence and plant height at 5 and 8 wk after planting (WAP) when grown from seed tubers derived from mother plants that were treated with glyphosate and dicamba the previous growing season at Oakes, ND, 2016.

			Plant emergence[a]		Plant height[a]	
Treatment	Glyphosate	Dicamba	5 WAP	8 WAP	5 WAP	8 WAP
	———— g ae ha^{-1} ————		———————— % ————————		———————— cm ————————	
1	0	0	87 a	94 ab	48 ab	61 a
2	8	0	84 a	95 ab	49 a	60 a
3	40	0	82 a	82 ab	48 ab	59 a
4	197	0	36 c	54 c	32 d	46 b
5	0	4	81 ab	89 ab	45 abc	62 a
6	0	20	76 ab	90 ab	40 bc	60 a
7	0	99	73 ab	76 b	39 cd	55 a
8	8	4	8 a	95 a	46 abc	63 a
9	40	20	7 ab	82 ab	41 bc	56 a
10	197	99	6 b	7 b	43 abc	57 a

[a]Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05.

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Table 3. 'Russet Burbank' potato emergence and plant height at 5 and 8 wk after planting (WAP) when grown from seed tubers derived from mother plants that were treated with glyphosate and dicamba the previous growing season at Inkster, ND, 2017.

			Plant emergence[a]		Plant height[a]	
Treatment	Glyphosate	Dicamba	5 WAP	8 WAP	5 WAP	8 WAP
	——— g ae ha^{-1} ———		——— % ———		——— cm ———	
1	0	0	93 a	95 a	23 ab	65 a
2	8	0	83 abc	96 a	24 a	65 a
3	40	0	87 ab	86 a	23 ab	62 a
4	197	0	35 d	49 b	10 c	50 b
5	0	4	85 abc	89 a	24 ab	63 a
6	0	20	80 abc	91 a	21 ab	61 ab
7	0	99	66 bc	79 a	21 ab	57 ab
8	8	4	90 a	95 a	23 ab	62 a
9	40	20	79 abc	83 a	18 ab	58 ab
10	197	99	64 c	80 a	17 bc	57 ab

[a]Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05.

8 WAP at Inkster 2016 and Oakes 2017 compared with the nontreated control. At Inkster 2016, treatment with 20 g ha^{-1} dicamba caused emergence reductions at 5 WAP, but by 8 WAP emergence was similar to that of the nontreated control. The combination of 99 g ha^{-1} dicamba + 197 g ha^{-1} glyphosate resulted in a decrease of plant emergence at 5 WAP at all site-years. By 8 WAP, plant emergence was no different than that of the nontreated control at Oakes 2016 and Inkster 2017. Plant height recovered by 8 WAP at all site-years, and no differences existed between plants treated with 99 g ha^{-1} dicamba + 197 g ha^{-1} glyphosate and the nontreated control. In general, the combination of 99 g ha^{-1} dicamba + 197 g ha^{-1} glyphosate was not worse than either treatment alone on plant emergence or plant height. The effects of glyphosate tended to persist longer (up to 8 WAP) on plant emergence and plant height than dicamba or glyphosate + dicamba. Reduced emergence at 8 WAP could be explained by the observation that potato seed tuber pieces planted for generation 2 that did not have sprout emergence aboveground by 8 WAP often remained in the soil the entire growing season with multiple, short 1- to 3-cm sprouts.

Similar to our results, Colquhoun et al. (2017) reported that a low dose of dicamba to the mother plants did not cause an emergence reduction in the next generation. However, our study indicates that plant emergence could be reduced when mother

Table 4. 'Russet Burbank' potato emergence and plant height at 5 and 8 wk after planting (WAP) when grown from seed tubers derived from mother plants that were treated with glyphosate and dicamba the previous growing season at Oakes, ND, 2017.

