Boll Removal Studies Provide Insights into Compensation Ability of Virginia Cotton: A Necessary Step for Further Improvement of Insect Management Strategies[1]

D. Ames Herbert, Jr.,[2] Sean Malone, Susanne Aref,[3] Joel Faircloth,[4] and Ozzie Abaye[5]

Virginia Tech, Tidewater Agricultural Research and Extension Center, Suffolk, VA 23437 USA

J. Entomol. Sci. 41(2): 147-154 (April 2006)

Abstract In developing management strategies for hemipteran pests in cotton (*Gossypium hirsutum* L.), it is important to understand the potential of plants to compensate for loss of the fruiting structures. Because of its northern latitude, Virginia has fewer available heat units relative to other cotton-producing states. Therefore, there may be limited opportunity for compensation relative to more southerly production areas. Previous work in Virginia demonstrated that cotton can sustain relatively high levels of first position square loss with no yield loss. This study evaluated the impact of a single event loss of 10-14-d-old bolls via mechanical removal on cotton lint yields with the premise that boll loss would have greater impact than square loss as less time and fewer heat units are available for compensation. Field experiments examining four levels of boll removal (0, 5, 15 and 20%) were conducted in 2001, 2002 and 2003. Each boll removal level was imposed at three different dates, beginning 2 wks after first flower and at 3- to 5-d intervals thereafter. Yields ranged from 1103-1422 in 2001, 909-1124 in 2002, and 843-1015 kg lint per ha in 2003. There were no significant differences in lint yields among the boll removal dates or removal levels. The results of our study showed that cotton in Virginia, which approaches the northernmost latitude for cotton production, is capable of sustaining losses as high as 20% of 10-14-d-old bolls at a single removal event without affecting lint yield. Results were consistent despite the wide variation in rainfall and temperatures during the 3 study years.

Key words Hemipteran management, lint yield, mechanical boll removal

Recent increases in the use of cotton, *Gossypium hirsutum* L., varieties expressing the Bollgard® trait (Monsanto Co., St. Louis, MO) have altered the practices Virginia producers use to manage bollworm (*Helicoverpa zea* [Boddie]) and tobacco budworm (*Heliothis virescens* [F.]). An estimated 85% of the acreage is currently planted to varieties containing the Bollgard® trait. Changes in management practices include reductions in number of pyrethroid sprays and delaying the time of an initial application. These reductions in insecticide usage have increased the risk of hemipteran species surviving in and damaging cotton (Bacheler 2005). Based on annual field

[1]Received 10 November 2005; accepted for publication 20 December 2005.
[2]Address inquiries (email: herbert@vt.edu).
[3]Virginia Tech Dept. of Statistics, 401A Hutcheson Hall, Blacksburg, VA 24061.
[4]Virginia Tech Dept. of Crop and Soil Environmental Sciences, Tidewater Agricultural Research and Extension Center, 6321 Holland Rd., Suffolk, VA 23437.
[5]Virginia Tech Dept. of Crop and Soil Environmental Sciences, 245 Smyth Hall, Blacksburg, VA 24061.

surveys beginning in 2002 (Herbert and Malone 2004), both tarnished plant bug (*Lygus lineolaris* [Palisot de Beauvois]) and stink bug (predominately green stink bug, *Acrosternum hilare* [Say] and brown stink bug, *Euschistus servus* [Say]) populations in Virginia appear to have increased. Plant bugs primarily attack squares and small bolls, causing abscission. Stink bugs attack both small and larger bolls, causing abscission or damage to developing seed and fiber. As a result, recommendations must be developed that will allow growers and crop consultants to better manage these pests.

