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WEED SCIENCE

Response of Glyphosate-resistant Cotton to Pre-harvest Glyphosate Application

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ABSTRACT

Growers of glyphosate-resistant (GR) cotton (*Gossypium hirsutum* L.) often apply glyphosate postemergence over-the-top (POST) late in the season to control escaped weeds and to increase harvesting efficiency. Labels for glyphosate products currently permit such applications only after the 20% cracked-boll stage, which is later than most growers want to apply the glyphosate. An experiment was conducted eight times in Georgia, Louisiana, and North Carolina during 2000 and 2001 to determine the effect of glyphosate applied pre-harvest prior to the 20% cracked-boll stage on fruit set and retention and yield of GR cotton. Glyphosate isopropylamine salt at 840 g acid equivalent (a.e.) ha^{-1} was applied POST 7 d prior to an arbitrarily determined last effective bloom date (LEBD) or 0, 7, 14, or 21 d after the LEBD. The final application generally corresponded to the 20% cracked-boll stage. Cotton was box-mapped for fruit distribution and yield prior to mechanical harvest. No differences among treatments were detected by box mapping. Treatments containing glyphosate produced yields similar to the non-treated control, but application 7 d before or 0 or 7 d after the LEBD reduced yield compared with application 21 d after the LEBD. These results indicate that pre-harvest glyphosate application should be delayed until 14 d after the LEBD.

Cotton growers have readily adopted the planting GR cultivars (USDA-AMS, 2003). This technology allows for excellent weed control, greater convenience in weed management, greater flexibility in crop rotation, and net returns comparable to conventional weed management systems (Culpepper and York, 1998; 1999).

Labels for glyphosate products currently restrict POST application to GR cotton through the four-leaf stage of crop development (Anonymous, 2004a; 2004b). After this developmental stage, application is restricted to postemergence-directed sprays to minimize glyphosate contact with leaf and stem tissue. These label restrictions are thought to be related to the potential for fruit loss following application during reproductive development.

Studies have addressed the impact of glyphosate on early season fruiting patterns of GR cotton. Glyphosate applied POST after the four-leaf stage often causes boll abortion on the lower sympodia (Jones and Snipes, 1999; Pline-Srnic et al., 2004). This boll abortion has been attributed to reduced pollen viability and deposition on the stigma (Pline et al., 2002; 2002b). The impact on cotton yield from glyphosate applied POST after the four-leaf stage has been variable (Jones and Snipes, 1999; Kalahar and Coble, 1998; Light et al., 2003; Pline-Srnic et al., 2004; Reynolds et al., 1999). Cotton can compensate for early season fruit loss by setting more bolls on higher sympodia and at positions more distal to the main stem (Jones et al., 1996). Early season fruit loss will delay crop maturity, but the impact on yield depends upon whether growing conditions are conducive for maturity of the later-set bolls.

In situations where weeds are present late in the season, growers like to apply glyphosate POST prior to defoliation of GR cotton to increase harvest efficiency. Labels for glyphosate products currently allow for late-season POST application only after the 20% cracked-boll stage (Anonymous, 2004a; 2004b). Growers are familiar with the concept of a LEBD (last effective bloom date), which can be defined as the last day on which a flower has a greater than 50% chance of maturing into a harvestable boll and have been educated about the adverse effects of glyphosate on cotton fruiting occur in the early stages of square development. Extension personnel are increasingly being asked if glyphosate applied POST after the LEBD but prior to the 20% cracked-

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boll stage adversely affects GR cotton. Research that addresses this question has not been reported.

The number of cotton fruiting structures is positively correlated with the amount of lint produced (Wells and Meredith, 1984; Heitholt, 1993). Boll production and seed cotton weight per boll typically decline as main-stem node and fruiting position increase (Jenkins et al., 1990), so the relative value of each fruiting position is less as fruiting progresses up and out on the plant. Jenkins et al. (1990) reported that the greatest portion of yield occurs on main-stem nodes nine through 16, with nodes higher than 16 contributing little to overall yield. This suggests fruit abortion at these upper positions, as might be expected from a late POST application of glyphosate, would have little impact on overall yield. If fruit distribution is such that upper and outer fruiting positions would make up a significant portion of the yield, glyphosate applied POST late in the season might reduce yield.

This research was conducted to determine the effect of glyphosate applied POST late in the season on yield of GR cotton and the components that contribute to yield.

