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ARTHROPOD MANAGEMENT

Cotton (*Gossypium hirsutum* L.) Yield and Fiber Quality Response to Premature Insect-simulated and Harvest-aid Defoliation

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ABSTRACT

The effects of late-season insect-simulated defoliation and premature harvest-aid application on cotton lint yield and physical fiber properties were evaluated in field experiments at two locations in Louisiana. Insect-simulated defoliation was accomplished by manually removing leaves with scissors, while all harvest-aids were applied with a CO_2 backpack sprayer. Defoliation timings were NAWF5 + 450 heat units (HU), + 550 HU, + 650 HU, + 750 HU, and + 850 HU. Insect-simulated defoliation at NAWF5 + 450 HU reduced lint yield by 18% compared with the standard (chemical defoliation at 80% open, NAWF5 + 1050 HU); however, insect-simulated defoliation at NAWF5 + 550 HU and later developmental stages had no effect on lint yields. Chemical defoliation at NAWF5 + 450 HU, + 550 HU, and + 650 HU development stages reduced lint yield by 38, 37, and 15%, respectively, below the standard. Harvest-aid applications at NAWF5 + 750 HU and + 850 HU did not affect lint yields compared with the standard. Insect-simulated defoliation did not impact fiber properties, but chemical defoliation of plants at growth stages ≤NAWF5 + 550 HU significantly lowered fiber micronaire at one location in both years. Chemical defoliation did not influence fiber strength, length, elongation, or uniformity. These results indicate that management strategies for late-season bottom defoliating insects should be terminated at plant development ≥NAWF5 + 550 HU, while chemical defoliation should not be initiated until plant development ≥NAWF5 + 750 HU.

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Management of late-season defoliating insects on cotton (*Gossypium hirsutum* L.) in mid-south and southeastern states has changed dramatically with the introduction of transgenic cotton with Bt [*Bacillus thuringiensis* (Berliner)] genes, the use of selective insecticides, and boll weevil [*Anthonomus grandis grandis* (Boheman)] eradication. These factors have dramatically reduced the number of broad spectrum insecticide applications per season.

Soybean looper [*Pseudoplusia includens* (Walker)] and cabbage looper [*Trichoplusia ni* (Hübner)] are generally considered secondary pests of cotton. Late-season infestation and defoliation prior to physiological maturity of the last harvestable boll may negatively impact yield, as demonstrated by previous studies with simulated insect defoliation (Torrey et al., 1999). Soybean looper populations in Georgia are significantly higher in cotton - soybean (*Glycine max* L.) agroecosystems compared with a soybean monoculture (Beach and Todd, 1986). In Mississippi, populations of soybean looper and cabbage looper adults are highest from early to mid-August, and generally decline in September (Jost and Pitre, 2002). Weir and Boethel (1995) determined soybean looper was the most serious defoliating pest of cotton and soybean in Louisiana. In Louisiana, soybean looper is characterized by dense larval populations in cotton and soybean ecosystems during late August or September (Burleigh, 1972).

Several studies have indicated that a first position white flower located five main stem nodes below the terminal (NAWF5) is the last boll likely to develop to maturity or contribute to yield. Flowers set above this position contributed little to overall yield (Benson et al., 1999; Bourland et al., 1992; Jenkins et al., 1990).

Managing for early crop maturity can help to avoid losses caused by adverse weather and late season insect injury (Isely, 1957). Termination of late-season insect management strategies using the NAWF + accumulated heat unit (HU) method vary among insect pest species, cotton cultivar, and the environment (Torrey et al., 1997). Multi-state evaluations of insecticide termination rules supported by the cotton modeling program COTMAN generally show that insecticide applications beyond NAWF5 + 350 HU are not economically feasible (Bryant et al., 1999; Cochran et al., 1998).

A range of boll maturities confer tolerance to cotton insect pests. Bagwell and Tugwell (1992) reported boll weevil damage to cotton bolls decreased dramatically at 350 HU after anthesis. Bollworm [*Helicoverpa zea* (Boddie)] significantly reduced yield of conventional and transgenic *Bt* cotton until bolls accumulated >426 HU and >299 HU after anthesis, respectively (Gore et al., 2000). Beet armyworm [*Spodoptera exigua* (Hübner)] penetrated the endocarp of bolls from conventional and transgenic *Bt* cotton until bolls accumulated >360 HU and >390 HU, respectively (Adamczyk et al., 1998). In the same study, fall armyworm [*Spodoptera frugiperda* (J.E. Smith)] successfully penetrated >60% of conventional bolls that had accumulated 852 HU, but <10% of transgenic *Bt* bolls that had accumulated 864 HU (Adamczyk et al., 1998). Cotton bolls are generally safe from significant yield losses due to tarnished plant bug [*Lygus lineolaris* (Palisot de Beauvois)] (Russell, 1999), brown stink bug [*Euschistus servus* (Say)] (Willrich et al., 2004; Fromme, 2000), and southern green stink bug [*Nezara viridula* (L.)] (Greene et al., 2001) injury at 327 HU, 550 HU, and 559 HU after anthesis, respectively.