Virginia currently has no research-based treatment recommendations for hemipteran pests of cotton. Such treatment recommendations should consider the ability of cotton plants to compensate for fruit loss. The degree to which plants compensate for damage may depend on both the timing of the occurrence of damage and subsequent environmental conditions. Other studies have examined the degree of plant compensation resulting from fruit removal (Ungar et al. 1987, Brook et al. 1992, Terry 1992). Willrich et al. (2004b) reported that the level of compensation in Louisiana cotton for boll injury following stink bug infestation was influenced by the time the infestation occurred during the flowering period. Significant reductions in total yield occurred where bolls were damaged in the latter part of the flowering period (during week 5 in 2002 and weeks 4 and 5 in 2003). However, Virginia represents a northern production region with fewer available heat units than many other areas and results of previous studies may be of limited value.

Preliminary studies in Virginia have indicated that cotton can compensate for relatively high levels (up to 40%) of early-season square loss (Herbert and Abaye 1999, Pitman et al. 2000, Abaye et al. 2001). However, similar information regarding the loss of small bolls is not available for Virginia. The objective of this project was to examine the ability of cotton to compensate for various levels of mechanical boll removal during the early-bloom period under Virginia conditions.

Materials and Methods

The field experiment was conducted in each of 3 yrs (2001, 2002, and 2003) at the Virginia Tech Tidewater Agricultural Research and Extension Center research farm located in Suffolk, VA (N36.728 W76.584). The soil type was Nansemond coarse-loamy, siliceous, thermic Aquic Hapluduit soil. Cotton was planted into seed beds prepared in herbicide-killed wheat stubble. Beds were prepared using a strip-till cultivator mounted with a leading fluted coulter, followed by a 0.46-m subsoil ripper shank in the row middle which created a 0.36-m wide seed bed with wheat stubble standing in the row middles. Plots (four rows wide × 12.2 m long) were planted the first week in May to FiberMax ‘FM 989R’ (normal leaf shape, smooth pubescence) (Bayer CropScience, Research Triangle Park, NC) cotton using a 0.91-m row spacing with an average final stand of six to nine plants per m. Plots were nonirrigated and all fertilization and cultural practices were according to standard recommendations (Faircloth and Parker 2004).

Weather conditions were monitored at the research center within 1 km of the experiment field. Rainfall was monitored using a tipping-bucket mounted 1.22 m above ground level. Air temperature was recorded at 15-min intervals and cumulative daily heat units were calculated using a base of 15.3°C (Mauney 1986) using the following equation (temperatures < 15.3°C did not contribute to heat units):

$$\text{Daily heat units} = \sum [(\text{avg. hourly temp.} - 15.3)/24].$$

The experiment was in the same field each year, but rotated on halves each year with peanut to maintain a 2-yr cotton/peanut rotation. A new treatment randomization scheme was used each year. Treatments included removal of 10-14-d-old bolls at four levels (0, 5, 15, and 20%), each occurring at three different dates. Although mechanical boll removal does not exactly simulate damage by insects, it has been a common method for evaluating plant response to boll loss (Kincade et al. 1970, Kletter and Wallach 1982, Ungar et al. 1987, Brook et al. 1992). The percentage boll removal approach was used because many state extension recommendations are based on percent of bolls with external (feeding punctures) and internal (warts, damaged seed or lint) damage. It is based on the recommendation that a random sample of 10-14-d-old (quarter-sized, or 2.426 cm in diameter) bolls is pulled from throughout a field to serve as a representative sample of the total population. Ten to 14-d-old bolls were removed because they are in the size class commonly considered most vulnerable to abscission resulting from damage by stink bug pests (Willrich et al. 2004a) and, in many states, damage levels to this size class are used to determine the need for protective insecticide treatments (Patrick and Lentz 2001, Boyd and Phipps 2003, Bacheler 2004). This method also applies to some extent to plant bug species. Tarnished plant bug may cause abscission of bolls up to 13-d-old (Russell et al. 1999). There is more evidence that plant bug species cause internal boll damage symptoms that are indistinguishable from those caused by stink bugs (Greene et al. 1999).

