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WEED SCIENCE

Effect of Glyphosate on Fruit Partitioning in Early and Late Maturing Bollgard II/Roundup Ready Flex Cotton Varieties

Jonathan A. Huff, Darrin M. Dodds, J. Trenton Irby, and Daniel B. Reynolds*

ABSTRACT

Roundup Ready Flex cotton was introduced commercially in 2006. Although research is available documenting Roundup Ready cotton tolerance to glyphosate, little to no data exists regarding the effect of glyphosate application on fruit partitioning in Roundup Ready Flex cotton. The objective of this research was to evaluate the effect of glyphosate application on fruit partitioning in Roundup Ready Flex cotton varieties. Five experiments were conducted at three locations throughout Mississippi in 2004 and 2005. Varieties chosen for the study were DP 117 B2RF, DP 143 B2RF, ST 4554 B2RF, and ST 6611 B2RF. Variety selection was based upon differing relative maturity among the varieties. Glyphosate was applied at a labeled rate (0.84 kg ae/ha), to all varieties, four separate times throughout the growing season. Data were collected using box mapping, a technique designed to depict yield partitioning on a cotton plant. These data indicate that yield partitioning was different among varieties but was unaffected by glyphosate application for any variety. Lower percent seed cotton partitioned to lower nodes was observed for the DP 143 B2RF and ST 6611 B2RF varieties compared to DP 117 B2RF and ST 4554 B2RF. However, DP 143 B2RF and ST 6611 B2RF partitioned more seed cotton to higher nodes, starting with node 12, compared to DP 117 B2RF and ST 4554 B2RF. These data indicate that the four varieties evaluated exhibited excellent tolerance to multiple glyphosate applications with no significant differences with respect to yield. Additionally, glyphosate application had no impact on seedcotton partitioning in Roundup Ready Flex cotton.

J.A. Huff, D.M. Dodds, J.T. Irby and D.B. Reynolds, Department of Plant and Soil Sciences, Mississippi State University, 117 Dorman Hall, Box 9555, Mississippi State, MS 39762
*Corresponding author: dreynolds@pss.msstate.edu

Bollgard/glyphosate-resistant (BR) cotton has greatly improved grower success in controlling problematic weeds during the first 4 to 6 wk after planting (Jones et al., 2006). This is due to ease of use and broad range of control over many grass and broadleaf weed species with glyphosate. The current labeled topical application timing for BR varieties is through the fourth leaf stage of development. Glyphosate applied after this stage might affect boll retention and square abscission, delay maturity, and subsequently affect yield (Ferreira et al., 1998; Kalaher and Coble, 1998; Kalaher et al.,1997; Martens et al., 2003; Matthews et al., 1998). Yield losses are attributed to exhibition of vegetative, but not reproductive, tolerance to glyphosate by Roundup Ready (RR) cotton (Nida et al., 1996). Monopodial limbs, or vegetative branches, begin formation at the same time the main stem begins unfolding and continues through the development of the third or fourth true leaf (Mauney, 1984). The first sympodial (reproductive) branch usually occur at nodes five to seven and continues to arise at each successive main stem node throughout the growing season (Jenkins et al., 1990). Due to current label restrictions and BR cotton's susceptibility to glyphosate during the reproductive stage, producers have a limited amount of time for over-the-top application of glyphosate, minimizing the chances of obtaining season-long weed control. Under favorable growing conditions, cotton can compensate for fruit abscission on lower sympodia at lower main stem nodes by setting more fruit at higher nodes (Jenkins et al., 1990; Jones and Snipes, 1999). However, these late-season bolls might be non-harvestable and yield reductions might occur (Kalaher and Coble, 1998).

Bollgard II/Roundup Ready Flex (B2RF) cotton was released commercially in 2006. B2RF cotton exhibits both vegetative and reproductive tolerance to glyphosate, thus allowing glyphosate to be applied over the top at any growth stage without risk of boll abortion (May et al., 2004). Bollgard II/Roundup Ready Flex technology uses a new "transformation event" (MON 88913) with a different promoter but the same CP4 EPSPS gene to help provide vegetative and reproductive tolerance in cotton (Monsanto, 2005). This new technology shows promise by providing producers with a wider window for over-the-top glyphosate applications without risk of yield loss (Murdock and Mullins, 2006).