Several studies reported the effects of removal of various plant parts on cotton yield and fiber quality. Jones et al. (1996) found that cotton plants compensated from early-season square removal by shifting fruit production to higher fruiting branches on the main stem and to more distal sites on all fruiting branches. Delayed photosynthetic decline has been associated with floral bud removal (Wells, 2001; Holman and Oosterhuis, 1999). These studies indicated that cotton has the ability to either delay photosynthetic decline in relation to cutout, or alter the source-sink relationship in response to the removal of fruiting structures, but little data exist regarding crop yield and fiber quality effects from late-season foliage removal before the crop reaches physiological maturity. Foliage injury or complete leaf removal indirectly affected yield by reducing leaf area that provides photosynthate to mature bolls (Mascarenhas et al., 1999). Cotton plants withstood ≤57% simulated defoliation before first-square without a significant reduction in lint yield (Kerby et al., 1988). Defoliation >20% during boll maturation stages affected yield by reducing the production of photosynthate necessary for maximum boll development (Russell et al., 1993). Torrey et al. (1997) reported significant yield loss associated with removal of all foliage from the bottom 66% of the cotton canopy when plant development was at NAWF ≤ 5 + 350 HU.

The objectives of this study were to determine the effects of late-season simulated insect defoliation and premature harvest-aid application on cotton lint yield and fiber quality, and to establish guidelines for managing late-season defoliating insect pests of cotton, specifically pests, such as soybean and cabbage looper, that begin feeding in the lower canopy and progress towards the terminal.

MATERIALS AND METHODS

Site location and management practices. Experiments were conducted at the Dean Lee Research Station in Alexandria, LA, and the Macon Ridge Research Station near Winnsboro, LA, during 2003 and 2004. Cultivars planted at the Macon Ridge Station were DeltaPearl (Delta Pine and Land Co.; Scott, MS) and Stoneville 5599 BR (ST 5599 BR; Stoneville Pedigreed Seed; Memphis, TN) and at the Dean Lee Station were Deltapine 451 BG/RR (DP 451 BR; Delta Pine and Land Co.) and Stoneville 4892 BR (ST 4892 BR; Stoneville Pedigreed Seed) in 2003 and 2004, respectively. For optimum productivity, general agronomic practices for fertilization and pest control were followed as recommended by the LSU AgCenter.

Thrips (Thysanoptera: Thripidae), cotton aphid (*Aphis gossypii* Glover), tarnished plant bug, stinkbugs (Heteroptera: Pentatomidae), and heliothines, which are common in cotton fields in Louisiana, were observed across the experimental areas. Prior to test initiation, during the test period, and until the standard harvest-aid treatment was applied, the test area was inspected weekly, and insect pests were managed below damaging levels with preventative applications of insecticide treatments. Although numbers of late-season defoliating pests (i.e. soybean looper and beet armyworm) were very low during the test period, methoxyfenozide (Intrepid 2SC; Dow AgroSciences; Indianapolis, IN) was sprayed across the experimental area at 0.09 kg ai ha^{-1} to prevent economic injury from occurring. Nearly all foliage injury (>95%) was created by the manual leaf removal treatments. Supplemental irrigation was applied to the test at Macon Ridge in 2004.

The experimental design at each location was a randomized complete block with a factorial arrangement of treatments with four replications. Plot size was three rows (centered on 96.5 or 101.6 cm) by 3 m. All data were collected from the center row of each three-row plot. The first factor was defoliation method, which consisted of insect-simulated (manual) or chemical. The second factor was defoliation timing, which included NAWF5 + 450 HU, + 550 HU, + 650 HU, + 750 HU, and + 850 HU. Main stem nodes above the upper-most first position white flower (NAWF) and daily heat unit (HU) accumulations were used to characterize the late-season reproductive stages of plant development. Daily HU accumulation was calculated as follows: HU = ([maximum daily temperature + minimum daily temperature]/2) – 60, using a base of 15.5 °C (60 °F) (Landivar and Benedict, 1996).

