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Glyphosate-Resistant Cotton Response to Glyphosate Applied in Irrigated and Nonirrigated Conditions

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Field experiments were conducted in Alabama during 1999 and 2000 to test the hypothesis that any glyphosate-induced yield suppression in glyphosate-resistant cotton would be less with irrigation than without irrigation. Yield compensation was monitored by observing alterations in plant growth and fruiting patterns. Glyphosate treatments included a nontreated control, 1.12 kg ai/ha applied POST at the 4-leaf stage, 1.12 kg/ha applied DIR at the prebloom stage, and 1.12 kg/ha applied POST at 4-leaf and postemergence directed (DIR) at the prebloom cotton stages. The second variable, irrigation treatment, was established by irrigating plots individually with overhead sprinklers or maintaining them under dryland, nonirrigated conditions. Cotton yield and all measured parameters including lint quality were positively affected by irrigation. Irrigation increased yield 52% compared to nonirrigated cotton. Yield and fiber quality effects were independent of glyphosate treatments. Neither yield nor any of the measured variables that reflected whole plant response were influenced by glyphosate treatment or by a glyphosate by irrigation interaction.

Nomenclature: Glyphosate; cotton, *Gossypium hirsutum* L. 'Delta and Pine Land 458 BGRR'.

Key words: Environmental stress, glyphosate-resistant cotton, herbicide-tolerant cotton, irrigation, water stress.

Since the introduction of glyphosate-resistant cotton in 1996, the adoption rate by producers has been overwhelming. During the first four years of commercialization, utilization of the glyphosate-resistant system increased to just over 15% of the total cotton hectareage in the United States (Kalaitzandonakes and Suntornpithug 2001). In 2005, glyphosate was applied to 71% of the planted cotton hectareage in cotton-producing regions (NASS 2006). Production systems utilizing herbicide-resistant technology in cotton have proven to be less labor intensive than conventional systems and provide consistent weed control. As a result, the extensive use of glyphosate with many row crops has resulted in the replacement and reduction in the use of traditional herbicides (Shaner 2000). Crop injury, weed control, and net return results using these new systems have generally been positive and, in some cases, superior to those of conventional systems (Culpepper and York 1998; Faircloth et al. 2001; Murdock and Sherrick 2000).

It has been shown that the uptake and translocation of many herbicides can be affected by growth stage as well as relative humidity, soil moisture, temperature, and mixture with other herbicides and surfactants (Gaskin and Holloway 1992; Pline et al. 2001a; Reddy 2000; Reddy et al. 1990; Sherrick et al. 1986; Waldecker and Wyse 1985; Wills 1978). Postemergence over-the-top broadcast applications of glyphosate that occur after the fourth true leaf of cotton growth can result in lower yields and are not permitted by registration directions (Edenfield et al. 2000; Light et al. 2003; Pline-Srnic et al. 2004; Viator et al. 2000). Glyphosate-resistant cotton is sometimes adversely affected by glyphosate applications when applied according to registration directions (Brown and Bednarz 1998), although the effect can be inconsistent even when applied over the crop canopy later in the season (Blackely et al. 1999; Viator et al. 2004). Late postemergence glyphosate applications also can result in a redistribution of fruit to the upper sympodial branches on the plant due to pollen reduction without an overall yield effect (File et al. 2000; Jones and Snipes 1999; Pline et al. 2001b, 2002). Redistribution of bolls from the lower to upper sympodial branches without yield reductions might be an indication that growing conditions were favorable during the season to allow crop compensation (File et al. 2000; Yasuor et al. 2000) or that glyphosate absorption was insufficient to affect yield (Ahmadi et al. 1980).

We hypothesized that under irrigation, yield-compensating alterations in the fruiting pattern might serve to minimize or alleviate potential glyphosate-induced yield suppression. The occurrence of any such yield compensation would be evident by a lack of any glyphosate-induced yield suppression, combined with significant alterations in fruiting pattern. Because some data suggest that current glyphosate application practices might affect yield, our objective was to determine to what extent registered glyphosate applications affected cotton growth, yield, and fiber quality and whether or not yield-compensating alterations would occur with irrigation.