B2RF tolerance studies, regulatory studies, variety trials, and development of weed management recommendations began in 2001 (Murdock and Mullins, 2006). B2RF cotton exhibits excellent reproductive tolerance to glyphosate (Jones et al., 2006; Martens et al., 2003). However, data assessing the tolerance of multiple commercial cotton varieties to multiple glyphosate applications are lacking. During the release of RR technology many transgenic cultivars were offered for sale with fewer years of public testing than most growers and advisors prefer (May et al., 2006). Many growers experienced monetary losses due to the release of unsatisfactory RR varieties in an effort to speed new technology to the marketplace (Kerby et al., 2002). Variety selection should be based on multiple years of data (Stewart et al., 2006). Furthermore, RR Flex varieties were available for public testing for the first time in 2005; hence, growers making selections for subsequent growing seasons were doing so based on limited data (Stewart et al., 2006). Additionally, many commercial varieties are not available for public testing for more than two to three years. Therefore, experiments were initiated to determine the effect of glyphosate application on multiple varieties in an effort to determine glyphosate tolerance of varieties containing RR Flex technology.

The objective of this research was to evaluate the effect of glyphosate application on fruit partitioning in early and later maturing RR Flex cotton varieties.

MATERIALS AND METHODS

Experiments were conducted in 2005 and 2006 to evaluate the tolerance of four B2RF cotton varieties to glyphosate. Experiments were conducted at the following locations: Greenwood, MS (2005); Starkville, MS (2005 and 2006); and Brooksville, MS (2005 and 2006). Experimental units consisted of four rows that were 3.9 m wide by 12.2 m long. Two varieties were used from both Delta & Pine Land Company (DP) and Stoneville Pedigree Seeds Company (ST). Varieties from DP included DP 117 B2RF (early maturity) and DP 143 B2RF (mid-maturity). Varieties from ST included ST 4554 B2RF (early-mid maturity) and ST 6611 B2RF (full-season maturity). All varieties were planted at a rate of 12.4 seeds row meter^{-1}. Treatments were arranged as a 2-factor factorial in a randomized complete block design. Factor A consisted of the four B2RF varieties. Factor B encompassed herbicide treatments consisting of an untreated check or glyphosate applications at each of the following growth stages: 3- fb 6- fb 9- fb 12- nodes. All glyphosate applications were made at a rate of 0.84 kg ae ha^{-1}. All treatments were applied with a tractor-mounted compressed-air sprayer or a CO_2-pressurized backpack sprayer delivering a volume of 169 L ha^{-1}. All plots were kept weed free throughout the entire growing season by mechanical cultivation and hand weeding to prevent any weed interference. Insecticides, plant growth regulators, and defoliants were applied uniformly across each test according to standard management practices for Mississippi.

Data collection consisted of in-season visual estimates of cotton injury that were based on a scale of 0 to 100, where 0 = no cotton injury and 100 = complete cotton death (Frans et al., 1986). Additionally, end-of-season box mapping and machine-harvest seed cotton yield were collected. Box mapping data were collected from all plants in a 3-m section of row as described by Jenkins et al. (1990). Plants were collected from each allotted section of row and each boll was harvested by hand and sorted by their associated main stem nodes and sympodial branch positions (Jenkins et al., 1990). The number of bolls, seed-cotton weight at each fruiting position, and total seed-cotton weight, as well as total number of plants was determined. Plants that had lost apical dominance were categorized as aborted plants, and lint was hand-harvested from the entire plant without regard to position. Seed cotton from vegetative branches was also separated and added to the total weight to determine total yield. Seed-cotton data were analyzed using horizontal fruiting positions by calculating the percentage of yield located on sympodial branches in fruiting positions one, two, and three. Position one represents the first position closest to the stem at each node on a fruiting branch, position two represents the second horizontal fruiting position, and position three includes any horizontal position beyond the second position. Yield was also partitioned vertically on the plant by combining the amount of yield located on sympodial branches at various nodes. Vertical zones were divided into three sections: zone one represents all seed cotton located on fruiting branches five to eight, zone two represents nodes nine to 12, and zone three represents any nodes above the 12th node. The assumption was made that cotton has a 3-day vertical and 6-day horizontal fruiting interval (Jenkins et al. 1990). Utilizing this time interval, plants were also sectioned into cohorts, according to maturity. Cohort positions represent the fruiting sites that are technically the same age, for example: cohort four represents node eight, position one; node six, position two; and node four, position three. Data were analyzed through the 16th cohort. All box mapping and yield data were subjected to analysis of variance using the PROC MIXED procedure of the Statistical Analysis System (SAS® version 9.1; SAS Institute Inc.; Cary, NC). Box mapping and yield data were combined over environments where each year-location combination was considered an environment. Environments, replications (nested within environment), and all interactions of these effects were considered random effects (Bond et al., 2008; Ottis et al., 2004; Walker et al., 2006, 2008; Zhang et al., 2005). Means were separated by Fisher's protected LSD at the 0.05 level of significance.