Boll removal treatments were applied to the center two rows of each plot. Flowers were marked with different color plastic tags so that 10-14-d-old bolls could be identified based on their age. The total number of 10-14-d-old bolls was determined for each plot. Then, either 0, 5, 15 or 20% of that total was removed. An effort was made to remove bolls uniformly down the row from wherever they occurred on the plant. The boll removal procedure was conducted on three separate dates each year. The first boll removal (6 August 2001, 26 July 2002, 4 August 2003) occurred 10-14 d after first flower. First flower was defined as when an average of 5-6 white flowers occurred per 7.62 m of row. Additional removals occurred at 17-18 d after first flower and at 21-23 d after first flower. This arrangement resulted in 12 treatment combinations (four boll removal levels and three removal dates) in a four replicate split-plot design. Native infestations of lepidopteran and hemipteran pests were eliminated with two applications of Baythroid® 2 (cyfluthrin, Bayer CropScience, Research Triangle Park, NC, USA) at 0.034 and 0.067 kg ai per ha.

Defoliants and boll openers were applied to entire tests when the percentage of open bolls per plant averaged 60-65% across all treatments (Faircloth and Parker 2004). In 2001, Finish 6® (ethephon and cyclanilide, Bayer CropScience, Research Triangle Park, NC, USA) at 1.75 L formulation per ha was applied on 2 October; in 2002, Finish 6® at 2.34 L formulation per ha and Folex 6EC® (tribufos and petroleum hydrocarbons, Amvac Chemical Corporation, Los Angeles, CA, USA) at 0.58 L formulation per ha were applied on 19 September; and in 2003, Finish 6® at 2.34 L formulation per ha was applied on 26 September.

Plots were harvested when all harvestable bolls were fully open but prior to exposure to adverse fall weather conditions. Seedcotton yield was determined for each plot by harvesting the two center rows using a spindle picker on 29, 17, and 23 October in 2001, 2002, and 2003. The seedcotton from each plot was collected in a mesh bag, weighed, and a single 1-kg subsample was removed. These subsamples were ginned to determine percent lint turnout for each plot. Lint yield was determined for each plot using percent lint turnout and seedcotton weight.

An ANOVA for a split-plot design was conducted for lint yield using SAS PROC MIXED (SAS ver. 9.1, SAS Institute, Cary, NC). The year and block (or replicate) were the blocks. The main-plot was the date of boll removal using year by block by date of boll removal as the error term. The boll removal level was the subplot. The residual was the error for boll removal level and the interaction with date of boll removal. A reduced model included date of boll removal, boll removal level, and all appropriate random effects (replication, year, the interaction of replication and year, and the interaction of replication, year, and date of boll removal).

Results and Discussion

The range in mean number of bolls removed per plot (per 24.4 row m) for the 3 experiment years was 1.3-14.3, 3.8-40.0, and 6.3-39.3 for the 5, 15 and 20% removal levels (Table 1). In all years at each boll removal level, more bolls were removed as removal dates progressed due to increased boll production by the plant (Table 1).

Lint yields ranged from 1103-1422 kg lint per ha in 2001, from 909-1124 kg lint per ha in 2002, and from 843-1015 kg lint per ha in 2003 (Table 2). In the full model, the interaction between boll removal dates and removal levels was not significant with a

Table 1. Mean number of 10 to 14-d-old bolls removed from 24.4-row m plots corresponding to four levels of simulated boll removal at each of three removal dates*

Year	Percent bolls removed of total	n	Mean (±SD)		
			Removal date 1	Removal date 2	Removal date 3
2001	0	4	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	5	4	1.3 (1.0)	3.3 (2.6)	7.3 (2.9)
	15	4	3.8 (2.2)	14.3 (10.8)	20.5 (7.8)
	20	4	6.3 (3.9)	14.3 (9.3)	28.0 (12.9)
2002	0	4	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	5	4	6.8 (0.5)	9.0 (2.2)	14.3 (2.6)
	15	4	21.5 (6.5)	25.0 (1.4)	40.0 (5.6)
	20	4	28.0 (8.0)	39.3 (9.0)	38.3 (14.3)
2003	0	4	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	5	4	3.3 (1.3)	7.0 (2.2)	11.5 (4.2)
	15	4	10.0 (3.9)	19.3 (4.0)	27.5 (5.2)
	20	4	16.8 (3.1)	25.5 (5.5)	39.0 (6.8)

* Boll removal dates in days after first bloom were date 1, 10-14 d; date 2, 17-18 d; and date 3, 21-23 d.