Materials and Methods

Field experiments were conducted to evaluate the response of glyphosate-resistant cotton to glyphosate applied under irrigated and nonirrigated conditions in a conventional tillage production system. Experiments were conducted in 1999 and 2000 at the Tennessee Valley Research and Extension Center located near Belle Mina, AL. Soil type is a Decatur silt loam (Plinthic Paleudults) with 1.0% organic matter and pH 6.1. Experimental areas were limed and fertilized according to soil

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Table 1. Glyphosate treatments for cotton study, 1999–2000.[a]

Glyphosate treatment	Rate	Cotton stage	Application[b]	Application date 1999	Application date 2000
	kg ai/ha				
Nontreated[c]					
Glyphosate	1.12	4-leaf	POST	May 25	May 24
Glyphosate	1.12	prebloom	DIR	June 18	June 21
Glyphosate	1.12	4-leaf and prebloom	POST, DIR		

[a] Treatments were in a 2 by 4 factorial design arranged in a completely randomized order.

[b] Abbreviations: DIR, postemergence directed; POST, postemergence over the top of the crop canopy.

tests, and insect control and defoliation were performed according to Alabama Cooperative Extension System recommendations. The test area was maintained weed-free for the duration of the study using trifluralin, 0.56 kg ai/ha PPI; fluometuron, 2.2 kg ai/ha plus pyrithiobac, 0.07 kg ai/ha PRE; and cultivation. 'Deltapine 458RR' cotton was planted on April 19 and 24 in 1999 and 2000, respectively. Mepiquat chloride (25 g ai/ha) was applied each year at first bloom.

Experimental plots were eight, 97-cm rows by 16 m long in a completely randomized experimental design with four replications. Treatments consisted of a factorial arrangement of four glyphosate treatments with and without irrigation. The four glyphosate treatments were: nontreated, 1.12 kg/ha applied POST at the 4-leaf stage, 1.12 kg/ha applied postemergence directed (DIR) at the prebloom cotton stage, and 1.12 kg/ha applied POST at 4-leaf and DIR at the prebloom stage (Table 1). Herbicide treatments were applied in a water carrier at a rate of 94 L/ha to the entire plot area using a tractor-mounted sprayer. In 1999 and 2000, glyphosate applications were made within two to four days following rainfall or irrigation events of at least 0.64 cm. The irrigation variable was addressed by irrigating plots individually with overhead sprinklers or by maintaining them under dryland, nonirrigated conditions. Irrigation scheduling was based on evapotranspiration rate as determined by an on-site weather station (Table 2).

Prior to defoliation and harvest each year, the number of open and closed bolls was recorded from two, 2.6-m sections in adjacent rows from the center of each plot. Boll counts were recorded when the most mature treatments reached 65% open. After defoliation and prior to harvest, first- and second-position bolls were hand-harvested from 15 consecutive plants from two adjacent rows (rows 6 and 7) in each plot (30 plants total). Bolls from each fruiting node were kept separate for further processing, and number of hard-locked bolls and seed cotton yields were recorded. The 30-boll samples were ginned on a 10-saw experimental gin, and lint yield, fiber quality, seed number, and seed index recorded. Plant mapping was conducted after defoliation and prior to machine-harvest according to the procedures described by Bourland and Watson (1990). Ten plants from each plot were mapped to obtain internode length, plant height, number of reproductive nodes/plant, percent boll retention on the first and second fruiting positions, and boll retention on nodes 6 to 10 and nodes 11 to 15. Cotton was machine-harvested from 4 rows in each plot (rows 2, 3, 6, and 7) and seed cotton yield recorded on October 4 and September 18 in 1999 and 2000, respectively.

All data were subjected to ANOVA using SAS.[1] In the first step, data for every response variable for which no significant treatment-by-year interaction was detected ($P \geq 0.05$) were pooled over years. Subsequently, data for irrigated and nonirrigated comparisons were partitioned and subjected to separate ANOVA. We hypothesized that under irrigation, yield-compensating alterations in the fruiting pattern would be better able to alleviate any glyphosate-induced yield suppression or significant alterations in fruiting pattern compared to nonirrigated cotton. Our experimental objective was best served by comparing irrigated and nonirrigated cotton, and the occurrence of any glyphosate compensation would be evident by a lack of any glyphosate-induced yield suppression, combined induced differences in yield, and associated yield

Table 2. Monthly irrigation and rainfall amounts.[a]

Month	1999 Irrigation	1999 Rainfall	2000 Irrigation	2000 Rainfall
	cm		cm	
April	0	4.0	0	1.3
May	0	11.9	2.4	1.9
June	0	16.6	9.6	8.0
July	7.6	9.3	25.5	4.5
August	7.0	0	2.9	3.4
Total recorded	14.6	41.8	40.4	19.1

[a] Irrigation and rainfall from seed emergence in late April through mid-August (late bloom) both years. The 30-yr long-term average rainfall for this area of the state is 50.0 cm.