RESULTS AND DISCUSSION

No visual injury was observed due to glyphosate application for any variety at any time throughout the growing season (data not shown). Percent seed cotton partitioned in horizontal fruiting positions, vegetative branches, and aborted plants are shown in Table 1. No significant difference (NSD) was observed in percent seed cotton partitioned in position one, two, or three fruiting sites among varieties due to glyphosate application (Table 1). However, when data are pooled over glyphosate treatment (treated vs. untreated), ST 6611 B2RF had less seed cotton partitioned in position two fruiting sites compared to the other varieties (Table 2). No differences in percent seed cotton partitioned to position one or three fruiting sites were observed when data were pooled over glyphosate treatment (Table 2). Jenkins et al. (1990) reported differences in yield partitioning in fruiting positions one and two between early-maturing and full-season varieties. No difference in seed cotton partitioned to vegetative branches was observed due to glyphosate application for any variety (Table 1). However, DP 117 B2RF partitioned less seed cotton in vegetative branches compared to the other varieties when data are pooled over glyphosate treatment (Table 2). No differences were observed among varieties with respect to percent seed cotton located on aborted plants regardless of glyphosate application (Tables 1 and 2).

Seed cotton partitioned in vertical fruiting zones and yield data are displayed in Table 3. No differences in seed cotton partitioning to fruiting zone one, two, or three were observed due to glyphosate application (Table 3). Similar to the findings of Jenkins et al. (1990), DP 143 B2RF and ST 6611 B2RF, the later maturing varieties, partitioned less seed cotton to zone one, compared to the other varieties, regardless of glyphosate treatment (Table 2). In addition, ST 6611 B2RF partitioned less seed cotton

Table 1. Percentage of seed cotton partitioned in horizontal positions, aborted plants, and vegetative branches as affected by glyphosate application.

Variety	Position 1[Z]		Position 2[Y]		Position 3[X]		Vegetative[W]		Aborted[V]	
	Glyphosate Application[U]									
	None	Treated[T]	None	Treated	None	Treated	None	Treated	None	Treated
	(%)									
DP 117 B2RF	74	71	20	19	5	6	2	4	0.2	0.3
DP 143 B2RF	70	71	20	19	5	4	5	5	0.5	0.2
ST 4554 B2RF	72	68	18	18	4	6	6	8	0.0	0.0
ST 6611 B2RF	73	74	16	15	5	4	6	7	0.6	0.6
LSD (0.05)[S]	NSD[R]		NSD		NSD		NSD		NSD	

[Z] Position 1: the percentage of total seed-cotton weight located at position one fruiting sites.
[Y] Position 2: the percentage of total seed-cotton weight located at position two fruiting sites.
[X] Position 3: the percentage of total seed-cotton weight located at position three fruiting sites and beyond.
[W] Vegetative: the percentage of total seed-cotton weight on monopodial (vegetative) branches.
[V] Aborted: the percentage of total seed-cotton weight on aborted plants.
[U] Glyphosate was applied at 0.84 kg ae ha^{-1} as Roundup Weathermax®
[T] Treated indicates applications were applied sequentially at 3, 6, 9, and 12 nodes of growth.
[S] LSD: Least significant difference separated by Fisher's protected LSD at 0.05 level of significance.
[R] NSD: No significant difference among treatments.

Table 2. Percentage of seed cotton partitioned to vertical fruiting positions and horizontal fruiting zones pooled over glyphosate application[Z].

Variety	Aborted[Y]	Vegetative[X]	Position 1[W]	Position 2[V]	Position 3[U]	Zone 1[T]	Zone 2[S]	Zone 3[R]
	------ % ------							
DP 117 B2RF	0.2	3	72	19	5	39	44	13
DP 143 B2RF	0.4	5	71	19	5	30	44	19
ST 4554 B2RF	0.0	7	70	18	5	38	41	14
ST 6611 B2RF	0.6	6	73	15	5	31	40	23
LSD (0.05)[Q]	NSD[P]	2	NSD	2	NSD	4	3	3

[Z] Data were pooled over glyphosate treatment (treated vs. untreated) due to no significant glyphosate application by variety interactions. In treated areas, glyphosate was applied at 0.84 kg ae ha^{-1} as Roundup Weathermax®.