Insect-simulated and chemical defoliation treatments. Insect-simulated defoliation levels were based on previous research that established ≥66% of leaf removal at NAWF5 + 350 HU significantly reduced seedcotton yield (Torrey et al., 1999). Plant height was used to divide the plant into three equal vertical zones (bottom, middle, and top). The 66% defoliation level corresponded to removal of all leaves from the bottom and middle zones of each plant on all three rows of the plot. Leaves were removed by cutting petioles with scissors, thereby removing the entire leaf from the plant. At each treatment application, all leaves were removed on the same date. Chemical defoliation treatments were applied with a CO_2 backpack sprayer calibrated to deliver a carrier volume of 140 L ha^{-1} at 220 kPa and 5.2 km h^{-1} through a one-row boom equipped with ConeJet (TeeJet Spraying Systems; Wheaton, IL) nozzles. All rows of each plot were treated with a co-application of thidiazuron at 56.1 g ai ha^{-1} (Dropp SC; Bayer CropScience; Research Triangle Park, NC) + tribufos at 841 g ai ha^{-1} (DEF 6; Bayer CropScience) + ethephon at 1261.6 g ai ha^{-1} (Prep; Bayer CropScience). A standard chemical defoliation treatment targeted at 80% open bolls using the same harvest-aids was also included.

Determination of yield components. Cotton plants were monitored twice weekly until they reached the NAWF5 reproductive stage of development. At NAWF5, plastic "snap-on-tags" (A.M. Leonard, Inc.; Piqua, OH) were placed on the fourth main stem internode below the plant terminal. This marker was used to bisect the main stem into harvest zones and identify bolls set below NAWF5 and above that point. Seedcotton yield was determined by hand-harvesting the center row of each plot 2 wk after a defoliation treatment was applied. All plots were hand-harvested a second time 2 wk after application of the standard chemical defoliation treatment. Each plot was harvested in zones (above or below the NAWF5 tag) to determine the contribution of each section to total yield. Seedcotton subsamples (approximately 200 g) from each plot were ginned with a 12-saw laboratory gin to determine lint percentage and lint weight. Fiber properties were measured using the high volume instrumentation (HVI) method (Sasser, 1981) at the LSU AgCenter Fiber Laboratory, Department of Agronomy, Baton Rouge, LA.

Statistical analysis. Seedcotton yields and fiber properties were analyzed using PROC GLM. Dunnett's *t*-tests ($P = 0.05$) was used to compare the means of each treatment to the chemical defoliation standard (SAS Institute; Cary, NC).

RESULTS AND DISCUSSION

The interaction between year and location was not significant for lint yield, fiber strength, uniformity, length, and elongation, so the data were combined across locations and years. The location affect was significant for micronaire, so these data are presented by location averaged across years. Flowers that become harvestable bolls after a field average of four nodes above white flower have been shown to contribute less than 2% to overall yield (Bernhardt et al., 1986; Bernhardt and Phillips, 1986). The lint harvested above the NAWF5 tag contributed ≤7.3% to total yield and was not significant (data not shown), so yield data were combined across vertical zones on the plant.

The removal of 66% of the leaves (all leaves from the bottom two-thirds of the plant) significantly reduced total lint yield 18% at the NAWF5 + 450 HU timing compared with the chemically defoliated standard (Table 1). Micronaire (Table 2,) fiber strength, length, uniformity, and elongation (Table 3) were not significantly affected by simulated insect defoliation treatments. These data show that management of late-season defoliating pests, such as cabbage looper and soybean looper, can be terminated at NAWF5 + 550 HU, which corresponds to 10% open bolls and seven nodes above cracked boll (NACB) (Fig. 1).

Table 1. Effect of insect-simulated and chemical defoliation on lint yield averaged across locations and years

Defoliation timing[y]	Lint yield (kg ha^{-1})[z]	
	Insect-simulated	Chemical
NAWF5 + 450 HU	877.7 ± 58.0*	660.2 ± 33.8**
NAWF5 + 550 HU	928.5 ± 60.8	681.1 ± 36.1**
NAWF5 + 650 HU	927.5 ± 60.3	911.6 ± 57.3*
NAWF5 + 750 HU	976.0 ± 47.0	984.4 ± 34.9
NAWF5 + 850 HU	1059.7 ± 66.4	985.5 ± 48.5
Standard (NAWF5 + 1050 HU)	1072.3 ± 80.4	

[y] Manual removal of leaves from the bottom two-thirds of cotton plants; NAWF5 = 5 nodes above white flower.

[z] Lint yield followed by * or ** was significantly different from chemically defoliated standard according to Dunnett's *t*-test at $P = 0.05$* and $P = 0.01$**, respectively.