Table 3. Plant growth, fiber quality, and yield of glyphosate-tolerant cotton as influenced by irrigation, glyphosate regime, and corresponding interactions. NS is not significant.

Response variables	Irrigation (IRR)	Glyphosate (GLY)	IRR by GLY interaction	Irrigation main effect	
				With	Without
Plant growth					
Internode length (cm)	< 0.01	NS	NS	4.8	3.9
Plant height (cm)	< 0.01	NS	NS	109	71
Reproductive node (no./plant)	< 0.01	NS	NS	19	16
Boll retention by node (%)					
First fruiting position	< 0.01	NS	NS	55	47
Second fruiting position	< 0.01	NS	NS	28	14
6 to 10; 1999[a]	< 0.01	NS	NS	39	46
6 to 10; 2000[a]	< 0.01	NS	NS	60	44
11 to 15, 1999[a]	< 0.01	NS	NS	44	32
11 to 15, 2000[a]	< 0.01	NS	NS	42	16
Fiber quality					
Micronaire (unit)	NS	NS	NS	4.1	
Fiber length (cm)	< 0.01	NS	NS	2.84	2.67
Fiber strength (g/tex)	< 0.01	NS	NS	30.2	27.8
Open bolls (%)	< 0.01	NS	NS	17	65
Seed cotton yield (kg/ha)	< 0.01	NS	NS	3,880	1,850

[a] Significant year effect.

parameters. For response variables where glyphosate treatment had no effect, the main effect means were compared between the irrigated and nonirrigated main effects.

Results and Discussion

Cotton Injury. Cotton exhibited no visual injury due to glyphosate application in either 1999 or 2000, regardless of irrigation regime (data not presented).

Plant Growth and Boll Retention. Internode length, plant height, number of reproductive nodes/plant, boll retention on the first and second fruiting positions, and micronaire data were pooled due to absence of year interactions or glyphosate effects (Table 3). Internode length and plant height, both measurements of plant growth, were positively increased with irrigation (Table 3). Marois et al. (2004) indicated that environment (in our study rainfall and irrigation), can play a major role in structural development in cotton and can affect vegetative and fruit development.

Factors known to reduce boll retention in cotton include insect damage (Cook and Kennedy 2000; Sadras 1995), water stress (Guinn et al. 1981), increased plant population (Bednarz et al. 2000; Vories and Glover 2006), and excessive shading (Guinn 1982). In our study, there were year and irrigation effects on boll retention on the lower (nodes grouped 6 through 10) and upper (nodes grouped 11 through 15) fruiting regions. Because there was no glyphosate effect, these data were pooled and results presented separately by year (Table 3). In 1999, boll retention in the lower region was higher (46%) in nonirrigated cotton when compared to irrigated cotton (39%); whereas boll retention was shifted to the upper fruiting region in irrigated cotton. There was no rainfall received during the fruit-set period in August 1999, preventing late-season compensation by nonirrigated cotton. In 2000, boll retention was higher in both lower and upper fruiting regions in irrigated cotton compared to nonirrigated cotton. Cotton was more dependent upon irrigation earlier in the season for maintaining growth and fruit development the second year due to lower rainfall amounts received the first three months (Table 2). The timing of irrigation or rainfall events in relation to the bloom and boll development periods in cotton is critical for beneficial effect (Pettigrew 2004a, 2004b). In our study, the total amount of water received was not greatly different between nonirrigated and irrigated treatments in 1999; however, most of the rainfall received occurred prior to the full bloom and boll development periods in July and August.