Table 2. Mean lint yields (kg lint/ha) after removal of 10 to 14-d-old bolls from 24.4-row m plots corresponding to four levels of simulated boll removal at each of three removal dates*

Removal date	Percent bolls removed of total	n	Mean (±SD) 2001	2002	2003
1	0	4	1195 (194)	1066 (246)	976 (169)
	5	4	1208 (277)	1090 (251)	967 (48)
	15	4	1155 (169)	1124 (127)	939 (241)
	20	4	1422 (170)	1116 (137)	946 (210)
2	0	4	1189 (182)	1049 (235)	843 (174)
	5	4	1134 (138)	909 (189)	996 (118)
	15	4	1212 (172)	1096 (299)	1015 (208)
	20	4	1103 (223)	1091 (348)	1009 (129)
3	0	4	1256 (214)	1086 (98)	967 (147)
	5	4	1281 (192)	1064 (282)	939 (139)
	15	4	1140 (108)	1058 (233)	931 (170)
	20	4	1115 (151)	1061 (322)	955 (157)

* Cotton was harvested on 22 Oct 2001, 17 Oct 2002, and on 3 Oct 2003. Gross yields were reduced by 62.5% (2001), 58.8% (2002) and 59.3% (2003) to account for seed and trash according to ginned sub-samples from each plot.

P = 26.62%. There were no significant differences in lint yields among the boll removal dates (P = 45.98%) or removal levels (P = 87.26%). In the reduced model with only the main effects, the effects were not significant for either boll removal date (P = 45.98%) or boll removal level (P = 87.53%). The least squares means from the reduced model are presented in Table 3. Irrespective of boll removal levels or removal dates, lint:seed/trash ratios were similar in all 3 yrs with 37.5% lint in 2001, 41.2% in 2002, and 40.7% in 2003.

The results of our study showed that cotton in Virginia, which approaches the northernmost latitude for cotton production, is capable of sustaining losses as high as 20% of 10-14-d-old bolls at a single removal event without affecting lint yield. Results were consistent despite the wide variation in rainfall and temperatures during the three study years. Cumulative rainfall from 7 May to 30 September varied from 36 cm in 2002, to 55 cm in 2001, to 102 cm in 2003 (Powell and Gray 2001, 2002, 2003). Cumulative heat units from 7 May to 23 October also varied from 2119 in 2001, to 2148 in 2003, to 2474 in 2002.

Many studies at more southerly locations have shown that cotton has considerable ability to compensate from damage to bolls. Kincade et al. (1970) working in Stoneville, MS, USA (N33.424 W90.915) and Yazoo City, MS (N32.855 W90.406) using a single event mechanical boll removal process similar to the one used in our study showed that removal of either 42 or 84 bolls per 22 row m did not cause lint yield

Table 3. Least squares mean of lint yields (kg lint/ha) of 10 to 14-d-old bolls removed from 24.4-row m plots corresponding to four levels of simulated boll removal at each of three removal dates*

Percent bolls removed of total	Least squares mean
0	1069.76
5	1065.30
15	1074.22
20	1090.99
SE	73.32
Removal date	**Least squares mean**
1	1100.34
2	1053.92
3	1070.95
SE	73.68

* Cotton was harvested on 22 Oct 2001, 17 Oct 2002, and on 3 Oct 2003. Gross yields were reduced by 62.5% (2001), 58.8% (2002) and 59.3% (2003) to account for seed and trash according to ginned sub-samples from each plot.