[Y] Aborted: the percentage of total seed-cotton weight on aborted plants.

[X] Vegetative: the percentage of total seed-cotton weight on monopodial (vegetative) branches.

[W] Position 1: the percentage of total seed-cotton weight located at position one fruiting sites.

[V] Position 2: the percentage of total seed-cotton weight located at position two fruiting sites.

[U] Position 3: the percentage of total seed--cotton weight located at position three fruiting sites.

[T] Zone 1: the percentage of total seed-cotton weight located at zone one (nodes 5-8).

[S] Zone 2: the percentage of total seed-cotton weight located at zone two (nodes 9-12).

[R] Zone 3: the percentage of total seed-cotton weight located at zone three (node 12 and above).

[Q] LSD: Least significant difference separated by Fisher's protected LSD at 0.05 level of significance.

[P] NSD: No significant difference among treatments.

Table 3. Percentage of seed cotton partitioned in horizontal zones and total box mapping yields as affected by glyphosate application.

Variety	Zone 1[Z]		Zone 2[Y]		Zone 3[X]		Box Mapping Total Weights[W]		Machine-Harvested Seed Cotton	
	Glyphosate Application[V]									
	None	Treated[U]	None	Treated	None	Treated	None	Treated	None	Treated
	------ (%) ------						------ kg ha^{-1} ------			
DP 117 B2RF	39	40	45	44	14	13	2216	2393	1912	1842
DP 143 B2RF	31	32	44	44	19	20	2262	2447	1920	1883
ST 4554 B2RF	39	37	42	40	13	14	2328	2259	1889	1937
ST 6611 B2RF	33	30	39	41	22	23	2289	2226	1885	1942
LSD (0.05)[T]	NSD[S]		NSD		NSD		NSD		NSD	

[Z] Zone 1: the percentage of total seed-cotton weight located at zone one (nodes 5-8).

[Y] Zone 2: the percentage of total seed-cotton weight located at zone two (nodes 9-12).

[X] Zone 3: the percentage of total seed-cotton weight located at zone three (node 12 and above).

[W] Box Mapping Total Weight (kg/ha).

[V] Glyphosate was applied at 0.84 kg ae ha^{-1} as Roundup Weathermax®.

[U] Treated indicates applications were applied sequentially at 3, 6, 9, and 12 nodes of growth.

[T] LSD: Least significant difference separated by Fisher's protected LSD at 0.05 level of significance.

[S] NSD: No significant difference among treatments

to fruiting zone two compared to DP 117 B2RF (Table 2). DP 117 B2RF and ST 4554 B2RF, earlier maturing varieties, partitioned significantly less seed cotton to zone three compared to the mid-late season varieties (Table 2). Reduced seed cotton partitioned to fruiting zone one in DP 143 B2RF and ST 6611 B2RF was partially compensated for by increased seed cotton partitioned to fruiting zone three in these varieties compared to DP 117 and ST 4554 B2RF. No differences were observed for box mapping total weights or machine-harvested seed cotton yields due to glyphosate application in any variety (Table 3).

Percent seed cotton partitioned in cohorts are displayed in Table 4. No significant difference was observed in percent seed cotton partitioned in cohorts due to glyphosate application for any of the varieties evaluated. Greater percentages of seed cotton were observed in cohorts three through eight with DP117 B2RF and ST 4554 B2RF compared to DP 143 B2RF and ST 6611 B2RF. Lesser amounts of seed cotton partitioned to lower nodes in DP 143 B2RF and ST 6611 B2RF were accompanied by increased seed cotton partitioned to upper nodes in these varieties.

Table 4. Percentage of seed cotton partitioned in cohorts as affected by variety and glyphosate application.