Fiber Quality, Boll Maturity, and Seed Cotton Yield. Micronaire averaged 4.1 and was not affected by any treatment regardless of year (Table 3). Because fiber length and strength were not affected over years or by glyphosate treatment, these data were pooled. Irrigation resulted in longer fiber measurements in irrigated cotton (2.84 cm) compared to nonirrigated cotton (2.67 cm). Strength also was positively affected by irrigation (30.2 grams-force/[g/km fiber {tex}]) relative to nonirrigated cotton (27.8 g/tex). In a review of the literature, Bradow and Davidonis (2000) explain how much of the fiber quality characteristics in cotton are dependent upon the inherent genetics of the individual variety (Meredith and Bridge 1972). However, environmental factors, including rainfall and irrigation enable the plant to express its genetic potential. In our trial, sufficient water in the irrigated plots provided a more favorable environment for the development of the fiber and thus improved fiber length and strength. The positive effect of irrigation on fiber length is not unusual to our study (Pettigrew 2004a)

Boll maturity (open and closed boll counts) and seed cotton yield data were pooled over years and glyphosate treatment due to absence of interaction and effect. Irrigation resulted in later overall boll maturity when compared to the nonirrigated plots (Table 3). Pettigrew (2004a) also found that irrigation delayed cutout and increased overall yield when compared to

Table 4. Plant distribution of yield components on glyphosate-tolerant cotton as influenced by irrigation, glyphosate regime, and corresponding interactions. NS is not significant.

Response variables	Irrigation (IRR)	Glyphosate (GLY)	IRR by GLY interaction	Irrigation main effect	
				With	Without
Total number of bolls (no./30 plants)					
Nodes 7 to 11[a]	NS	NS	NS	24.3	
Node 12[a]	< 0.01	NS	NS	21.9	16.6
Node 13; 1999	< 0.01	NS	NS	26.9	10.8
Node 13; 2000	NS	NS	NS	17.6	
Node 14; 1999	< 0.01	NS	NS	30.3	15.4
Node 14; 2000	NS	NS	NS	14.7	
Hardlock boll incidence (no./30 plants)					
Nodes 7 to 9[a]	< 0.01	NS	NS	8.1	14.2
Node 10; 1999	< 0.01	NS	NS	4.7	17.5
Node 10; 2000	NS	NS	NS	8.1	
Node 11; 1999	< 0.01	NS	NS	5.0	20.9
Node 11; 2000	NS	NS	NS	7.5	
Node 12; 1999	< 0.01	NS	NS	3.0	22.5
Node 12; 2000	NS	NS	NS	9.7	
Node 13[a]	< 0.01	NS	NS	10.2	17.9
Lint turnout (%)					
Nodes 7 to 13; 1999	< 0.01	NS	NS	40.9	33.6
Node 7; 2000	NS	0.02	< 0.01	See Table 6	
Node 8; 2000	NS	NS	0.04	See Table 6	
Node 9; 2000	NS	0.03	0.02	See Table 6	
Node 10; 2000	NS	< 0.01	0.03	See Table 6	
Node 11; 2000	NS	NS	NS	42.0	
Node 12; 2000	NS	NS	0.01	See Table 6	
Node 13; 2000	NS	NS	NS	42.5	

[a] No significant year effect.

nonirrigated cotton in the southeastern United States. There are many stresses including moisture deficit that can cause cotton to cutout and open earlier than cotton that does not experience the same stresses (Oosterhuis et al. 1993; Patterson et al. 1978; Stringer et al. 1989). Irrigation resulted in higher seed cotton yields with 3,880 kg/ha recorded in irrigated plots relative to 1,850 kg/ha in nonirrigated cotton.

Yield Distribution and Turnout. Glyphosate application had no effect on overall yield potential in our study when number of reproductive nodes/plant, fruit retention, total bolls/node, boll weights, and hardlock boll incidence were considered. Bednarz and Roberts (2001) showed that cotton under stress might not be able to compensate for early-season bud or fruit loss. Likewise, first position boll size and weight might also be affected as plants attempt to compensate by setting fruit on more distal positions. In our study, yield potential was higher using irrigation as reflected by an increase of 3 reproductive nodes/plant and higher fruit retention at the first and second fruiting positions (Table 3). Similar trends were noted when the total number of bolls/node and boll weight at each node were considered (Tables 4 and 5). Irrigation resulted in a similar or higher number of total bolls at each node compared to nonirrigated cotton (Table 4). When boll weight at each node in irrigated cotton was considered, it was either higher (nodes 8 to 11 combined; 12 and 13, 1999) or equal to those recorded in nonirrigated cotton (nodes 12 and 13, 2000; Table 5). Likewise, the general incidence of hardlocked bolls in nonirrigated cotton was higher relative to irrigated cotton, again resulting in a general decrease in overall yield (Table 4).