			Plant emergence[a]		Plant height[a]	
Treatment	Glyphosate	Dicamba	5 WAP	8 WAP	5 WAP	8 WAP
	——— g ae ha^{-1} ———		——— % ———		——— cm ———	
1	0	0	90 a	97 a	13 a	50 ab
2	8	0	85 ab	90 ab	14 a	53 a
3	40	0	84 ab	90 ab	12 ab	54 a
4	197	0	38 c	68 c	6 bc	34 b
5	0	4	93 a	95 a	14 a	52 a
6	0	20	87 ab	83 abc	11 ab	48 ab
7	0	99	66 b	78 bc	12 a	44 ab
8	8	4	89 a	95 a	14 a	54 a
9	40	20	84 ab	90 ab	11 ab	49 ab
10	197	99	40 c	67 c	1 c	41 ab

[a]Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05.

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Figure 1. Foliar injury at 5 wk after planting expressed in stems of generation 2 potato seed tubers derived from generation 1 plants treated with 20 g ha^{-1} dicamba (A), 99 g ha^{-1} dicamba (B), 20 g ha^{-1} dicamba + 40 g ha^{-1} glyphosate (C), and 99 g ha^{-1} dicamba + 197 g ha^{-1} glyphosate (D) at Inkster, ND, in 2016.

plants are exposed to higher rates (40 to 99 g ha^{-1}) of dicamba at tuber initiation.

Although foliar injury of experimental generation 2 plants was not rated, foliar chlorosis, stunting, and twisted leaves and stems were evident when generation 1 plants had been treated with 20 or 99 g ha^{-1} dicamba alone or with glyphosate (Figure 1). Similarly, Hatterman-Valenti (2014) reported delayed emergence, distorted leaflets with random puckers on the leaf surface, and leaf strapping when potato seed tubers derived from mother plants treated with glyphosate were grown. These symptoms are also similar to what would be expected from synthetic auxin herbicide activity on potato (Thornton et al. 2013). Symptom severity varied widely and, as reported by Hatterman-Valenti (2014), did not appear to be associated with a specific glyphosate and/or dicamba rate applied to the mother plants.

Differences observed in individual plant responses were attributed to differences in sink strength of different daughter tubers at the time of mother plant exposure (Hatterman-Valenti 2014). During tuber initiation, the tuber becomes a major sink for photosynthate deposition. This causes exogenous chemicals such

Table 5. Total yield of 'Russet Burbank' potatoes grown from potato tuber seed derived from mother plants that were treated the previous season with glyphosate and dicamba at Inkster, ND, 2016.

			Potato tuber yield[a]						
Treatment	Glyphosate	Dicamba	<133 g	113–169 g	170–282 g	283–397 g	>397 g	Total	Total marketable[b]
	——— g ae ha^{-1} ———		——— Mg ha^{-1} ———						
1	0	0	7	12	21 ab	11	5	55 a	48 a
2	8	0	6	12	21 a	9	4	51 ab	45 a
3	40	0	7	13	21 a	7	2	51 ab	43 a
4	197	0	9	8	10 c	6	6	38 c	30 c
5	0	4	5	11	22 a	11	7	55 a	50 a
6	0	20	5	7	17 ab	11	7	48 abc	43 ab
7	0	99	5	8	16 abc	8	5	44 bc	38 abc
8	8	4	7	11	22 a	10	3	54 ab	47 a
9	40	20	7	11	18 ab	9	4	49 abc	41 ab
10	197	99	6	9	13 bc	7	3	38 c	32 bc

[a]Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05. No significant differences within a column were observed when no letters are included.
[b]Total marketable yield includes U.S. No. 1 and U.S. No. 2 tubers >113 g.

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Table 6. Total yield of 'Russet Burbank' potatoes grown from potato tuber seed derived from mother plants that were treated the previous season with glyphosate and dicamba at Oakes, ND, 2016.