	Variety								
	DP 117 B2RF		DP 143 B2RF		ST 4554 B2RF		ST 6611 B2RF		
	Glyphosate Application[Z]								
Cohort	None	Treated[Y]	None	Treated	None	Treated	None	Treated	LSD[H]
	%								
1[X]	0.71	0.78	0.82	0.59	0.97	1.22	0.93	0.57	NSD[G]
2[W]	1.65	1.80	1.43	1.44	1.78	1.84	1.56	1.08	NSD
3[V]	3.42	3.28	2.54	2.41	3.15	2.82	2.65	3.02	NSD
4[U]	4.33	3.85	2.94	3.39	3.97	3.50	3.43	2.81	NSD
5[T]	4.51	4.28	3.42	3.62	4.39	3.86	3.65	3.68	NSD
6[S]	4.47	3.93	4.14	3.85	3.97	3.79	2.88	3.53	NSD
7[R]	3.85	3.58	3.98	3.72	3.67	3.59	3.32	3.48	NSD
8[Q]	3.55	3.13	3.51	3.70	3.23	2.81	3.05	3.16	NSD
9[P]	2.26	2.29	3.00	2.86	2.33	2.61	2.76	2.88	NSD
10[O]	1.71	1.50	2.18	2.44	1.62	1.86	2.24	2.49	NSD
11[N]	0.79	1.64	1.43	1.69	0.89	1.17	1.77	1.73	NSD
12[M]	0.43	0.45	0.77	0.90	0.42	0.50	1.11	1.18	NSD
13[L]	0.14	0.20	0.31	0.41	0.20	0.16	0.56	0.80	NSD
14[K]	0.44	0.03	0.07	0.08	0.06	0.02	0.23	0.21	NSD
15[J]	0.01	0.01	0.05	0.03	0.02	0.00	0.13	0.13	NSD
16[I]	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.03	NSD

[Z] Glyphosate was applied at 0.84 kg ae ha^{-1} as Roundup Weathermax®.
[Y] Treated indicates applications were applied sequentially at 3, 6, 9, and 12 nodes of growth.
[X] One: percent of total seed-cotton weight of all bolls on node 5 position 1.
[W] Two: percent of total seed-cotton weight of all bolls on node 6 position 1.
[V] Three: percent of total seed-cotton weight of all bolls on node 7 position 1 + node 5 position 2.
[U] Four: percent of total seed-cotton weight of all bolls on node 8 position 1 + node 6 position 2.
[T] Five: percent of total seed-cotton weight of all bolls on node 9 position 1 + node 7 position 2 + node 5 position 3.
[S] Six: percent of total seed-cotton weight of all bolls on node 10 position 1 + node 8 position 2 + node 6 position 3.
[R] Seven: percent of total seed-cotton weight of all bolls on node 11 position 1 + node 9 position 2 + node 7 position 3.
[Q] Eight: percent of total seed-cotton weight of all bolls on node 12 position 1 + node 10 position 2 + node 8 position 3.
[P] Nine: percent of total seed-cotton weight of all bolls on node 13 position 1 + node 11 position 2 + node 9 position 3.
[O] Ten: percent of total seed-cotton weight of all bolls on node 14 position 1 + node 12 position 2 + node 10 position 3.
[N] Eleven: percent of total seed-cotton weight of all bolls on node 15 position 1 + node 13 position 2 + node 11 position 3.
[M] Twelve: percent of total seed-cotton weight of all bolls on node 16 position 1 + node 14 position 2 + node 12 position 3.
[L] Thirteen: percent of total seed-cotton weight of all bolls on node 17 position 1 + node 15 position 2 + node 13 position 3.
[K] Fourteen: percent of total seed-cotton weight of all bolls on node 18 position 1 + node 16 position 2 + node 14 position 3.
[J] Fifteen: percent of total seed-cotton weight of all bolls on node 19 position 1 + node 17 position 2 + node 15 position 3.
[I] Sixteen: percent of total seed-cotton weight of all bolls on node 20 position 1 + node 18 position 2 + node 16 position 3.
[H] LSD: Least significant difference separated by Fisher's protected LSD at the 0.05 level of significance.
[G] NSD: No significant difference among treatments.

These data indicate that all RR Flex varieties evaluated were unaffected by topical glyphosate application. No difference in box mapping total weight was observed between the untreated check and B2RF varieties that received a total of 3.36 kg ae ha^{-1} glyphosate in four treatments. Early-maturing varieties, DP 117 B2RF and ST 4554 B2RF, exhibited slightly greater percent seed cotton partitioned to the lower fruiting nodes with respect to zone and cohort data. Similarly, Jenkins et al. (1990) observed that nodes six to eight were more important to yield in early-maturing varieties. Less seed cotton partitioning on the lower nodes, in mid-late maturing varieties, had correspondingly greater partitioning in upper nodes. These varieties had greater seed cotton partitioned to upper nodes than early-maturing varieties. No total seed cotton yield reductions were observed among any of the four varieties due to the usage of maximum allowable labeled rates of topical glyphosate. These data indicate that the four varieties tested were not affected by glyphosate application timing and could provide producers with an alternative to traditional RR cropping systems. Furthermore, these data indicate that the fruiting characteristics commonly associated with early- and later- maturing varieties were unaffected by glyphosate application and are in agreement with the findings of Jenkins et al. (1990).

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