Lint turnout (by node) for the 30 plant samples was affected differently each year; therefore, these data are presented separately by year (Tables 4 and 6). In 1999, there was no effect of glyphosate treatment, and lint turnout was higher in irrigated (40.9%) compared to nonirrigated cotton (33.6%; Table 4). Lint turnout was not presented for nodes higher than thirteen due to lack of adequate data from the upper fruiting regions. Our positive results with irrigation are in agreement with those presented by Balkcom et al. (2006) and Campbell and Bauer (2006) using several different varietal lines of cotton. However, Campbell and Bauer (2006) indicated that irrigation can affect varieties differently and suggested that they must be tested individually for accurate placement in production situations.

Lint turnout in 2000 was affected by an irrigation by glyphosate interaction on nodes 7, 8, 9, 10, and 12 (Table 4). The general trend indicated a slightly higher lint turnout in nontreated cotton compared to cotton treated with glyphosate; however, most comparisons made were not statistically significant and were above 40%. The exception was in cotton treated with glyphosate directed prebloom (nonirrigated) or postemergence at the 4-leaf stage (irrigated; Table 6) where turnout was 39%.

Seed characteristics. An important consideration when evaluating glyphosate effect on the reproductive development of cotton is seed index (Horak et al. 2007). In our study, seed index (g/100 seed) was not affected by glyphosate treatment at nodes 7 through 9, regardless of year (Table 5). Irrigation resulted in heavier seeds as reflected by a higher seed index at these nodes. There was a year effect at nodes 10, 11, 12, and

Table 5. Boll weight, seed index, and seed count on glyphosate-tolerant cotton as influenced by irrigation, glyphosate regime, and corresponding interactions. NS is not significant.

				Irrigation main effect	
Response variables	Irrigation (IRR)	Glyphosate (GLY)	IRR by GLY interaction	With	Without
Boll weight (g/boll)					
Node 7[a]	NS	NS	NS	4.2	
Nodes 8 to 11[a]	< 0.01	NS	NS	4.6	3.6
Node 12; 1999	< 0.01	NS	NS	4.7	3.5
Node 12; 2000	NS	NS	NS	4.4	
Node 13; 1999	< 0.01	NS	NS	4.4	3.3
Node 13; 2000	NS	NS	NS	4.3	
Seed index (g/100 seeds)					
Nodes 7 to 9[a]	< 0.01	NS	NS	8.9	8.5
Node 10; 1999	< 0.01	NS	NS	8.6	7.4
Node 10; 2000	NS	NS	NS	8.9	
Node 11; 1999	< 0.01	NS	NS	8.6	7.4
Node 11; 2000	NS	NS	NS	8.7	
Node 12; 1999	< 0.01	NS	NS	8.7	7.2
Node 12; 2000	NS	NS	NS	8.5	
Node 13; 1999	< 0.01	NS	NS	See Table 6	
Node 13; 2000	NS	NS	NS	8.3	
Seed count (no./30 plants)					
Nodes 7 to 11[a]	NS	NS	NS	724	
Node 12[a]	< 0.01	NS	NS	694	500
Node 13[a]	< 0.01	NS	NS	740	400

[a] No significant year effect.

13; therefore, these data are presented separately by year. There was no effect of glyphosate treatment on seed index at nodes 10, 11, or 12 in 1999; therefore, these data were pooled. Irrigation again resulted in heavier seeds at these nodes (1999) but had no effect on seed index at these same nodes (including node 13) in 2000 (Table 5). There were irrigation and glyphosate main effects found for seed index on node 13 in 1999. Irrigation resulted in higher seed index at node 13; however, seed index was lower (compared to nontreated cotton) where glyphosate was applied DIR in a single application (Table 6). This was not observed in cotton treated with glyphosate applied POST or POST plus DIR.

Seed counts (total number/30 plants at each node) were not affected by glyphosate treatment, regardless of year; therefore, these data were pooled. Seed counts were higher in irrigated cotton at nodes 12 and 13 but were not different at the lower nodes (Table 5).