reductions. Ungar et al. (1987) working in the coastal plain of Israel (N32.001 E34.830) found that mechanical removal of 60 small bolls per m^2 (bolls removed 10 d after flowering) over a 2-wk period did not reduce yield. They concluded that a sufficiently long growing season was critical to the expression of compensation. Gore et al. (2000) working in St. Joseph, LA, USA (N31.918 W91.233) reported that in nonBt cotton, up to 40% boll injury at weeks 1-4 of flowering did not reduce yields; however, 20% injury during week 4 delayed crop maturity. Lei (2002) working in Narrabri, Australia (S30.4 E149.8) showed no significant lint yield reductions following fruit damage simulating 2-8 *Helicoverpa* larvae per m^2, but maturity was delayed with the higher levels of damage. Our study was more northerly (N36.728 W76.584) than these previous studies, with a shorter growing season and less time for compensation from injury.

This study was needed to help researchers and growers better understand the ability of cotton in Virginia to compensate from boll loss. Our techniques and results cannot be compared directly with damage by insects. Boll damage by the hemipteran complex occurs as a cumulative process over the entire boll formation period rather than as a single event; occurs on a wider range of boll ages; and encompasses a wide variety of damage symptoms. Symptoms can range from severe (e.g., rotted or aborted bolls) to minor (e.g., single internal boll wall feeding puncture). However, our results do show that cotton in Virginia can tolerate and compensate from some level of boll loss without suffering a reduction in lint yield. Currently, both Virginia and North Carolina Cooperative Extension information for management of hemipteran species in cotton recommend initial protective action at 10% internal injury to 10-14-d-old bolls. That 10% encompasses all types of damage, a lot of which may not have a large impact on final lint yield. The most important implication of this work is that the action threshold for hemipterans in Virginia may be increased to at least 15% without jeopardizing lint yields. This means that fewer fields may require protective insecticide sprays. These studies could also have implications for insects beyond plant bugs and stink bugs (i.e., heliothines) which also cause boll abscission and damage. New studies are ongoing to evaluate the relationship of external bug-induced feeding punctures to internal boll damage. Research is planned to evaluate boll injury later in the season and sustained over the several-week period that hemipteran species can occur in cotton. These additional studies will allow for further refinement of hemipteran management recommendations.

Acknowledgments

We gratefully thank the Virginia Cotton Board, Cotton Incorporated, and the Virginia State Cotton Support Committee for providing funding support for this project.

References Cited

Abaye, A. O., D. A. Herbert Jr., D. Oosterhuis and J. C. Maitland. 2001. Compensation of cotton to square removal, p. 498. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

Bacheler, J. S. 2004. Managing insects on cotton, pp. 122-147. *In* K. L. Edmisten (ed.), 2004 Cotton Information. Publ. AG-417. North Carolina Coop Ext. Ser., Raleigh, NC.

2005. Managing insects on cotton, pp. 115-141. *In* K. L. Edmisten (ed.), 2005 Cotton Information. Publ. AG-417. North Carolina Coop Ext. Ser., Raleigh, NC.

Boyd, M. L. and B. J. Phipps. 2003. University of Missouri Cotton Insect Management Guide-2003. http://www.aes.missouri.edu/delta/muguide/ctnmgtgs.stinkbugs.

Brook, K. D., A. B. Hearn and C. F. Kelly. 1992. Response of cotton to damage by insect pests in Australia: compensation for early season fruit damage. J. Econ. Entomol. 85: 1378-1386.

Faircloth, J. C. and J. Parker. 2004. Cotton in Virginia, pp. 1-6. *In* J. C. Faircloth (ed.), Virginia Cotton Production Guide 2004. Publ. 424-200. Virginia Coop. Ext., Blacksburg, VA.