Chemical defoliation at the NAWF5 + 450 HU, + 550 HU, and + 650 HU developmental stages reduced yields by 38%, 36%, and 15%, respectively, compared with the standard chemical defoliation treatment (Table 1). Chemical defoliation before NAWF5 + 650 HU at the Dean Lee location in both years significantly reduced micronaire when compared with the chemically defoliated standard (Table 2), but did not affect other fiber properties (Table 3). Snipes and Baskin (1994) demonstrated that micronaire was decreased by prematurely defoliating plants. Early crop termination can be utilized to beneficially reduce micronaire in an effort to avoid discounts on lint quality (Bednarz et al., 2002; Lewis, 1993); however, precautions should be exercised in timing harvest-aid application, because plant defoliation prior to 60% open bolls may reduce lint yields (Bednarz et al., 2002; Snipes and Baskin, 1994; Williford, 1992).

Carbon allocation among plant parts in reproductive cotton can explain why removal of the older leaves did not significantly influence yield. Asynchrony between carbon assimilation and utilization occurs in flowering cotton. At anthesis, the subtending leaf is approximately 17-d-old (Wullschleger and Oosterhuis, 1990a), and peak photosynthesis in that leaf occurs 13 to 16 d after it unfolds. These peak photosynthetic rates are maintained for approximately 12 d. A linear decline occurs beyond that point until the leaf reaches 70 d and stabilizes at 20% of the maximum (Constable and Rawson, 1980). The subtending leaf is not operating at peak photosynthetic capacity during the majority of the boll filling period and carbon must be allocated from other plant parts. Collectively for lower position sympodial bolls on the plant (node eight), >60% of the carbon must be imported to sustain optimum growth rates during the season (Wullschleger and Oosterhuis, 1990b). These bolls rely heavily on carbon allocation from leaves higher on the main stem, in addition to photosynthate supplied by the bracts and boll walls (Bhatt, 1988; Elmore, 1973; Ashley, 1972; Brown, 1968). Accelerated deterioration of the photosynthetic system exhibited by leaves lower in the canopy could be due to mutual shading (Wullschleger and Oosterhuis, 1990b). It is likely that the photosynthetic contribution of leaves low in the crop canopy is negligible by the end of the growing season.

Although crop development rules for terminating late-season insect pest management are accepted in several southeastern states, the decisions for terminating integrated pest management strategies in Louisiana do not consistently follow the NAWF5 + 350 HU rule. Studies at the Macon Ridge research station in 1994 showed significantly higher seedcotton yields in plots that had termination intervals ≥NAWF5 + 400 HU. From 1993 to 1995, seedcotton yields generally increased when termination treatments were delayed to NAWF5 + 350 to 400 HU (Torrey et al., 1997). Torrey et al. (1998) reported significantly lower yields in plots receiving ≥66% simulated insect defoliation (removal of all lower leaves from bottom two-thirds of each plant) at NAWF5 + 350 HU. These findings were similar to those reported by Burris et al. (1997) and are consistent with the results of the present study. These data can reduce unnecessary insecticide applications for potentially beneficial infestations of late-season bottom defoliators, with respect to reducing the incidence of boll rotting pathogens. Jones et al. (1981) suggested that open canopy architecture of okra-leaf cotton cultivars increased air movement and sunlight penetration making the canopy environment less favorable for boll infection by pathogens. A similar change in canopy architecture can be achieved from leaf removal by defoliating insects.

Under the conditions of these studies, when chemical defoliation was initiated at 40% open bolls and 5.6 NACB (NAWF5 + 750 HU), significant yield losses were not observed. Maximum lint yield occurred by chemically defoliating at NAWF5 + 1050 HU, or 80.2% open bolls and 2.6 NACB (Fig. 1). These results confirm the current defoliation timing recommendations at 65 to 90% open bolls (Brecke et al., 2001) and NACB ≤4 (Kerby et al., 1992).

Defoliation timing based on HU accumulation after cutout (NAWF5) is a published method based on cotton management with the COTMAN decision-aid tool (Tugwell et al., 1998). COTMAN recommends defoliation timing of NAWF5 + 850 HU; however, Benson et al. (2000) reported one situation where timing according to this method resulted in defoliation one week prior to the grower standard and significantly reduced yield. Timing defoliation using the COTMAN system may not be suited for locations outside Arkansas where longer growing seasons and other cultural practices may require more HU accumulation before harvest-aid application in order to maximize yield.