As expected, cotton yield and all the measured parameters that contributed to both yield and lint quality were positively affected by irrigation. Nonirrigated cotton yielded 52% less than irrigated. Neither yield nor any of the measured variables

Table 6. Glyphosate application effect on cotton seed and yield parameters, 1999–2000.[a]

				2000 Lint turnout				
				Node				
Irrigation	Glyphosate application[b]	Cotton stage	1999 Seed weight Node 13[c]	7	8	9	10	12
			g/100 seed	%				
None	Nontreated			42.4	42.3	42.8	43	42.8
	POST	4-leaf		41.2	42	41.8	42	42.7
	DIR	prebloom		39.4	40.5	40.8	40.9	40.3
	POST, DIR	4-leaf and prebloom		40.2	40.7	40.7	40.3	41.9
	Mean			40.8	41.4	41.5	41.6	41.9
Irrigated	Nontreated		7.7	42.3	42.1	43	44.5	41.8
	POST	4-leaf	7.7	36.7	38	39.4	40	40.8
	DIR	prebloom	7.3	41.8	41.9	42.3	42.1	42.8
	POST, DIR	4-leaf and prebloom	7.9	41.7	42	42.6	42.3	43.3
	Mean			40.6	41	41.8	42.2	42.2
	LSD (0.05)		0.4	2.6	2.9	2.1	2	2

[a] Data presented by irrigation and application treatment due to presence of an interaction.

[b] Abbreviations: DIR, postemergence directed; POST, postemergence over the top of the crop canopy.

[c] Data were pooled over irrigation treatments.

that reflected the whole plant response were influenced by glyphosate applied according to registration directions or by a glyphosate by irrigation interaction. However, Pline-Srnic et al. (2004) reported that nonregistered applications of glyphosate applied over the top can result in boll abscission and reduced yield. Pline et al. (2003) found that water stress and glyphosate applications caused the abortion of young bolls. Although it has been shown that cotton has the ability to compensate for fruit loss due to late post-emergence glyphosate applications by setting bolls higher on the plant (Yasuor et al. 2000), we found only a few isolated cases (i.e., those that reflected response at individual plant nodes) where the response was influenced by either glyphosate or a glyphosate by irrigation interaction. These responses were not replicated over time. Therefore, although it has been shown that irrigation can markedly influence cotton plant structure, plant growth, yield, and lint quality (Pettigrew 2004b), these responses were independent of glyphosate applications. In our study, cotton without irrigation was not disadvantaged in its ability to deal with glyphosate when compared to irrigated cotton. Thus, our original hypothesis that any glyphosate-induced yield suppression would be influenced by irrigation is proven false.

Sources of Materials

[1] SAS version 9.0, Statistical Analysis Systems Institute, Cary, NC 27513.

Literature Cited

Ahmadi, M. S., L. C. Haderlie, and G. A. Wicks. 1980. Effect of growth stage and water stress on barnyardgrass (*Echinochloa crus-galli*) control and on glyphosate absorption and translocation. Weed Sci. 28:277–282.

Balkcom, K. S., D. W. Reeves, J. N. Shaw, C. H. Burmester, and L. M. Curtis. 2006. Cotton yield and fiber quality from irrigated tillage systems in the Tennessee Valley. Agron. J. 98:596–602.

Bednarz, C. W., D. C. Bridges, and S. M. Brown. 2000. Analysis of cotton yield stability across population densities. Agron. J. 92:128–135.

Bednarz, C. W. and P. M. Roberts. 2001. Spatial yield distribution in cotton following early-season floral bud removal. Crop Sci. 41:1800–1808.

Blackley, R. H., D. B. Reynolds, C. D. Rowland, Jr., and S. L. File. 1999. Roundup Ready cotton tolerance to topical applications of Roundup Ultra. Proc. South. Weed Sci. Soc. 1999:252–253.

Bradow, J. M. and G. H. Davidonis. 2000. Quantification of fiber quality and the cotton production–processing interface: a physiologist's perspective. J. Cotton Sci. 4:34–64.

Brown, S. M. and C. W. Bednarz. 1998. Tolerance of Roundup Ready® cotton to mid- and late-post application of Roundup. Pages 849–850 *in* Proceedings of the Beltwide Cotton Conference. San Diego, CA.

Bourland, F. M. and C. E. Watson. 1990. COTMAP, a technique for evaluating structure and yield of cotton plants. Crop Sci. 30:224–226.

Campbell, B. T. and P. J. Bauer. 2006. Investigating variability for genotype response to supplemental irrigation in cotton [abstract]. ASA–CSSA–SSSA 2006 International Meetings, November 12–16, 2006, Indianapolis, IN.