Gore, J., B. R. Leonard, E. Burris, D. R. Cook and J. H. Fife. 2000. Maturity and yield responses of non-transgenic and transgenic Bt cotton to simulated bollworm injury. J. Cotton Sci. 4: 152-160. (Available at www.jcotsci.org).

Greene, J. K., S. G. Turnipseed, M. J. Sullivan and G. A. Herzog. 1999. Boll damage by southern green stink bug (Hemiptera: Pentatomidae) and tarnished plant bug (Hemiptera: Miridae) caged on transgenic *Bacillus thuringiensis* cotton. J. Econ. Entomol. 92: 941-944.

Herbert Jr., D. A. and A. O. Abaye. 1999. Compensation from systematic square removal by Virginia cotton, pp. 968-971. *In* Proc. Beltwide Cotton Conf., Orlando, FL. 3-7 Jan. 1999. Natl. Cotton Counc. Am., Memphis, TN.

Herbert Jr., D. A. and S. Malone. 2004. Boll removal studies and field surveys to improve management of bug species in Virginia cotton, pp. 1542-1546. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 5-9 Jan. 2004. Natl. Cotton Counc. Am., Memphis, TN.

Kincade, R. T., M. L. Laster and J. R. Brazzel. 1970. Effect on cotton yield of various levels of simulated *Heliothis* damage to squares and bolls. J. Econ. Entomol. 63: 613-615.

Kletter, E. and D. Wallach. 1982. Effects of fruiting form removal on cotton reproductive development. Field Crops Res. 5: 69-84.

Lei, T. T. 2002. Cotton (*Gossypium hirsutum*) response to simulated repeated damage by *Helicoverpa* spp. larvae. J. Cotton Sci. 6: 119-125. (Available at www.jcotsci.org).

Mauney, J. R. 1986. Vegetative growth and development of fruiting sites, pp. 11-28. *In* J. R. Mauney and J. McD. Stewart (ed.), Cotton Physiology. The Cotton Foundation, Memphis, TN.

Patrick, C. R. and G. L. Lentz. 2001. 2001 Cotton Insect Control Guide. Univ. Tennessee Agric. Ext. Ser. Publ. No. PB387-1M-1/01.

Pitman, V., O. Abaye, A. Herbert and D. Oosterhuis. 2000. Compensation of cotton to square and boll removal with different varieties and removal dates, p. 955. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Powell, N. C. and B. J. Gray. 2001. National Weather Service Observation Station (No. 44-4044-01), Holland, VA, Tidewater Agricultural Research and Extension Center Information Series No. 455.

2002. National Weather Service Observation Station (No. 44-4044-01), Holland, VA, Tidewater Agricultural Research and Extension Center Information Series No. 468.

2003. National Weather Service Observation Station (No. 44-4044-01), Holland, VA, Tidewater Agricultural Research and Extension Center Information Series No. 475.

Russell, J. S., B. R. Leonard, J. Gore and G. E. Church. 1999. Cotton boll abscission influenced by tarnished plant bug feeding, pp. 1046-1049. *In* Proc. Beltwide Cotton Conf., Orlando, FL. 3-7 Jan. 1999. Natl. Cotton Counc. Am., Memphis, TN.

Terry, L. I. 1992. Effect of early season insecticide use and square removal on fruiting patterns and fiber quality of cotton. J. Econ. Entomol. 85: 1402-1412.

Ungar, E. D., D. Wallach and E. Kletter. 1987. Cotton response to bud and boll removal. Agron. J. 79: 491-497.

Willrich, M. M., B. R. Leonard and J. Temple. 2004a. Injury to preflowering and flowering cotton by brown stink bug and southern green stink bug. J. Econ. Entomol. 97: 924-933.

Willrich, M. M., B. R. Leonard, R. H. Gable and L. R. Lamotte. 2004b. Boll injury and yield losses in cotton associated with brown stink bug (Heteroptera: Pentatomidae) during flowering. J. Econ. Entomol. 97: 1928-1934.