			Potato tuber yield[a]						
Treatment	Glyphosate	Dicamba	<133 g	113–169 g	170–282 g	283–397 g	>397 g	Total	Total marketable[b]
	——— g ae ha^{-1} ———		——— Mg ha^{-1} ———						
1	0	0	4 abc	7 a-d	20 ab	13 ab	15	58 a	54 ab
2	8	0	4 abc	8 ab	20 ab	18 a	10	60 a	56 ab
3	40	0	6 a	8 ab	21 ab	12 ab	13	60 a	54 ab
4	197	0	5 a	5 bcd	8 cd	4 cd	3	26 cd	20 de
5	0	4	4 abc	7 ab	25 a	16 a	9	62 a	58 a
6	0	20	5 ab	6 a-d	14 bc	9b cd	5	39 bc	34 cd
7	0	99	1 c	2 cd	5 d	4 d	7	19 d	18 e
8	8	4	6 a	11 a	23 a	12 ab	9	61 a	55 ab
9	40	20	5 abc	7 a-d	15 b	12 abc	8	46 ab	42 bc
10	197	99	2 bc	2 d	5 d	3 d	7	19 d	17 e

[a]Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05. No significant differences within a column were observed when no letters are included.
[b]Total marketable yield includes U.S. No. 1 and U.S. No. 2 tubers >113 g.

as glyphosate and dicamba to be translocated to the tuber shortly after the time of exposure (Smid and Hiller 1981). However, glyphosate and/or dicamba may not be equally distributed among the tubers on a single plant, as was shown with glyphosate by Crook (2016). Because of the potential variability among seed tuber pieces, residue analysis is a poor predictor of yield potential of plants in the next generation following exposure to herbicides (Crook 2016).

This study confirms the sensitivity of potato early growth to glyphosate and dicamba. Glyphosate and dicamba have been reported to cause a reduction in emergence and plant height in generation 2 plants derived from mother plants exposed to glyphosate the previous growing season (Crook 2016; Seefeldt et al. 2014). Interestingly, in some site-years, dicamba seemed to play a role in improving growth of potato seed tubers when dicamba and glyphosate treatments were applied to mother plants the previous growing year. Potato seed tubers containing herbicide residues can exhibit slow and erratic emergence, and this can limit yield potential.

Similar to plant emergence and height, glyphosate and dicamba treatments to generation 1 had a negative effect on generation 2

Table 7. Total yield of 'Russet Burbank' potatoes grown from potato tuber seed derived from mother plants that were treated the previous season with glyphosate and dicamba at Inkster, ND, 2017.

			Potato tuber yield[a]						
Treatment	Glyphosate	Dicamba	<133 g	113–169 g	170–282 g	283–397 g	>397 g	Total	Total marketable[b]
	——— g ae ha^{-1} ———		——— Mg ha^{-1} ———						
1	0	0	2	4	14 ab	14 abc	15 ab	49 a-d	46 abc
2	8	0	3	5	17 a	15 a	14 abc	55 a	51 a
3	40	0	3	5	13 abc	12 a-d	10 a-d	44 a-e	39 a-d
4	197	0	3	5	7 c	7 cd	5 d	27 e	24 d
5	0	4	3	6	15 ab	16 a	15 a	54 ab	50 ab
6	0	20	3	5	12 abc	9 a-d	10 a-d	39 a-e	34 bcd
7	0	99	4	4	10 bc	8b cd	6b cd	31 de	26 d
8	8	4	3	5	15 ab	15 ab	13 a-d	51 abc	46 abc
9	40	20	3	5	13 abc	9 a-d	5 d	36 b-e	32 cd
10	197	99	4	6	11 abc	7 d	5 d	33 cde	29 d

[a]Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05. No significant differences within a column were observed when no letters are included.
[b]Total marketable yield includes U.S. No. 1 and U.S. No. 2 tubers >113 g.

Table 8. Total yield of 'Russet Burbank' potatoes grown from potato tuber seed derived from mother plants that were treated the previous season with glyphosate and dicamba at Oakes, ND, 2017.

			Potato tuber yield[a]						
Treatment	Glyphosate	Dicamba	<133 g	113–169 g	170–282 g	283–397 g	>397 g	Total	Total marketable[b]
	——— g ae ha^{-1} ———		——— Mg ha^{-1} ———						
1	0	0	9	11	23 a	15 ab	13 ab	70 a	61 a
2	8	0	9	10	19 ab	16 a	9 ab	62 ab	53 ab
3	40	0	7	9	21 a	15 ab	9 ab	61 ab	54 ab
4	197	0	8	8	15 ab	6 c	4 b	41 c	34 c
5	0	4	9	10	21 a	14 abc	13 ab	67 ab	58 ab
6	0	20	7	9	19 ab	16 a	14 a	65 ab	58 ab
7	0	99	6	8	17 ab	13 abc	8 ab	53 abc	47 abc
8	8	4	9	11	23 a	17 a	9 ab	69 a	60 ab
9	40	20	7	8	19 ab	10 abc	7 ab	51 bc	44 bc
10	197	99	6	9	12 b	7 bc	7 ab	41 c	36 c