Cook, D. R. and C. W. Kennedy. 2000. Early flower bud loss and mepiquat chloride effects on cotton yield distribution. Crop Sci. 40:1678–1684.

Culpepper, A. S. and A. C. York. 1998. Weed management in glyphosate-tolerant cotton. J. Cotton Sci. 2:174–185.

Edenfield, M. W., B. J. Brecke, D. L. Colvin, and D. G. Shilling. 2000. The effect of glyphosate (Roundup) application timing on weed control and boll development in glyphosate-tolerant (Roundup Ready®) cotton. Pages 1478–1479 *in* Proceedings of the Beltwide Cotton Conference. San Antonio, TX.

Faircloth, W. H., M. G. Patterson, C. D. Monks, and W. R. Goodman. 2001. Weed management programs for glyphosate-tolerant cotton (*Gossypium hirsutum*). Weed Technol. 15:544–551.

File, S. L., D. B. Reynolds, K. N. Reddy, and J. C. Arnold. 2000. Field and laboratory tolerance of Roundup Ready® cotton to glyphosate. Pages 608–609 *in* Proceedings of the Beltwide Cotton Conference. San Antonio, TX.

Gaskin, R. E. and P. J. Holloway. 1992. Some physicochemical factors influencing foliar uptake enhancement of glyphosate-mono(isopropylammonium) by polyoxyethylene surfactants. Pesticide Sci. 34:195–206.

Guinn, G. 1998. Causes of square and boll shedding. Pages 1355–1364 *in* Proceedings of the Beltwide Cotton Conference. San Diego, CA.

Guinn, G., J. R. Mauney, and K. E. Fry. 1981. Irrigation scheduling and plant population effects on growth, bloom rates, boll abscission, and yield of cotton. Agron. J. 73:529–534.

Horak, M. J., E. W. Rosenbaum, and C. L. Woodrum, et al. 2007. Characterization of Roundup Ready Flex Cotton, 'MON 88913', for use in ecological risk assessment: evaluation of seed germination, vegetative and reproductive growth, and ecological interactions. Crop Sci. 47:268–277.

Jones, M. A. and C. E. Snipes. 1999. Tolerance of transgenic cotton to topical applications of glyphosate. J. Cotton Sci. 3:19–26.

Kalaitzandonakes, N. G. and P. Suntornpithug. 2001. Why do farmers adopt biotech cotton? Pages 179–183 *in* Proceedings of the Beltwide Cotton Conference. Anaheim, CA.

Light, G. G., T. A. Baughman, P. A. Dotray, J. W. Keeling, and D. B. Wester. 2003. Yield of glyphosate-tolerant cotton as affected by topical glyphosate applications on the Texas high plains and rolling plains. J. Cotton Sci. 7:231–235.

Marois, J. J., D. L. Wright, P. J. Wiatrak, and M. A. Vargas. 2004. Effect of row width and nitrogen on cotton morphology and canopy microclimate. Crop Sci. 44:870–877.

Meredith, W. R., Jr. and R. R. Bridge. 1972. Heterosis and gene action in cotton, *Gossypium hirsutum* L. Crop Sci 12:304–310.

Murdock, E. C. and S. L. Sherrick. 2000. Tolerance of Roundup Ready® (glyphosate-tolerant) cotton to postemergence and postemergence-directed applications of Roundup Ultra (glyphosate). Page 1477 *in* Proceedings of the Beltwide Cotton Conference. San Antonio, TX.

NASS. 2006. Agricultural chemical usage 2005 field crops summary. http://usda.mannlib.cornell.edu/usda/nass/AgriChemUsFC//2000s/2006/AgriChemUsFC-05-17-2006.pdf. Accessed: January 18, 2007.

Oosterhuis, D. M., F. M. Bourland, N. P. Tugwell, and M. J. Cochran. 1993. Terminology and concepts related to crop monitoring, maturity, and defoliation. Pages 239–249 *in* D. M. Oosterhuis, ed. Proceedings of the 1993 Cotton Research Meeting. Fayetteville, AR: University of Arkansas, Arkansas Agricultural Experiment Station Special Report 162.

Patterson, L. L., D. R. Buxton, and R. E. Briggs. 1978. Fruiting in cotton as affected by controlled boll set. Agron. J. 70:118–122.