MATERIALS AND METHODS

The experiment was conducted at four locations in 2000 and 2001. Sites and soil types in 2000 included a Gilead loamy sand (fine, kaolinitic, thermic Aquic Hapludults) at Clayton, NC; a Norfolk sandy loam (fine-loamy, kaolinitic, thermic, Typic Kandiudults) at Rocky Mount, NC; a Tifton sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) at Tifton, GA; and a Norwood silt loam (fine-silty, mixed, superactive, hyperthermic Fluventic Eutrudepts) at Alexandria, LA. In 2001, the experiment was repeated at Clayton, Rocky Mount, and Tifton. Glyphosate-resistant cotton cultivar Stoneville 4892 BR (Stoneville Pedigreed Seed Co.; Memphis, TN) was planted in 97-cm rows in mid April to early May at all sites and individual plots consisted of four rows 15 m long. Treatments were replicated four times in a randomized complete block design.

Cotton was maintained weed-free by use of cultivation, pendimethalin (Prowl 3.3 EC, BASF Corp.; Research Triangle Park, NC) at 830 g a.i. ha^{-1} plus fluometuron (Cotoran, Griffin LLC; Valdosta, GA) at 1.4 kg a.i. ha^{-1} applied preemergence, glyphosate (Roundup UTRAMAX, Monsanto Co.; St. Louis, Mo) at 840 g ha^{-1} applied POST at the 3- to 4-leaf stage, and prometryn (Caparol, Syngenta Crop Protection; Greensboro, NC) at 0.8 kg a.i. ha^{-1} plus MSMA (MSMA 6.6, Drexel Chemical Co.; Memphis, TN) at 2.2 kg a.i. ha^{-1} applied postemergence-directed at the 12- to 14-leaf stage. Fertilization, growth management, insect control, and defoliation were based on extension recommendations. Defoliants were applied when 60 to 70% of the bolls were open.

Treatments consisted of glyphosate at 840 g ha^{-1} applied POST 7 d prior to an arbitrarily defined LEBD (15 August in North Carolina, 20 August in Georgia and Louisiana), on the LEBD plus 0, 7, 14, or 21 d after the LEBD. The LEBD was chosen based on historical weather data that indicate that blooms produced after the LEBD have less than a 50% chance of maturing into harvestable bolls due to decreasing temperatures and heat unit accumulation. The final application date generally corresponded to the 20% cracked-boll stage. Glyphosate was applied with a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles delivering 140 L ha^{-1} at 166 kPa. The glyphosate label did not recommend additional adjuvants (Anonymous, 2004a). A non-treated control was included at all locations.

Twenty consecutive plants from the non-treated control plots in North Carolina and Georgia were mapped for fruit distribution at the time of the initial application and all plots were mapped initially at the Alexandria locations. Percentage boll crack was determined on each application date. All plots at all locations were later hand-harvested by position according to box-mapping procedures used by Jenkins et al. (1990) prior to mechanical harvest of the center two rows of each plot. An approximate 350-g subsample of seed cotton was collected from machine harvested samples at the Alexandria and North Carolina locations for determination of physical fiber properties by high volume instrumentation (HVI) testing (Sasser, 1981). For analysis of box-mapping data, the upper-most main-stem node present at time of the initial glyphosate application was designated as node zero. Data were then segregated into three groups consisting of the combined first-, second-, and third-position seed cotton weight and number of bolls for nodes 3 and 4 below node zero, nodes 1 and 2 below node zero, and node zero plus nodes 1 and 2 above node zero. Plant mapping data at time of the initial application were also combined over nodes in these categories.

Data were analyzed using the general linear models procedure of the Statistical Analysis System (version 7.0, SAS Institute Inc.; Cary, NC). Means of treated cotton were compared with the non-treated check using Dunnett's *t*-tests at $P = 0.05$. Mean separation of glyphosate-containing treatments was also achieved using Fisher's protected LSD at $P = 0.05$. Data were pooled over locations, since the treatment by location interaction was not significant.

RESULTS AND DISCUSSION

Fruit number and distribution at the time of initial glyphosate application were not different among treatments at the Alexandria location (data not shown). Initial plant mapping averaged across all locations showed boll retention at position one of the first five sympodia ranged from 37 to 52%, which would be considered average for early fruit retention in Upland cotton production (Hake et al., 1990). Seed cotton yields of all treatments containing glyphosate were not different from the non-treated according to Dunnett's *t*-test procedure (Table 1), but some differences in yield were noted among glyphosate-containing treatments. Cotton receiving glyphosate 7 d before or 0 or 7 d after the LEBD produced significantly less than cotton treated 21 d after the LEBD, which approximated the 20% cracked-boll stage. Physical fiber properties at the Alexandria and North Carolina sites were not significantly different among treatments (data not shown).