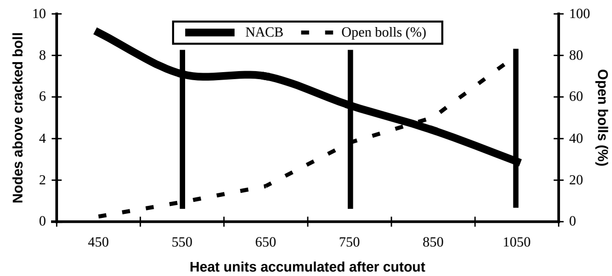

Figure 1. Relationship of nodes above cracked boll (NACB) and percentage of open bolls to heat unit accumulation after cutout. Vertical lines from left to right are as follows: bottom leaf defoliating insect management strategies may be terminated without negatively impacting lint yield (7 NACB, 10% open bolls); chemical defoliation may be initiated without significant yield reductions (5.6 NACB, 40% open bolls); chemical defoliation timing that maximized lint yield (2.6 NACB, 80% open bolls).

Table 2. Effect of insect-simulated and chemical defoliation on micronaire by location and averaged across years

Defoliation timing[y]	Micronaire[z]			
	Dean Lee		Macon Ridge	
	Insect	Chemical	Insect	Chemical
NAWF5 + 450 HU	4.5 ± 0.09	3.9 ± 0.10*	4.3 ± 0.16	4.2 ± 0.14
NAWF5 + 550 HU	4.6 ± 0.13	4.1 ± 0.16*	4.2 ± 0.16	4.0 ± 0.20
NAWF5 + 650 HU	4.7 ± 0.10	4.3 ± 0.08	4.2 ± 0.23	4.2 ± 0.13
NAWF5 + 750 HU	4.7 ± 0.13	4.7 ± 0.14	4.4 ± 0.12	4.1 ± 0.16
NAWF5 + 850 HU	4.7 ± 0.11	4.7 ± 0.11	4.4 ± 0.24	4.2 ± 0.19
Standard (NAWF5+1050 HU)	4.7 ± 0.11		4.6 ± 0.20	

[y] Manual removal of leaves from the bottom two-thirds of cotton plants; NAWF5 = 5 nodes above white flower.

[z] Within location, micronaire followed by * was significantly different from the chemically defoliated standard according to Dunnett's *t*-test (*P* = 0.05).

Table 3. Effect of insect-simulated and chemical defoliation on fiber strength, length, uniformity, and elongation averaged across locations and years

Defoliation timing[y]	Fiber property[z]							
	Strength (cN tex^{-1})		Upper half mean (cm)		Uniformity (%)		Elongation	
	Insect	Chemical	Insect	Chemical	Insect	Chemical	Insect	Chemical
450 HU	30.20 ± 0.63	29.70 ± 0.42	2.90 ± 0.03	2.90 ± 0.02	83.6 ± 0.35	83.4 ± 0.29	7.28 ± 0.20	7.52 ± 0.26
550 HU	29.64 ± 0.70	29.26 ± 0.52	2.90 ± 0.04	2.87 ± 0.02	83.3 ± 0.44	83.1 ± 0.33	7.21 ± 0.22	7.55 ± 0.29
650 HU	30.38 ± 0.56	39.84 ± 0.40	2.87 ± 0.02	2.90 ± 0.01	83.3 ± 0.42	83.0 ± 0.37	7.21 ± 0.20	7.51 ± 0.24
750 HU	30.00 ± 0.50	28.99 ± 0.50	2.87 ± 0.02	2.87 ± 0.02	82.9 ± 0.26	83.0 ± 0.32	7.28 ± 0.20	7.48 ± 0.24
850 HU	28.98 ± 0.54	28.90 ± 0.34	2.84 ± 0.02	2.82 ± 0.02	83.0 ± 0.35	82.3 ± 0.33	7.44 ± 0.24	7.36 ± 0.22
Std. (1050 HU)	28.72 ± 0.31		2.82 ± 0.03		82.7 ± 0.26		7.42 ± 0.21	

[y] Heat units (HU) accumulated after NAWF5 (5 nodes above white flower).

[z] Fiber properties of both insect-simulated and chemical defoliation treatments are not significantly different from chemically defoliated standard according to Dunnett's *t*-test (*P* = 0.05).

SUMMARY

Although bolls may be safe from many piercing and sucking insect pests at 350 HU after cutout, limited information is available on the effect of premature plant defoliation by insects. This study was an attempt to better define integrated pest management termination rules for late-season defoliating pests. Significant yield losses did not occur at insect-simulated defoliation levels of 66% after the crop accumulated 550 HU after cutout. Additional research should evaluate the late-season injury potential for other sporadic leaf feeding pests of cotton, and better define late season management strategies for individual cotton pests.

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