Pettigrew, W. T. 2004a. Moisture deficit effects on cotton lint yield, yield components, and boll distribution. Agron. J. 96:377–383.

Pettigrew, W. T. 2004b. Physiological consequences of moisture deficit stress in cotton. Crop Sci. 44:1265–1272.

Pline, W., K. Edmisten, J. Wilcut, and R. Wells. 2001b. Effect of glyphosate (Roundup Ultra®) on pollen viability and pollination in Roundup Ready® cotton. Pages 446–447 *in* Proceedings of the Beltwide Cotton Conference. Memphis, TN.

Pline, W. A., R. Viator, J. W. Wilcut, K. L. Edmisten, J. Thomas, and R. Wells. 2002. Reproductive abnormalities in glyphosate-resistant cotton caused by lower CP4-EPSPS levels in the male reproductive tissue. J. Cotton Sci. 50:438–447.

Pline, W. A., R. Wells, G. Little, K. L. Edmisten, and J. W. Wilcut. 2003. Glyphosate and water stress effects on fruiting and carbohydrates in glyphosate-resistant cotton. J. Cotton Sci. 43:879–885.

Pline, W. A., J. W. Wilcut, K. L. Edmisten, and R. Wells. 2001a. Absorption and translocation of glyphosate in glyphosate-resistant cotton as influenced by application method and growth stage. Weed Sci. 49:460–467.

Pline-Srnic, W. A., K. L. Edmisten, J. W. Wilcut, R. Wells, and J. L. Thomas. 2004. Effect of glyphosate on fruit retention, yield, and fiber quality of glyphosate resistant cotton. J. Cotton Sci. 8:1.

Reddy, K. N. 2000. Factors affecting toxicity, absorption, and translocation of glyphosate in redvine (*Brunnichia ovata*). Weed Technol. 14:457–462.

Reddy, V. R., D. N. Baker, F. D. Whisler, and J. M. McKinion. 1990. Analysis of the effects of herbicides on cotton yield trends. Agricultural Systems 33:347–359.

Sadras, V. O. 1995. Compensatory growth in cotton after loss of reproductive organs. Field Crops Res. 40:1–18.

Shaner, D. L. 2000. The impact of glyphosate-tolerant crops on the use of other herbicides and on resistance management. Pesticide Management Sci. 56:320–326.

Sherrick, S. L., H. A. Holt, and F. D. Hess. 1986. Effects of adjuvants and environment during plant development on glyphosate absorption and translocation in field bindweed (*Convolvulus arvensis*). Weed Sci. 34:811–816

Stringer, S. J., V. D. Wells, N. P. Tugwell, J. R. Phillips, M. J. Cochran, and F. L. Carter. 1989. Evaluation of uppermost white bloom node interval and heat unit accumulation for crop termination timing. Pages 233–238 *in* J. M. Brown, ed. Proceedings of the Beltwide Cotton Producers Research Conference, Nashville, TN. January 2–7, 1989. Menphis, TN: National Cotton Council.

Viator, R. P., S. M. Underbrink, P. H. Jost, T. K. Witten, and J. T. Cothren. 2000. Factors affecting Roundup Ready® cotton fruit retention and yields. Pages 689–691 *in* Proceedings of the Beltwide Cotton Conference. San Antonio, TX.

Victor, R. P., P. H. Jost, S. A. Senseman, and J. T. Cothren. 2004. Effect of glyphosate application timing and methods on glyphosate-resistant cotton. Weed Sci. 52:147–151.

Vories, E. D. and R. E. Glover. 2006. Comparison of growth and yield components of conventional and ultra-narrow row cotton. J. Cotton Sci. 10:235–243.

Waldecker, M. A. and D. L. Wyse. 1985. Soil moisture effects on glyphosate absorption and translocation in common milkweed (*Asclepias syriaca*). Weed Sci. 33:299–305.

Wills, G. D. 1978. Factors affecting toxicity and translocation of glyphosate in cotton (*Gossypium hirsutum*). Weed Sci. 26:509–513.

Yasuor, H., M. Sibony, B. Rubin, M. Litvak, K. Negba, I. Flash, and E. Gat. 2000. Influence of glyphosate (Roundup Ultra®) rate and time of application on weed control and performance of DP5415RR cotton in Israel: field and laboratory experiments. Pages 1480–1483 *in* Proceedings of the Beltwide Cotton Conference 2. San Antonio, TX.

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