Table 1. Effect of pre-harvest glyphosate application timing on seed cotton yield

Time of application [y]	Seed cotton (kg ha^{-1}) [z]
Non-treated	3260
7 days before LEBD	3040
0 days before LEBD	3100
7 days after LEBD	3080
14 days after LEBD	3230
21 days after LEBD	3360
LSD ($P = 0.05$)	200

[y] LEBD (last effective bloom date) arbitrarily set as 15 August in North Carolina and 20 August in Georgia and Louisiana. Glyphosate was applied at 840 g a.e. ha^{-1}.

[z] Data averaged over eight locations in Georgia, Louisiana, and North Carolina in 2000 and 2001. Yield between glyphosate treatments and the non-treated were not significantly different according to Dunnett's *t*-test at $P = 0.05$.

In cotton that matures later due to loss of fruit on lower sympodia caused by adverse weather, insects, or other stresses, sympodia from upper portions of the plant would contribute a greater portion of the total yield than cotton with high fruit retention on lower sympodia (Jones et al., 1996). Under these conditions or with late-planted cotton, glyphosate applied on the basis of an arbitrarily designated LEBD could cause a greater percentage of fruit loss and potentially a greater reduction in yield. This would be particularly important in seasons with better than average weather conditions for late-season boll development. Future investigations should attempt to assess potential losses that could occur following post-cutout applications of glyphsate to late-maturing cotton plants.

Total number of bolls and boll weight are important components of overall yield. Few second or third position bolls were present on sympodia from upper nodes of plants in this experiment (data not shown). Although most bolls were located at position one, data in Table 2 represent first-, second-, and third positions combined for a particular node zone. The number of bolls, boll weight, or seed cotton yield were not different between the glyphosate treatments and the non-treated control or among glyphoste treatments (Table 2). The box-mapping data do not explain the observed differences among glyphosate-containing treatments in machine-harvested yield. Moreover, individual location data revealed no differences or apparent trends (data not shown). While these parameters may be affected by glyphosate applied POST late in the season, the methodology employed in collecting plant mapping data probably was not accurate enough to detect the relatively small differences observed by mechanical harvest. In a similar experiment using the box-mapping technique to harvest cotton by nodal position, significant differences were observed, but six replications were used (Jenkins et al., 1990). Those researchers mapped 10 consecutive plants per plot whereas 20 plants per plot were mapped in this experiment. Additionally, the designation of nodal zones for analyzing the mapping data in this study was based on the average number of nodes per plant for an entire plot. Plant-to-plant variation in number of main-stem nodes within a plot may have created additional variation in the mapping data.

Table 2. Effect of pre-harvest glyphosate application timing on boll production, boll weight, and seed cotton yield at specific node zones

Time of application [x]	Yield parameter [y]		
	Boll production (bolls 20 plants^{-1})	Boll weight (g seed cotton boll^{-1})	Seed cotton (g 20 plants^{-1})
	Two nodes above and including node zero [z]		
Non-treated	1.7	3.26	43.6
7 days before LEBD	2.0	3.34	40.2
0 days before LEBD	1.8	3.23	35.9
7 days after LEBD	1.6	3.03	42.2
14 days after LEBD	1.7	3.30	42.2
21 days after LEBD	1.7	3.09	39.3
LSD (P = 0.05)	NS	NS	NS
	Two nodes below node zero		
Non-treated	3.8	4.03	106.6
7 days before LEBD	4.5	4.00	121.2
0 days before LEBD	3.8	4.02	103.7
7 days after LEBD	4.0	3.88	109.0
14 days after LEBD	4.5	3.92	127.0
21 days after LEBD	4.5	3.92	123.1
LSD (P = 0.05)	NS	NS	NS
	Nodes three and four below node zero		
Non-treated	6.0	4.35	170.6
7 days before LEBD	6.4	4.32	179.8
0 days before LEBD	5.9	4.29	166.2
7 days after LEBD	6.1	4.25	175.0
14 days after LEBD	6.1	4.38	182.2
21 days after LEBD	6.2	4.63	199.7
LSD (P = 0.05)	NS	NS	NS

[x] Data averaged over eight locations in Georgia, Louisiana, and North Carolina during 2000 and 2001. LEBD (last effective bloom date) arbitrarily set as 15 August in North Carolina and 20 August in Georgia and Louisiana. Glyphosate was applied at 840 g a.e. ha^{-1}.