[a]Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05. No significant differences within a column were observed when no letters are included.
[b]Total marketable yield includes U.S. No. 1 and U.S. No. 2 tubers >113 g.

total tuber yield (Tables 5–8). In all site-years, 197 g ha^{-1} glyphosate caused a 31% to 85% reduction in total yield and a 27% to 73% loss in marketable yield when compared with the nontreated control. Treatment with 99 g ha^{-1} dicamba caused a total yield reduction of 20% at Inkster 2016 and 67% at Oakes 2016, while total marketable yield loss was 43% at Inkster 2017 and 67% at Oakes 2016 when compared with the nontreated control. At Oakes 2016, dicamba treatment as low as 20 g ha^{-1} caused production to be 33% less for total yield and marketable yield compared with the nontreated control. In general, 197 g ha^{-1} glyphosate + 99 g ha^{-1} dicamba caused a 34% to 67% reduction in total yield and a 27% to 68% loss in marketable yield when compared with the nontreated control. The combination of 197 g ha^{-1} glyphosate + 99 g ha^{-1} dicamba did not cause a greater reduction in total yield or marketable yield than 197 g ha^{-1} glyphosate alone.

In general, yield reductions caused by 99 g ha^{-1} dicamba and/or 197 g ha^{-1} glyphosate could be explained by slower plant emergence and growth that resulted in a reduction of tubers ≥170 g (Tables 5–8). For example, when generation 1 plants were treated with 197 g ha^{-1}, the generation 2 plants at Inkster 2017 had a 50% reduction in tubers sized between 170 and 397 g and a total yield reduction of 45%. Although tubers <170 g were similar to the nontreated checks at each treatment, the tubers ≥170 g provide premium value in contracted processed potato production. These larger-sized tubers are of the most value, and they typically make up 65% or more of the total yield.

No differences in external defects or malformations of generation 2 progeny tubers were observed in plots whose mother plants were treated with dicamba and/or glyphosate. These results agree with the findings of Hatterman-Valenti (2014) and Hutchinson et al. (2014), who reported no injury when seed tubers derived from mother plants treated with glyphosate were planted and grown to maturity. As was the case with glyphosate, symptoms of dicamba were not expressed in progeny tubers of generation 2 plants.

Our results indicate that planting seed tubers from mother plants treated with 99 g ha^{-1} dicamba or 197 g ha^{-1} glyphosate or a combination of these two herbicides would in most cases result in reduced emergence, plant height, and yield the following season. Interestingly, the combinations of dicamba and glyphosate often produced effects similar to those of each herbicide treatment alone as measured by the parameters studied. Differences in responses by site-year could be attributed to source-to-sink differences as affected by plant health and environment. It has also been established that air temperature, among many environmental factors, can alter herbicide adsorption, translocation, and efficacy (Ellis et al. 2003; Gaine et al. 2017; Masiunas and Weller 1988).

Glyphosate or dicamba residues in seed tubers can result in poor emergence, causing an erratic plant emergence that could increase weed problems (Eberlein et al. 1997). In addition, a poor crop canopy can increase soil temperature, causing a loss of soil moisture and inefficient use of nutrients (Van Delden 2001). Furthermore, potato seed tubers with low vigor generally produce a weaker plant, allowing for pathogens to invade and cause infection (Stead 1999). Greater weed and pathogen problems could lead to more herbicide and fungicide treatments, increasing production costs.

Although services are available, testing residue levels in potato seed tubers is not a mandatory requirement of the state seed department, as only a portion of a potato seed tuber lot would be affected from an off-target herbicide incident, and those tubers generally appear similar to those without herbicide residues. Further research should develop cost-effective testing methods that potato seed growers could use to test for glyphosate and/or dicamba residues in potato seed tubers.

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