[y] Data averaged over eight locations in Georgia, Louisiana, and North Carolina in 2000 and 2001. Boll production, boll weight, and seed cotton yield between glyphosate treatments and the non-treated were not significantly different according to Dunnett's *t*-test at P = 0.05.

[z] Node zero is the uppermost main-stem node present at time of initial glyphosate application.

Results of this experiment suggest that glyphosate applied late in the season to desiccate weeds in preparation for harvest can reduce cotton yield if the application is made too early. The results of this study indicate that recommendations for late-season glyphosate application could reasonably be changed to allow application 14 or more days after LEBD if fruit retention on lower sympodia is normal. If early fruit retention is poor, delaying glyphosate application until the 20% cracked-boll stage would be advised to avoid potential adverse effects on yield.

REFERENCES

Anonymous. 2004a. Roundup ULTRAMAX herbicide label. Monsanto Co. St. Louis, MO. Available online at http://www.cdms.net/ldat/ld5HB027.pdf (verified 9 Dec. 2004).

Anonymous. 2004b. Roundup WEATHERMAX herbicide label. Monsanto Co. St. Louis, MO. Available online at http://www.cdms.net/ldat/ld5UJ000.pdf (verified 9 Dec. 2004).

Culpepper, A. S. and A. C. York. 1998. Weed management in glyphosate-tolerant cotton. J. Cotton Sci. 2:174-185 [Online]. Available at http://www.cotton.org/journal/1998-02/4/174.cfm (verified 9 Dec. 2004).

Culpepper, A. S. and A. C. York. 1999. Weed management and net returns with transgenic, herbicide-resistant, and non-transgenic cotton (*Gossypium hirsutum*). Weed Technol. 13:411-420.

Hake, K, T. Kerby, F. Bourland, and J. Jenkins. 1990. Plant mapping as a management tool. Cotton Phys. Today. January.

Heitholt, J. J. 1993. Cotton boll retention and its relationship to yield. Crop Sci. 33:486-490.

Jenkins, J. N., J. C. McCarty, and W. L. Parrott. 1990. Effectiveness of fruiting sites in cotton: Yield. Crop Sci. 30:365-369.

Jones, M.A. and C.E. Snipes. 1999. Tolerance of transgenic cotton to topical applications of glyphosate. J. Cotton Sci. 3:19-26 [Online]. Available at http://www.cotton.org/journal/1999-03/1/19.cfm (verified 9 Dec. 2004).

Jones, M. A., R. Wells, and D. S. Guthrie. 1996. Cotton response to seasonal patterns of flower removal: I. Yield and fiber quality. Crop Sci. 36:633-638.

Kalahar,C. J. and H. D. Coble. 1998. Fruit abscission and yield response of Roundup Ready cotton to topical applications of glyphosate. p. 849. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-9 Jan. 1998. Natl. Cotton Counc. Am., Memphis, TN.

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 [Online]. Available at http://www.cotton.org.journal/2003-07/4/231.cfm (verified 9 Dec. 2004).

Pline, W. A., K. L. Edmisten, T. Oliver, J. W. Wilcut, R. Wells, and N. S. Allen. 2002a. Use of digital image analysis, viability strains, and germination assays to estimate conventional and glyphosate-resistant cotton pollen viability. Crop Sci. 42:2193-2200.

Pline, W. A., R. Viator, J. W. Wilcut, K. L. Edmisten, J. Thomas, and R. Wells. 2002b. Reproductive abnormalities in glyphosate-resistant cotton due to lower CP4-EPSPS levels in male reproductive tissue. Weed Sci. 50:438-447.

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. 8:24-32 [Online]. Available at http://www.cotton.org.journal/2004-08/1/24.cfm (verified 9 Dec. 2004).

Reynolds, D. B., S. L. File, R. E. Blackley, and C. E. Snipes. 1999. The effect of Roundup on Roundup Ready cotton. p. 732. *In* Proc. Beltwide Cotton Conf., Orlando, FL. 3-7 Jan. 1999. Natl. Cotton Counc. Am., Memphis, TN.

Sasser, P.E. 1981. The basics of high volume instruments for fiber testing. p. 191-193. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 4-8 Jan. 1981. Natl. Cotton Counc. Am., Memphis, TN.

Wells, R. and W. R. Meredith, Jr. 1984. Comparative growth of modern and obsolete cotton cultivars II: Reproductive dry matter partitioning. Crop Sci. 24:863-868.

USDA-Agricultural Marketing Service (AMS). 2003. Cotton varieties planted - 2003 crop. USDA-AMS, Memphis, TN.